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Lead Guest Editor: Rijwan Khan
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Research Article

Artificial Bee Colony Algorithm for Fresh Food Distribution without Quality Loss by Delivery Route Optimization

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This paper enlightens the use of artificial intelligence (AI) for distribution of fresh foods by searching more viable route to keep intact the food attributes. In recent years, very hard-hitting competition is for food industries because of the individuals living standards and their responsiveness for fresh food products demand within stipulated time period. Food industry deals with the extensive kind of activities such as food processing, food packaging and distribution, and instrumentation and control. To meet market demand, customer satisfaction, and maintaining its own brand and ranking on global scale, artificial intelligence can play a vibrant role in decision-making by providing analytical solutions with adjusting available resources. Therefore, by integrating innovative technologies for fresh food distribution, potential benefits have been increased, and simultaneously risk associated with the food quality is reduced. Time is a major factor upon which food quality depends; hence, time required to complete the task must be minimized, and it is achieved by reducing the distance travelled; so, path optimization is the key for the overall task. Swarm intelligence (SI) is a subfield of artificial intelligence and consists of many algorithms. SI is a branch of nature-inspired algorithm, having a capability of global search, and gives optimized solution for real-time problems adaptive in nature. An artificial bee colony (ABC) optimization and cuckoo search (CS) algorithm also come into the category of SI algorithm. Researchers have implemented ABC algorithm and CS algorithm to optimize the distribution route for fresh food delivery in time window along with considering other factors: fixed number of delivery vehicles and fixed cost and fuel by covering all service locations. Results show that this research provides an efficient approach, i.e., artificial bee colony algorithm for fresh food distribution in time window without penalty and food quality loss.

1. Introduction

Fresh farm foods are perishable and dependent on time; hence, quality of food and its protection are the vital factors. To intact the food quality and avoiding its contamination, time required for shipping fresh food products must be less, and shipping environment must be safe. Therefore, the requirement of rational mechanism of logistic delivery of fresh farm foods arises which is of major concern for almost all customers [1, 2]. China developed cold chain logistics, and various developments have also been done depending upon requirements and concerns, but at some point of time, it has been identified that this was not sufficient. Because of the challenges faced during guaranteed distribution of fresh food, one solution has been identified which is the path planning of delivery of food products even without considering the cold chain distribution. Path planning of food products distribution can improve the guarantee of quality food, customer satisfaction, avoiding food contamination, reducing logistic cost etc., which is the significant proposal for this research paper.

Vehicle routing problem (VRP) deals with searching a best path from source to destination by serving a number of customers in a sequence where time window is the critical component. VRP was first proposed in year 1959 by Dantzig, and later on in the year 1987, then in 1989 and till now (year 2020), many others also studied and designed. In research, VRP is the most deliberated combinatorial optimization problems [3, 4]. Various variants of vehicle routing problem exist which have been developed one after another, and still researchers are exploring some new dimensions. In recent years, various heuristic methods, evolutionary algorithm, and hybrid optimization algorithms have been successfully applied for VRP [5] and have given quality solutions along with computational quickness. In research, some vehicle routing problems for supplying fresh agricultural foods and frozen foods have been applied with time window constraints [6, 7], but in some most of the cases, food contamination during transportation was not taken into consideration.

Optimization algorithms have replaced the traditional techniques to serve the purpose because of various appealing features to deploy in real-time problems for accomplishing various tasks as they are efficient, can serve customer in better way with lots of clarity, and follow all predefined rules and increased efficiency. They can be improved with time, or modifications can be done depending upon the nature of problem/application [8–10]. Optimization is very much essential in the business domain because of optimization, and only cost can be reduced with increased performance. Therefore, profit can be increased. Application of optimization algorithm in food industry has also proven and setup a benchmark for others by using best practices and techniques [11]. Motivation for the research is to accomplish distribution of fresh food without quality degradation, and it can be achieved if time required for distribution can be reduced.

In recent years, various novel optimization algorithms such as ant colony optimization (ACO) [12, 13], particle swarm optimization (PSO) [14], cuckoo search (CS) [15, 16], lion optimization algorithm (LOA) [17], grasshopper optimization algorithm [18], Levy flight algorithm [19], tree growth algorithm [20], grey wolf optimizer [21], bees pollen optimization algorithm [22], Harris Hawks optimization (HHO) [23], sine cosine algorithm [24], water wave optimization algorithm [25], whale optimization algorithm [26], moth search (MS) [27], elephant herding optimization (EHO) [28], slime mould algorithm (SMA) [28], kill heard [29], and butterfly optimization (BO) algorithm [30], and hybrid algorithms have drawn the attention of researchers for applying these algorithms in various unconstrained and constrained optimization problems. Upon studying all mentioned algorithms, it has been identified that they have been successfully applied for test suite optimization, path convergence-based optimization, and many other real-world engineering problems. One of the very interesting and challenging real-time problems is fresh food distribution because it has to meet various standards with available resources constraints and customer satisfaction is the most important requirement.

One of the novel heuristic algorithms is artificial bee colony (ABC) algorithm, inspired by bee's behavior which has been applied to get a solution of complex combinational optimization problems. Every optimization algorithm has certain advantages, but ABC algorithm is preferred by the researcher for adaptive nature of the problem over other algorithms because of less control parameters, fast convergence, robust nature, highly flexible, and simple approach within stipulated time duration. The quality of bee colony is to search nectar spontaneously and to do so sometimes they divide themselves into three groups: leaders, onlooker, and scouts. Among these three characters, information is communicated and colony collects the nectar rapidly and proficiently. ABC algorithm and some of its variants have been applied effectively in various problems such as assignment problems with neighbourhood mechanism, scheduling problem, integrated portioning, Schottky barrier diode, and image segmentation [31, 32]. Such fruitful applications of artificial bee colony optimization algorithm encouraged authors to implement in this paper. The objective of this paper is to apply vehicle routing problem with time windows (VRPTW) to maximize the probability of timely delivery of food product to customers by minimizing the number of vehicles required, distance travelled by each vehicle, cost involved in transportation, and other logistic requirements. Results achieved are compared with results extracted from the cuckoo search (CS) algorithm. CS algorithm has a slow rate of convergence but is compatible with the ABC algorithm in terms of other parameters and performance. Upon compassion, it has been observed that the proposed algorithm, i.e., artificial bee colony optimization algorithm looks like an effective and competent method for the defined problem.

Organization of the paper is as follows: food quality, food categorization, and preservation are presented in Section 2. Artificial bee colony (ABC) algorithm is defined in Section 3. Cuckoo search (CS) algorithm is described in Section 4. Vehicle routing problem (VRP) and its variants are discussed in Section 5. Problem description and implementation are presented in Section 6. Results are illustrated in Section 7. Lastly, conclusion and future scope are enumerated in Section 8.

2. Food Quality, Food Categorization, and Preservation

Food makes our body to work, to grow, and to repair itself whenever required. Basically, food is an organic substance and consumed for nutritional purpose, and it comes from animals and plants. Food is eaten by living things to become healthy, and it contains protein, moistness, carbohydrate, minerals, fat, and other organic ingredients [2, 6].

2.1. Food Quality. The objective of food business is to endure competitive in global market by maintaining food quality. The term food quality is a very important factor especially in the success of a food product. This term consists of addition of all properties and features of food items which must be acceptable to all buyers. The term "food quality" is frequently used by consumers, but its value varies from customer to customer even among various regions and cultures.

Generally, quality is subjective in nature; therefore, some reference is required for specific criteria or attributes. In food industry, product specifications are defined in view of quality attributes and specifications.

The attributes contributing to food quality are as follows:

(i) Appearance (it includes shape, size, color, shine, and consistency)
(ii) Nutritional content
(iii) Flavour
(iv) Texture
(v) Decent and viable production

2.2. Food Categorization. Figure 1 shows the classification of food and details about each category, and its subcategory is also explained in this section.

2.2.1. Categorization of Food Based on Shelf Life. Food spoilage with respect to time is a natural procedure because during this stage, food may progressively lose its color, odor, consistency, and nutritional values. In case someone consumed spoiled food, it can lead to mild to severe sickness till death also. In the basis of the self-life, food items can be categorized as follows:

(i) Nonperishable foods such as flour, nuts, and dry beans
(ii) Semiperishable foods such as cheese, vegetables, and fruits
(iii) Perishable foods such as milk, eggs, and dairy products

2.2.2. Categorization of Food Based on Functions. As per the functioning of the human body, it is categorized is as follows:

(i) Protective foods
(ii) Energy-giving foods
(iii) Body-building foods
(iv) Regulatory foods

2.2.3. Categorization of Food Based on Nutritional Values. On the basis of nutritional value, food items categorized are as follows:

(i) Protein-rich food
(ii) Vitamin-rich food
(iii) Mineral-rich food
(iv) Carbohydrate-rich food
(v) Fat-rich food

2.2.4. Categorization of Food Based on Extent and Purpose of Processing. Food industries try to convert fresh foods into food products. Therefore, various food processing techniques are utilized. In this category, further categorization is as follows:

(i) Marginally processed or unprocessed food
(ii) Processed cookery food
(iii) Ultraprocessed food

2.3. Food Preservation. It is always required to maintain food quality along with its nutritive values, color, consistency etc., for longer duration of time because food contamination is very dangerous. It can have serious apprehensions like sickness to increased level even till death also. Therefore, legal responsibilities lie with food managers or supervisors that they must ensure that food does not contain any type of contaminations which may impact customer health. In any such type of severe conditions, serious penalty may be bear by the food business owner which may impact business reputation also.

Food preservation is a procedure via which internal and external features of food is maintained to avoid food decay. The objective is to intact its nutritional values, consistency, color, and taste. Food preservation had been started long time ago in olden days. Figure 2 shows the classification of food preservation. Traditional old methods of preservation are drying in sun, cooling, chilling, and fermentation. With technological development, recent methods of food preservation also include addition of preservatives like some chemicals or natural preservatives.

3. Artificial Bee Colony (ABC) Algorithm

An artificial bee colony (ABC) algorithm is a stochastic algorithm based on popular swarm intelligence and was proposed by Karaboga in 2007 for solving various optimization problems. This algorithm mimics the actions of intelligent honey bees with an objective to search the source of food. In a colony, bees are divided into three groups depending upon their roles [32, 33]:

(i) Employed bees: also known as forager bees; they go to search for rich food sources and after returning back to squirrel, they exchange the information with observer bees with some probability.
(ii) Onlooker bees: also known as observer bees; these are a kind of unemployed bees which start searching while scouts initiate in its nest or in neighbourhood. Exploitation search is carried out.
(iii) Scout bees: they interpret from some forager bees which abandon their sources and start searching new. Exploration search is carried out by them.

In artificial bee colony optimization algorithm, location of food source is treated as the possible solution of the given problem and amount of fluid (nectar) of food sources as fitness, i.e., quality of related solution. One employed bee corresponds to one food source; therefore, the total number of employed bees is the same as the number of solutions, i.e., food sources.

ABC algorithm executes four different selection processes:

(1) Global selection process: it is used by onlookers

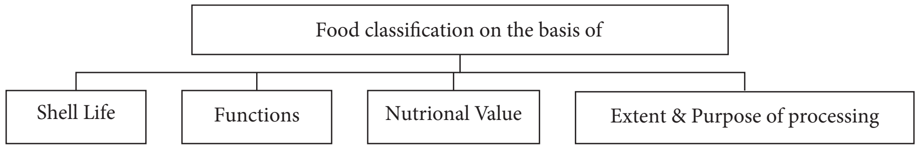

Figure 1: Classification of food preservation.

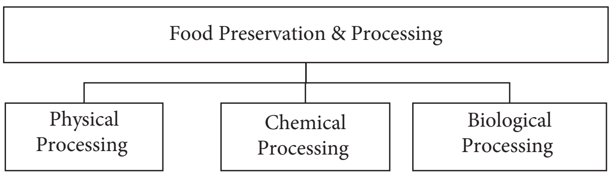

Figure 2: Classification of food preservation.

(2) Local selection process: it is carried out in a region by employed and onlooker bees
(3) Greedy selection process: it is used by all bees
(4) Random selection process: it is used by scouts

3.1. Organization of Artificial Bee Colony Algorithm. All the vectors (x_m) are initialized corresponding to the food source population, population size is set by scout bees, and other controlled parameters are also kept set. Let SS is the swarm size of the artificial bee colony (ABC) which randomly dispersed initial population of food sources. If X_i is the solution among swarm and dimension is denoted by M, then

$$X = \left[x_{i,1}, x_{i,2}, x_{i,3}, \ldots, x_{i,M}\right]. \quad (1)$$

Each and every employed bee will generate a new candidate solution in the neighbourhood of the current location. If new solution is represented by Y_i, where X_k is the randomly chosen solution and random number is $\varphi_{i,j}$ which lies in between [−1, 1], then

$$Y_{i,j} = x_{i,j} + \varphi_{i,j}\left(x_{i,j} - x_{k,j}\right). \quad (2)$$

A greedy selection is used once the new candidate solution Y_i is generated. Now, the fitness value of X_i is compared with Y_i. If Y_i is better than X_i, then update X_i with Y_i; otherwise, X_i will be unchanged.

Once all employed bees will complete their search process, they share the food source details with onlooker bees via waggle dance. The onlooker bee tends to evaluate the nectar details received from all employed bees and selects that food source which has probability for its nectar amount. Roulette wheel selection mechanism is used for probabilistic choice. For swarm, the fitness value of the i^{th} solution is FIT_i and is written as follows:

$$P_i = \frac{FIT_i}{\sum FIT_j}. \quad (3)$$

Food source will be assumed as abundant if position is not improved in defined number of cycles. Let us assume X_i as an abundant source, then the new food source identified by the scout bee is replaced by the previous one, which is as follows:

$$x_{i,j} = \text{lb}_j + \text{rand}(0, 1)(\text{ubj} - \text{lbj}). \quad (4)$$

Here, ub and lb are the upper and lower boundaries of j^{th} dimension

4. Cuckoo Search (CS) Algorithm

It is also a metaheuristic algorithm with good global search and fast convergence, proposed in the year 2009 [13]. In recent years, it has been applied to various applications where some process parameters need to be optimized. CS algorithm imitates the brood parasitism conduct of cuckoos and Levy flying actions of birds. It has extended search space because of a combination of recurrent short jumps and unplanned long jumps [15, 16]. Some low-grade nests used to be abolished by probability discovery (P_a), and new nests are created by a mechanism known as random walk. Fitness function F_i needs to be calculated for every iteration by taking cuckoos randomly and accordingly best solution, i.e., nest with quality solution, is updated for ranking the solution.

5. Vehicle Routing Problem (VRP)

A general version of travelling salesman problem (TSP) is vehicle routing problem (VRP) [34, 35]. In this problem, vehicle tends to start and terminate service at the depot itself by providing service to all the customers. In VRP, multiple salesmen provide services to many consumers. Therefore, various parameters need to be optimized. Parameters for optimization may be time, distance, and cost of related routes [36–38]. Different variants of VRP are as follows:

(i) Capacitated vehicle routing problem (CVRP)
(ii) Time-dependent vehicle routing problem (TDVRP)
(iii) Vehicle routing problem with time windows (VRPTW)
(iv) Vehicle routing problem with heterogeneous fleet (VRPHF)

Vehicle routing problem with time windows (VRPTW) is a variation of capacitated vehicle routing problem where time duration is allocated to each consumer and the required services must be provided in that time window.

6. Problem Description and Implementation

A delivery center provides distribution on fresh products. Let us assume that there are N service locations for food distributions and there are total M delivery vehicles. Each and every delivery vehicle starts its service from the delivery center, and by covering all service locations, it reaches back to the delivery center. Each service location has specified time duration in which the delivery of fresh food must be done. Therefore, the objective is optimization for delivery vehicles of distributing fresh food products so that the required target can be achieved. Parameters for optimization for maintaining food quality can be shortest path travelled, finest service quality, and minimum cost of supply. This paper proposed a process for the timely distribution model of fresh food products route without any quality loss of food.

Quality loss function of perishable fresh products expresses the quality transformation with respect to time involved in the delivery process. Modelling is done by considering fresh products as perishable, and its temperature is kept constant during the entire delivery route. Metamorphic function is expressed as follows:

$$X(t) = X_0 \mathrm{K} e^{-\beta t}, \tag{5}$$

where

t: delivery time

X_0: quality of fresh food product before delivery which is very good

K: rate of food quality loss

β: sensitivity of food products w.r.t. time (its value will be small when food products are highly sensitive otherwise vice versa)

If the customer is not satisfied with delivered food quality which is directly correlated with the time window problem, the penalty function needs to be introduced. Time window for penalty is being discussed in this paper. Let the time window is $[U_i, V_i]$ for satisfactory food delivery for each service location, and if food is delivered timely, i.e., within this window, the satisfaction level is met and no penalty is to be kept.

By considering various restrictions and for minimized cost of logistics distribution, the objective function for the fresh food distribution model can be written as follows:

$$\min(Y) = X_1 + X_2 + X_3 + X_4, \tag{6}$$

(i) X_1: fixed cost

$$\mathrm{X}_1 = \mathrm{mF}, \tag{7}$$

(ii) where F is the fixed cost of each delivery vehicle which includes all kinds of expenses

(iii) X_2: transportation cost

$$X_2 = \sum\sum\sum d_{ij} X_{ijK} C', \tag{8}$$

where $(i = 0, 1, \ldots, N)$, $(j = 0, 1, \ldots, N)$ $(K = 0, 1, \ldots, S)$

(iv) X_3: goods lost cost

$$X_3 = \mathrm{pgiK}\left(1 - e^{-\beta 0 t}\right). \tag{9}$$

(v) X_4: punishment cost

$$X_4 = \theta_1 (t_i - M_i). \tag{10}$$

When each service location has one delivery vehicle for distribution of fresh food and all service locations use total M delivery vehicles, it is mathematically written as

$$\sum_{S \in M} B_{iS} = 1 \quad \text{for } i \in N, \quad M \text{ for } i = 0. \tag{11}$$

Each delivery vehicle has only one route for food distribution, and summation of all distribution routes is small than the total number of delivery vehicles, i.e.,

$$\sum_{S \in M} \sum_{j \in N} A_{ijS} \le M, \quad \forall i = 0. \tag{12}$$

Every delivery vehicle starts from a fresh logistic delivery center and ends its service there itself after accomplishing task; therefore, it is a closed delivery track.

$$\sum_{j \in N} A_{jiS} = \sum_{j \in N} A_{jiS} \le 1, \quad i = 0, K = 1, 2, 3, \ldots, M. \tag{13}$$

The total stretch travelled by each delivery vehicle on each delivery route does not exceed the maximum stretch of vehicles.

$$\sum_{i,j \in N} d_{ij} A_{ijK} \le D, \quad \forall S \in M. \tag{14}$$

Total demand arriving at each delivery path must be less than the maximum capacity of each delivery vehicle.

$$\sum_{j \in N} g_i B_{ki} \le X_L, \quad S = 1, 2, \ldots, M. \tag{15}$$

7. Results and Discussion

In this paper, the artificial bee colony optimization algorithm is used for solving the discussed problem because this algorithm improves the convergence time. Various parameters for ABC algorithm are number of iterations, size of colony, limit value etc. The same problem is solved by applying one more swarm algorithm, i.e., cuckoo search algorithm. By varying the population size, results have been computed, and analysis has been done for optimality of result whether it depends on variable population size or increasing search space. Results have been tabulated for both algorithms, in two cases. The first case consists of 20 delivery locations, i.e., stores, and 5 delivery vehicles, and second case consists of 40 delivery locations and 10 delivery vehicles. Table 1 comprises the data corresponding to 20 delivery locations with 5 delivery vehicles for both ABC algorithm and CS algorithm. Table 2 comprises the data corresponding to 40 delivery locations with 10 delivery vehicles for both ABC algorithm and CS algorithm. Data related to each food delivery route, distance travelled, time required, and number of delivery locations, i.e., stores, have been enumerated in

Table 1: 20 delivery locations with 5 delivery vehicles.

Algorithm	Route no.	Route travelled	Number of stores	Distance travelled (Km)	Travelling time (mins)
Artificial bee colony (ABC)	R1	S-10-4-13-20-S	4	6.04	51
	R2	S-1-6-18-S	3	4.51	42
	R3	S-3-11-8-12-14-19-S	6	9.93	79
	R4	S-5-17-9-S	3	4.48	44
	R5	S-15-16-7-2-S	4	5.92	48
Cuckoo search (CS)	R1	S-1-18-19-S	3	4.52	45
	R2	S-8-20-15-S	3	4.8	49
	R3	S-17-10-14-7-12-3-S	6	10.09	87
	R4	S-2-9-11-6-S	4	5.56	64
	R5	S-13-16-4-5-S	4	5.49	59

Table 2: 40 delivery locations with 10 delivery vehicles.

Algorithm	Route no.	Route travelled	Number of stores	Distance travelled (Km)	Travelling time (mins)
Artificial bee colony (ABC)	R1	S-3-26-9-S	3	5.23	42
	R2	S-8-21-35-19-2-S	5	6.52	61
	R3	S-18-4-23-30-S	4	5.89	46
	R4	S-25-5-7-32-39-31-17-S	7	11.3	93
	R5	S-12-36-6-S	3	5.44	38
	R6	S-11-40-S	2	4.34	31
	R7	S-1-15-20-29-S	4	5.91	51
	R8	S-22-10-38-S	3	5.29	42
	R9	S-14-24-13-37-S	4	5.88	48
	R10	S-16-28-33-34-27-S	5	6.6	58
Cuckoo search (CS)	R1	S-9-19-32-S	3	4.98	41
	R2	S-1-10-7-26-S	4	6.11	67
	R3	S-28-21-14-8-2-S	5	6.73	73
	R4	S-11-5-18-23-29-30-38-S	7	12.8	101
	R5	S-17-36-40-S	3	4.99	45
	R6	S-31-13-25-S	3	5.55	58
	R7	S-16-22-37-S	3	6.01	63
	R8	S-12-39-33-S	3	5.97	55
	R9	S-24-34-3-6-S	4	5.88	60
	R10	S-4-20-15-35-27-S	5	6.82	84

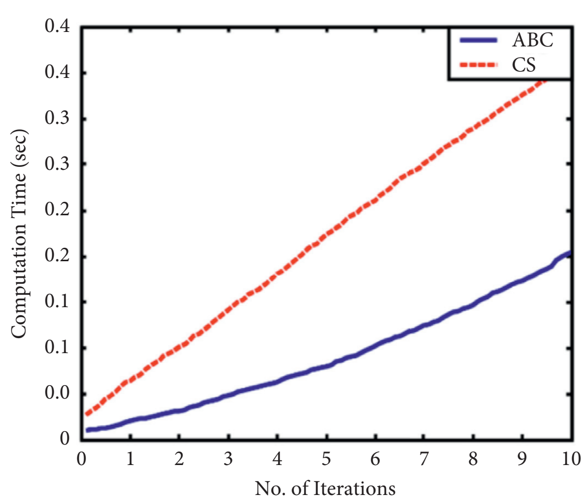

Figure 3: Convergence graph.

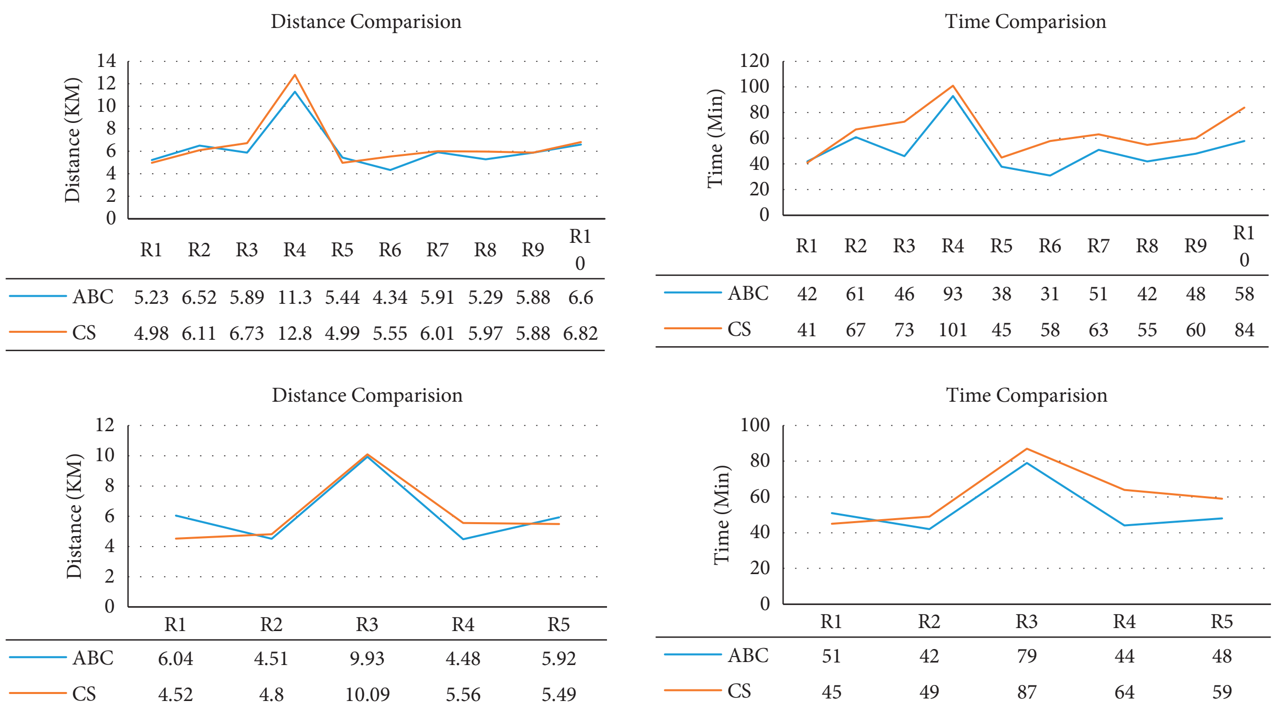

FIGURE 4: Comparison of distance travelled and time taken.

Tables 1 and 2. S denotes the initial location, i.e., depot from where vehicles will start and terminate their services.

Computation time is the time required by the algorithm to complete the task. Figure 3 shows the computation time for the artificial bee colony algorithm and cuckoo search algorithm for path planning of distribution of fresh food among various delivery locations without food quality loss and limited number of delivery vehicles. From Figure 3, it is clear that time required by the ABC algorithm is less than the CS algorithm; therefore, the performance of ABC algorithm is very much efficient and effective.

Figure 4 shows the distance travelled and time required for each route in both the cases, i.e., 40 delivery locations with 10 delivery vehicles and 20 delivery locations with 5 delivery vehicles using the artificial bee colony algorithm and cuckoo search algorithm. It can be observed that performance of the artificial bee colony algorithm is better in comparison with cuckoo search algorithm.

8. Conclusion and Future Scope

Food distribution within time window is always a research area for researchers in food industry because of its dynamic nature with lot many constraints. Reputation of the food industry and related owner depends upon the feedback of customers, which is directly associated with the quality of food and service. In this paper, fresh food delivery route optimization is applied on multiple delivery vehicles with multiple delivery locations including penalty function and quality loss function. ABC algorithm and CS algorithm are applied by varying the selection of function indicating the shortest route; therefore, food distribution is done within the time window. By analyzing all constraints, the overall process is examined, and path optimization is done and it has been observed that performance is better by using ABC algorithm. Some of the limitations are still here because of not considering the dynamics of delivery vehicle and real-time traffic and other environment scenarios; therefore, further revision in the food distribution model can be done. Researchers suggest that further some more descriptive computational intelligence algorithms can be used to solve the same nature of problems, such as Monarch butterfly optimization (MBO), lion optimization algorithm (LOA), grasshopper optimization algorithm, earthworm optimization algorithm (EWA), elephant herding optimization (EHO), moth search (MS) algorithm, slime mould algorithm (SMA), Harris Hawks optimization (HHO), and butterfly optimization (BO). Some hybrid algorithms can also be applied to reduce other fresh food distribution limitations or reducing quality loss, and results can be compared to ascertain which algorithm works better. [28]

Data Availability

No data were used to support this study.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

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Research Article

Safety of Food and Food Warehouse Using VIBHISHAN

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Food is one of the integral parts of human life making the quality of food one of the prime factors in its selection for consumption. In order to maintain the food quality, it must be taken care of from the very first step where its quality may be affected, that is, warehouses. Food safety and safety of its warehouses is one of the major concerns, because many people lose their lives due to poor food quality. A robot that can ensure the safety of both food and warehouse can be one of the possible solutions, because taking care of huge warehouses is a tedious task and sometimes food present inside the warehouse gets unnoticed and thus get contaminated. Also safety of warehouses from intruders can be done by a robot, in any condition where it is difficult for human beings. This robot would be cheap and efficient and also make sure of safety, keeping the food intact and ensuring its fine quality.

1. Introduction

Since the time living creatures like animals and human beings have come into the picture, food has been one of the core parts of their survival. Having wholesome food is a very basic need for every human being which should include good nutritious food that makes individuals healthy and feel vibrant. There are different types of food that can be consumed by human beings such as it vegetables, fruits, meat, and pulses, and their quality may vary. Quality is the main factor in the food industry because the finest the food quality is, the higher the chances of success of the industry in the competitive market [1] and its demand automatically goes up, along with the increase in consumer awareness nowadays. So, the expectations in terms of food quality had increased the need for monitoring the quality of food [2]. According to a report in the USA (shown in Figure 1), it was found that around $50–80 billion USD cost goes into illness treatment caused by food per year. In India, in 2019, it is around $15 billion annually and in 2020, it is around $28 billion (Rs 1,78,100 crore), as per the statistics by the World Health Organization (WHO). It was found that 1 out of 10 people fall ill due to food they consume which is not of the quality; as a result, we lose around 33 million in the world. This gives the reason why we need to focus on the quality of food, which begins from the very first step, that is, where they are produced and stored (safety of food and food warehouses) [4].

In some food industries, there are trained food inspectors which inspect the food quality manually which makes the inspection monotonous and slow, requires a lot of human effort, and is costly [5]. In numerous cases, it is found that a food inspector during an inspection of food falls ill, because of quality (worsening of food), foul smell, or tasting those food [6]. These industries have different sizes of warehouses and even some small vendors also have huge warehouses to store the foods, so ensuring safety manually is a big challenge to both industry (in monetary terms) and food inspectors (in terms of their health) [7]. So, we have to discover some methods that can decrease the risk of health issues and ensure the safety of food and food warehouses; for example, we can use a robot, which will have some sensors for identifying the quality of food or detecting the food and sending pictures of it; it can be used to protect the warehouse from intruders as well. Robots can be trained by using some artificial intelligence techniques/machine learning algorithms. So, robots can be used to determine the food and give better results in the food industry [8].

Artificial intelligence is basically mimicking functionality like that of a human brain. It includes subsets like deep

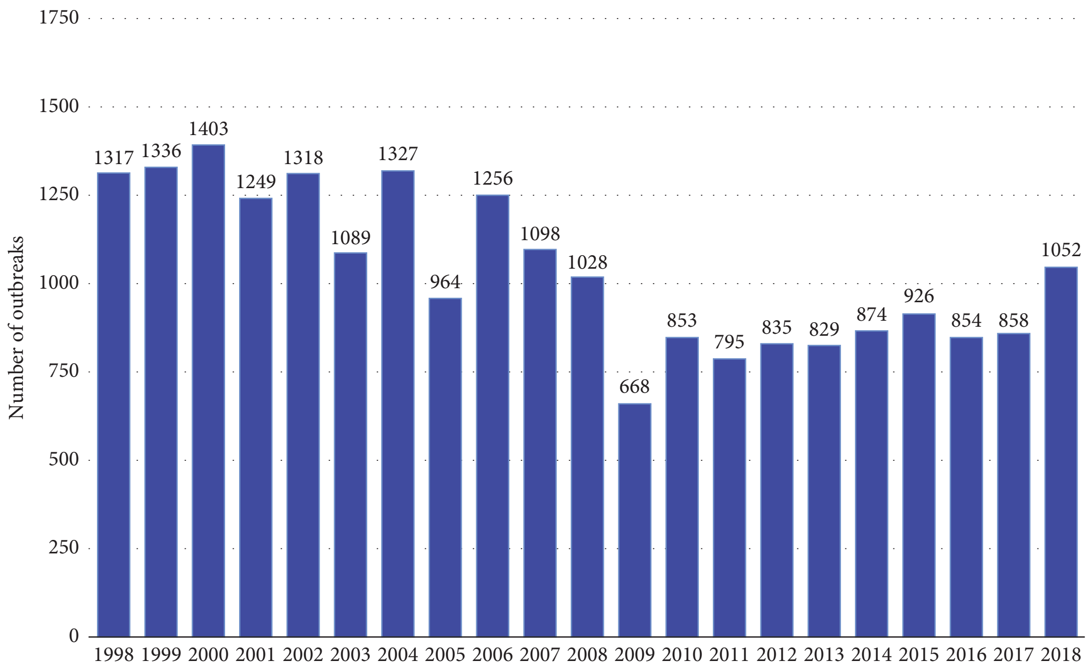

Figure 1: Food-related diseases rate in the USA [3].

learning and machine learning, which performs various tasks that need human intelligence like speech recognition, decision-making, and translating languages [9]. Artificial intelligence is used in the food industry (as shown in Figure 2) for various purposes such as food sorting, supply chain management, food preparation, food quality improvement, and food safety [10]. Many companies and government agencies are using these models for making predictions and also they have high efficiency and can operate difficult tasks such as food safety and food quality control [11]. There are a lot of problems that are still not addressed by using artificial intelligence alone [12]. Robots can be trained by using machine learning algorithms to solve the problems mentioned above. These robots can be positioned with the camera to ensure food safety such as monitoring the food condition and preventing intruders. Algorithms such as artificial neural networks (ANN) and convolution neural networks (CNN) are used in the food industry to solve challenges; for example, ANN is one of the best tools for examining food quality as well as food safety. In fruit sorting, wine bending, or other domains we can use ANN to ensure the quality of food. Since the purpose of a food warehouse is to store the food for future use, there are many things that we have to maintain in the warehouse for better food quality. There are a lot of challenges faced in the warehouses such as food storage, food safety, and safety from intruders. Robots can be used to address these problems and have great scope in the field of food industry and they can work in every condition without any interruption and even in the worst conditions [13,14], so the robots can be used to ensure the security of warehouses and food. Robot's ability to learn quickly and perform repetitive actions in any situation would be of great use [3]. This paper aims to find possible solutions using robots (VIBHISHAN 2.0) to solve the problem of food safety and food warehouses, as it can decrease the efforts and from time to time keep an eye on safety.

2. Literature Review

As shown in Figure 1, about the statistics of food-related diseases which lead to health issues or even death in some cases, we can infer that there is a need to find a solution that can improve the food quality or control the quality. There are many solutions available in the market from 2004 till now. In 2004, a paper mentioned the use of image processing methods in the food industry to give better results. The paper mentioned the applications of image processing techniques for food quality evaluation, in which they suggested methods to evaluate the food quality by capturing the images of food using a camera or MRI. The captured image is then improved in quality to find the distortion or some more features that are used for further processing. This method was cheap and fast to evaluate the food quality [5]. In 2006, "Learning Techniques Used in Computer Vision for Food Quality Evaluation: A Review" was a paper that gave a better estimation method using computer vision. There are many algorithms like ANN, Supervised Learning, Genetic algorithm, decision tree, and fuzzy logic that can be used to evaluate the result in terms of quality, in which genetic algorithm and decision tree algorithm give better results than other algorithms for food quality evaluation [1]. In 2007, a device named "electronic nose" was launched. It was similar to the human nose which was used for detection of food quality. It was based on sensors and was more beneficial than human sensory panels because it evaluated a very large number of samples and gave a more stable and consistent result [7,15,16]. After that, another electronic device was

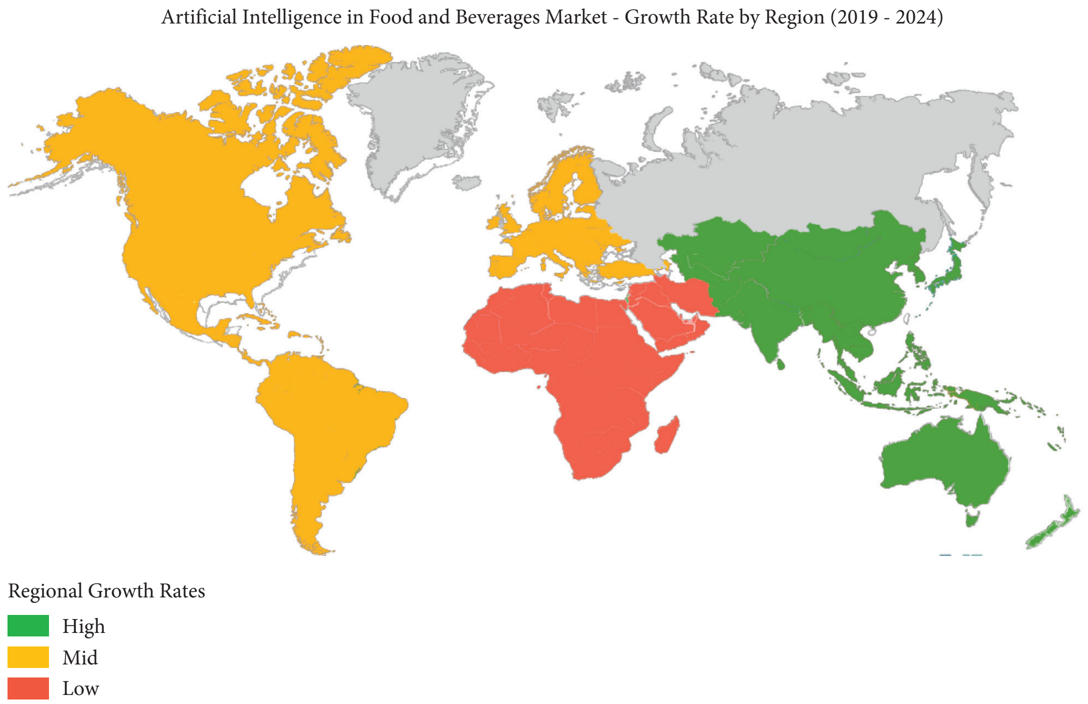

FIGURE 2: Artificial intelligence in the food and beverage market.

built named “electronic tongue” that gave a better detection and sensing capability than humans as it could also detect the odour of food and all dissolved compounds [17]. In 2008, a system for security was proposed that controlled the monitoring using some sensors and actuators. It had two-level communication systems in which one was used to communicate with modules and the other connected with the device for controlling processes [18]. In 2011, data mining techniques were more used in quality checking and for prediction or optimization processes. So, those techniques were used in food quality checking and making electronic devices for the food industry which made a big contribution in the food industry along with the ANN Algorithm that performed as an optimal process for improvement in food quality output [19].

In 2012, “Achieving Quality Assurance Functionality in the Food Industry Using a Hybrid Case-Based Reasoning and Fuzzy Logic Approach” was a paper that gave a solution for monitoring in a warehouse, in which a system IFQAS was made to aid and evaluate the safety as it used a decision-making process, in which CBR and FBR were the decision support technologies used [20]. In 2013, there was a device for grading the egg based on defect or size, which was done by using the fuzzy logic inferences and computer vision system, used to find the eggs with spots or cracks. It was possible using the designed algorithm in which they grade the eggs as 100% if they were normal, and if they contain blood spots, then the rate was graded as 83% [21]. In 2016, “Prediction of Banana Quality Indices from Color Features Using Support Vector Regression” is a paper which used Support Vector Regression (SVR) implementation and was used for quality prediction of bananas. Also the ANN model was used to give outcomes that were compared with the SVR outcome [22]. In 2017, a smart kitchen was developed named “Foodie” that provided many services for preparing a meal. It gave updates about diet goals or for recipe recommendation and also updates about preferences for better results. It used text or voice recommendation to provide better facility to the user in the field of AI [23]. In 2018, there was a paper for the safety and storage application of warehouses using robotics and Internet of Things (IoT) platforms which may produce an ideal solution for the management of warehouses and also reduce the storage efficiency or time with minimum distance coverage by robot [24]. In 2020, there will be many models developed for the food industry. One was related to bread quality improvement by using wheat germ which decreases the softness of bread throughout the storage process and it gave a specific volume to the bread [25]. Also in 2020, there was another model that was proposed on the basis of the artificial intelligence cloud project, which developed a smart refrigerator and it could send an alert to the user, if the food gets stale or the food is kept in the fridge for many days [26]. In 2020, another system was developed named “An Autonomous Food Wastage Control Warehouse.” It gave four major features using blockchain and various algorithms, in which the warehouse gave priority to the food which was kept first into the warehouse and tried to dispatch it before it turned into stale food [27]. In 2020, “Alternative Data Mining/Machine Learning Methods for the Analytical Evaluation of Food Quality and Authenticity” provided the use of various algorithms to evaluate the food quality, in which SVM, random forest, and regression tree algorithm were used in the area of food quality [28]. In 2021, “Deep Learning Based on Residual Networks for Automatic Sorting of Bananas” was published which gave an automatic mechanism to sort bananas on the basis of images.

3. Problem Statement

Food is the most crucial part of the nourishment of human life. Survival without shelter is still possible but without food is not possible for more than 10 days. So, food plays a very important role in human life as it provides nutrients, fats, minerals, vitamins, and energy to the body and so forth, but it can only be engrossed by the fine quality of food only, not by the food which is of poor quality or is stale/rotten. To maintain the quality of food, it is most important to keep a track of the very first step where the issue occurs, that is, warehouses (the place where food is stored). But food safety is a major concern especially in large warehouses where manual ways of ensuring safety are not feasible. Safety can be from an intruder trying to affect the food stored in a warehouse or food getting stale due to lack of attention on what kind of food is stored or shelf life of food; it causes a lot of food wastage [29]. Also, the government is trying to address this issue of safety for food and warehouses but there is a lot of scope in improving the technology for better transparency and monitoring systems [13]. Our traditional warehouse lacks a system that could provide safety to food and warehouses. So, our main goal is to develop a robot that can give us better results for food safety, which can be integrated with technology like artificial intelligence or machine learning.

4. Hardware Components Used

4.1. Ultrasonic Sensor. It is an electronic instrument that is used to evaluate the distance between the objects by transmitting the ultrasonic wave which gets reflected from the target object and converts the sound waves into electrical signals. For this, it uses the transducer to send the signals and the receiver to receive the signals. It is used as proximity sensors and it has a higher frequency than the human frequency. Sensors are used for object detection or people detection or for navigation. Ultrasonic sensors (as shown in Figure 3) were used to calculate the distance between the target objects by using the distance formula, that is,

$$D = 0.5 * T * C, \tag{1}$$

where D is the distance from the object, T is calculated time by sensors (i.e., signal transmission time and receiving time) and C is the speed of the signal, that is, 343 metres/second.

Here, to ensure the safety of warehouses from any intruder, the robot is positioned with an ultrasonic sensor as it will detect the distance between the intruder and from where the VIBHISHAN (robot) is capturing the image of the intruder. This distance is used by the robot to make its movement according to the distance between intruders.

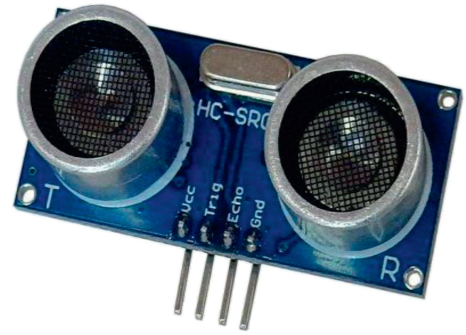

Figure 3: Ultrasonic sensor.

Figure 4: Passive infrared sensor.

Figure 5: Raspberry Pi.

Figure 6: ESP8266 WIFI.

4.2. Passive Infrared Sensor. PIR is a sensor that is used to detect the motion of an object when it passes into the range of the sensor. It is made up of pyroelectric sensors in which passive means it does not generate any energy in the detection of motion and it detects the amount of infrared radiation, in which if a warm object comes into the range of the sensor, it detects the positive differential range in one slot of the sensor and if it leaves the range of the sensor, then it detects negative differential change into another slot. So, if any human or animal passes through the range of the sensor, then it detects the energy and converts it into electrical signals. Figure 4 demonstrates the image of the PIR sensor, to ensure that the intruder is actually present in the warehouse; that is, some person (unauthorized) present in the warehouse is detected by this sensor.

Figure 7: ESP32-CAM.

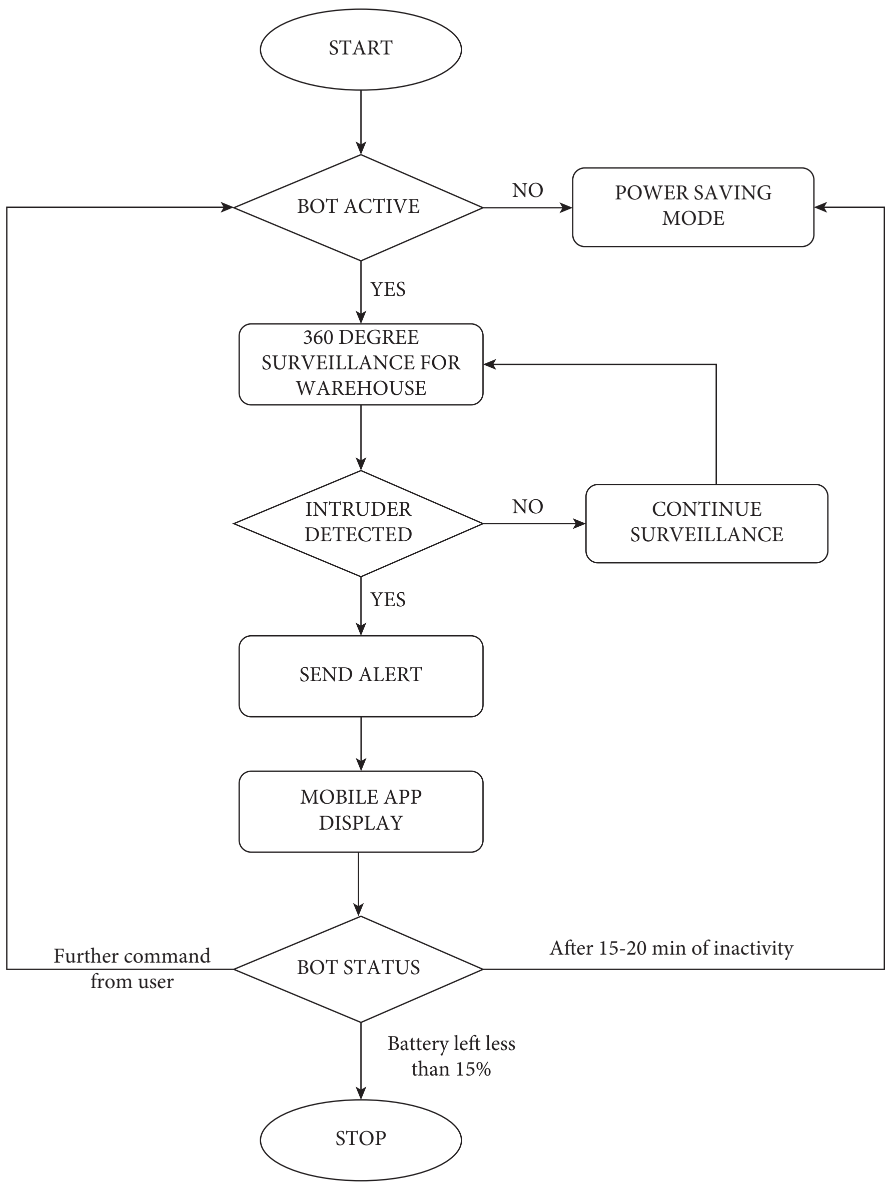

Figure 8: Flowchart of intruder detection using the bot.

4.3. Raspberry PI. It is a single computer board connected to devices such as a mouse and keyboard and used as a mini computer. It is used as a web server and to host websites in which we use a small SD card for storing purposes and also used for real-time processing of image and video, or in robotic applications and in IoT-based applications. It is useful for making robots or gaming consoles, tweetbot, or building a server and is also used for automating the home.

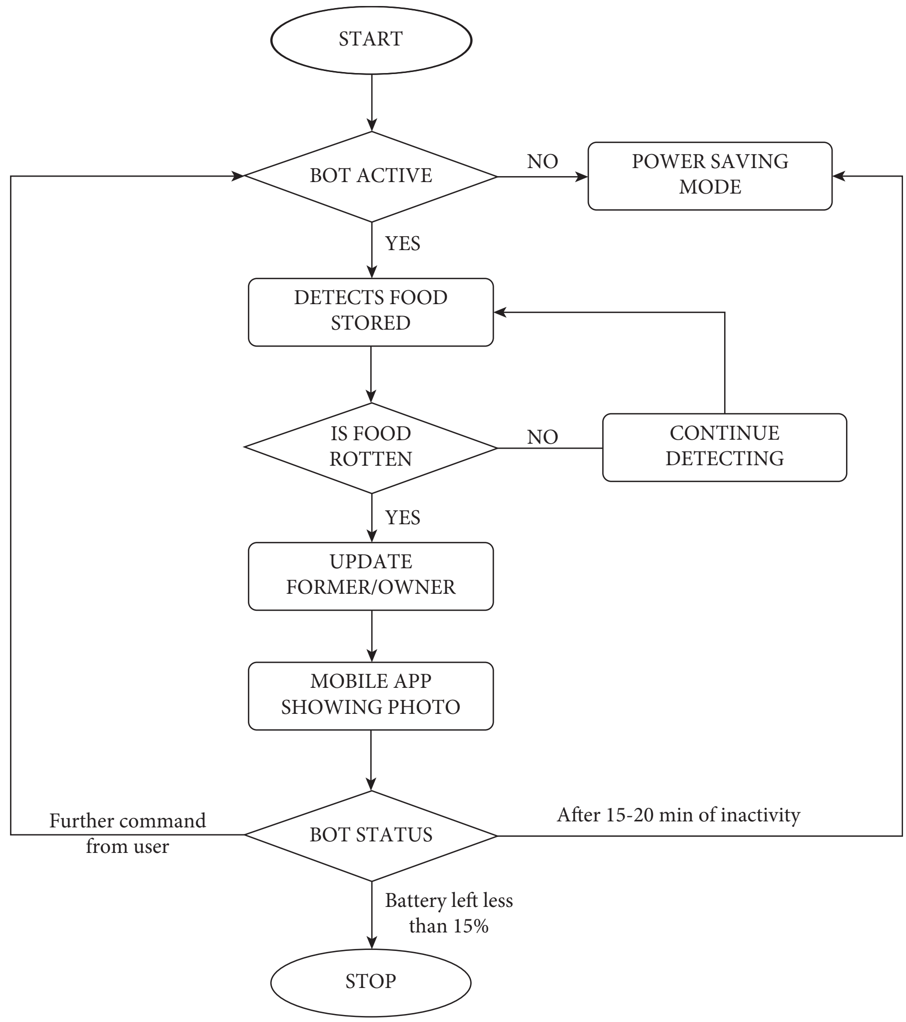

Figure 9: Flowchart of food safety using a bot.

It is the core component of a robot as it integrates all the sensors together and collects and processes the data collected from all the sensors, which is shown in Figure 5.

4.4. ESP8266 WIFI. ESP8266 is a very low-cost device used for Internet connectivity. It is used to fetch the data easily and also for uploading it to servers using the Internet. It has a maximum voltage of 3.6 V. It also works as a hotspot or Wi-Fi to provide Internet connectivity to the hardware device in the field of the Internet of things. It is used to send the data in the form of location, image, or video to databases. It can be used for providing the local Internet connectivity to the device where the Internet is necessary to use. Figure 6 demonstrates the pin and labels which is present on ESP8266 WIFI.

Transferring the data collected and processed by the raspberry pi to the owner of the warehouse, so that the owner can take necessary action at the earliest, is done with the help of Internet connectivity provided by WIFI.

4.5. ESP32-CAM. ESP32-CAM is a small camera device for monitoring, recognition, capturing videos and images, and so forth. It can contain a small SD card to store the video or images into it. It can help to detect the intruder using video streaming. It is integrated with the OV2640 camera and several GPIOs to connect peripherals and can store the images clicked by the camera. It is a cost-effective device in hardware for monitoring purposes including both a video camera or SD card for storing the images.

Capturing the images of the intruder, present in the warehouse, and ensuring the safety of food present inside the warehouse are done with the help of a camera installed on the robot. It will help the owner to make decisions faster. Figure 7 shows the sample image of the hardware used in the robot.

5. Working Procedure

A warehouse is required to store the food for the supply chain management. Many basic operations are performed in warehouses like receiving products, ensuring storage allocation, and ensuring the safety of food or transportation [30]. Since it is very difficult to track or monitor huge warehouses by manual efforts only [19,31], there is a need to improve the monitoring techniques for food and warehouse

Figure 10: Dataset used for training.

and also ensure the safety of food as well as warehouse. To solve this issue, we designed a robot (VIBHISHAN 2.0) which can detect the intruder and send an alert to the owner/farmer for the safety of the warehouse and it can also check the food and provide images of it (which is at the stage where it can infect other food and quality of food) to the owner/farmer so that they can take necessary action with less human interactions. Three functions are performed by the robot as follows.

5.1. Flow for Intruder Detection. To ensure the safety of the warehouses, a bot/robot named "VIBHISHAN 2.0" is used for intruder detection. Only authorized people should be able to access the warehouse. This bot can be used for this objective, which can be achieved by surveillance. In case the bot is not active, then it is in power saving mode, as shown in Figure 8.

If the robot is active, then, with the camera (ESP32-CAM) located on it, it will record videos and take pictures of the surroundings of the warehouse. During surveillance, it monitors the complete surroundings of the warehouse, as the camera has the ability to rotate 360 degrees. If it does not detect any stranger, it continues surveillance. If anything is detected, then it sends an alert to the owner/farmer that an intruder is detected and sends a picture of it on a mobile application. In case the battery is low or less than 15% or after 15 to 20 minutes of inactivity, it automatically goes into the power saving mode. In this way, the robot can ensure the safety of the warehouse and you will get complete information on mobile applications.

5.2. Flow for Food Safety. Food stored in warehouses should be of fine quality, to make sure this is a major concern. If the food gets stale or rotten, then there is no benefit of putting food into the warehouse as it can also rot other food products. So, there is a need to check the food from time to time and find the status of food to ensure safety.

Our robot also detects the food that is in good condition or not (got stale). As shown in Figure 9, if the bot is not active, then it is in power saving mode; otherwise, it will activate. In the active state, it goes to the warehouse and detects the food with the help of a camera. If food is in good condition, then it continues the food detection and in case the food is rotten or stale, then it sends an alert with the picture of stale food to the owner on the mobile application. If the battery is low or less than 15% or after 15 to 20 minutes of inactivity, it automatically goes into the power saving mode or it is active; then, it waits for further instructions from the user. In this way, we can ensure the safety of food, which is present inside the warehouse.

5.3. Flow for Image Processing. The above two processes demonstrate how we used robots/bot for the safety of food warehouses and food. The primary concept for security/safety is done by using image processing. Raspberry pi is

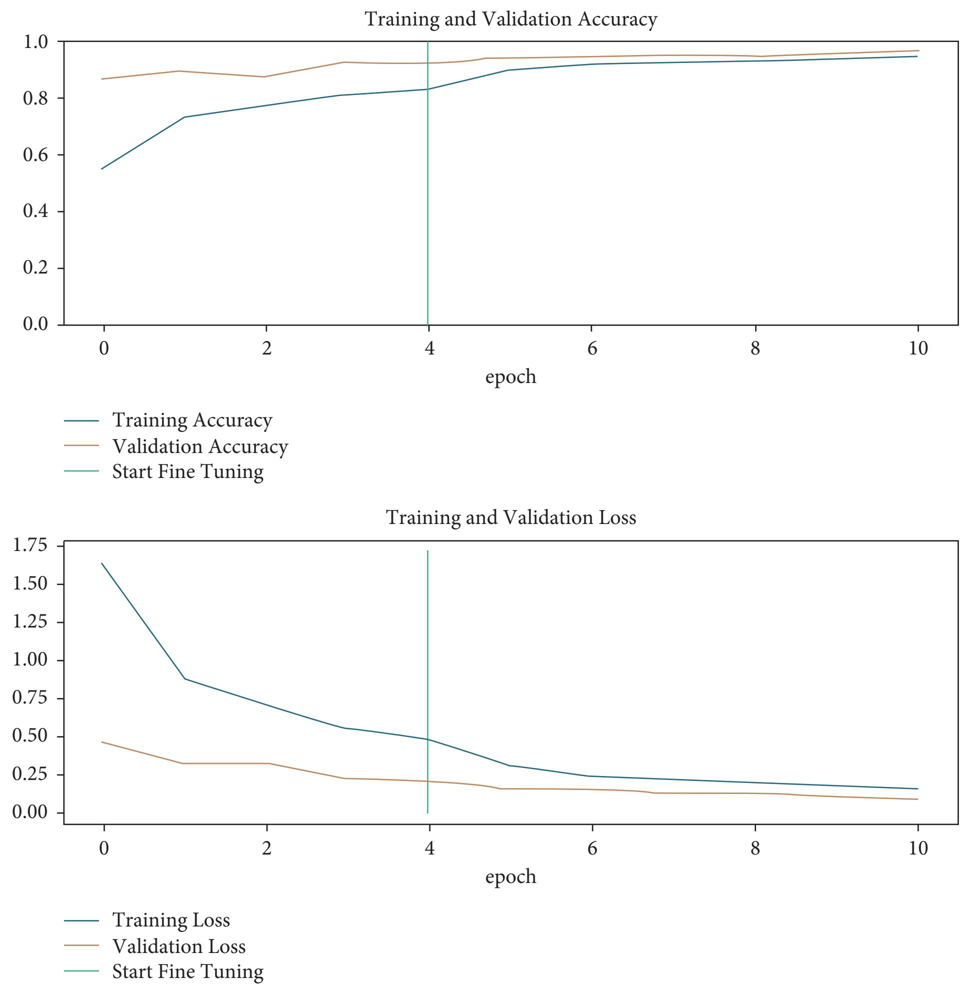

Figure 11: Training accuracy and loss graph.

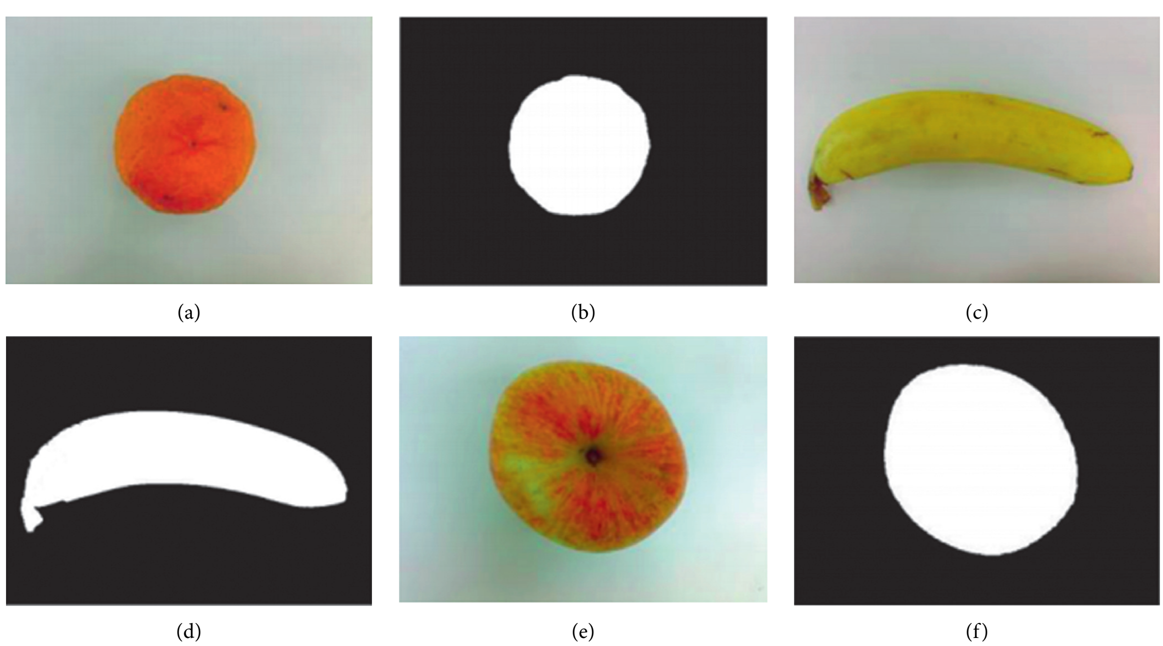

Figure 12: Colour images (food) are transformed into monochrome images. (a) Colour orange image. (b) Colour banana image. (c) Colour apple image. (d) Monochrome orange image. (e) Monochrome banana image. (f) Monochrome apple image.

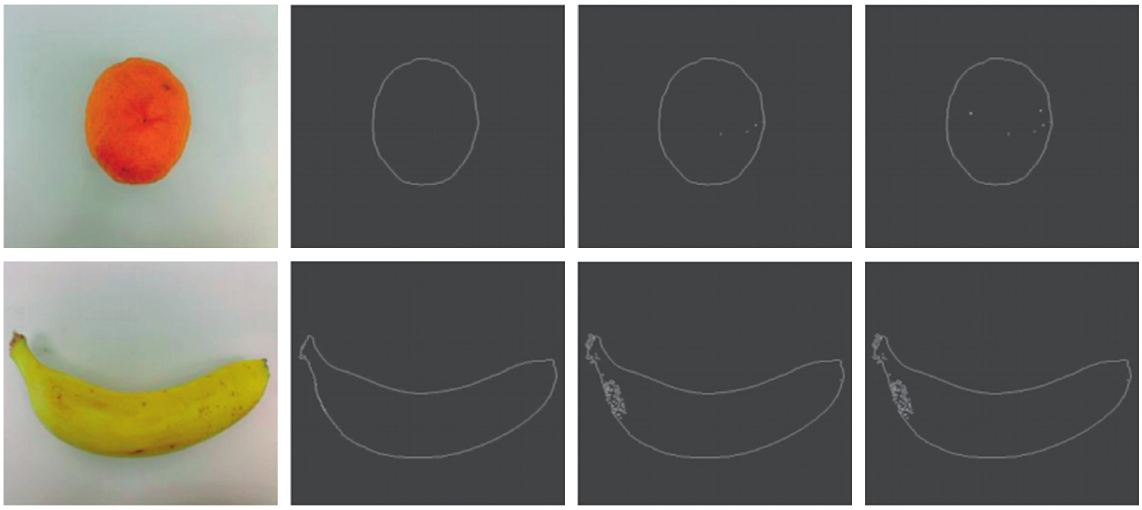

Figure 13: Shape detection.

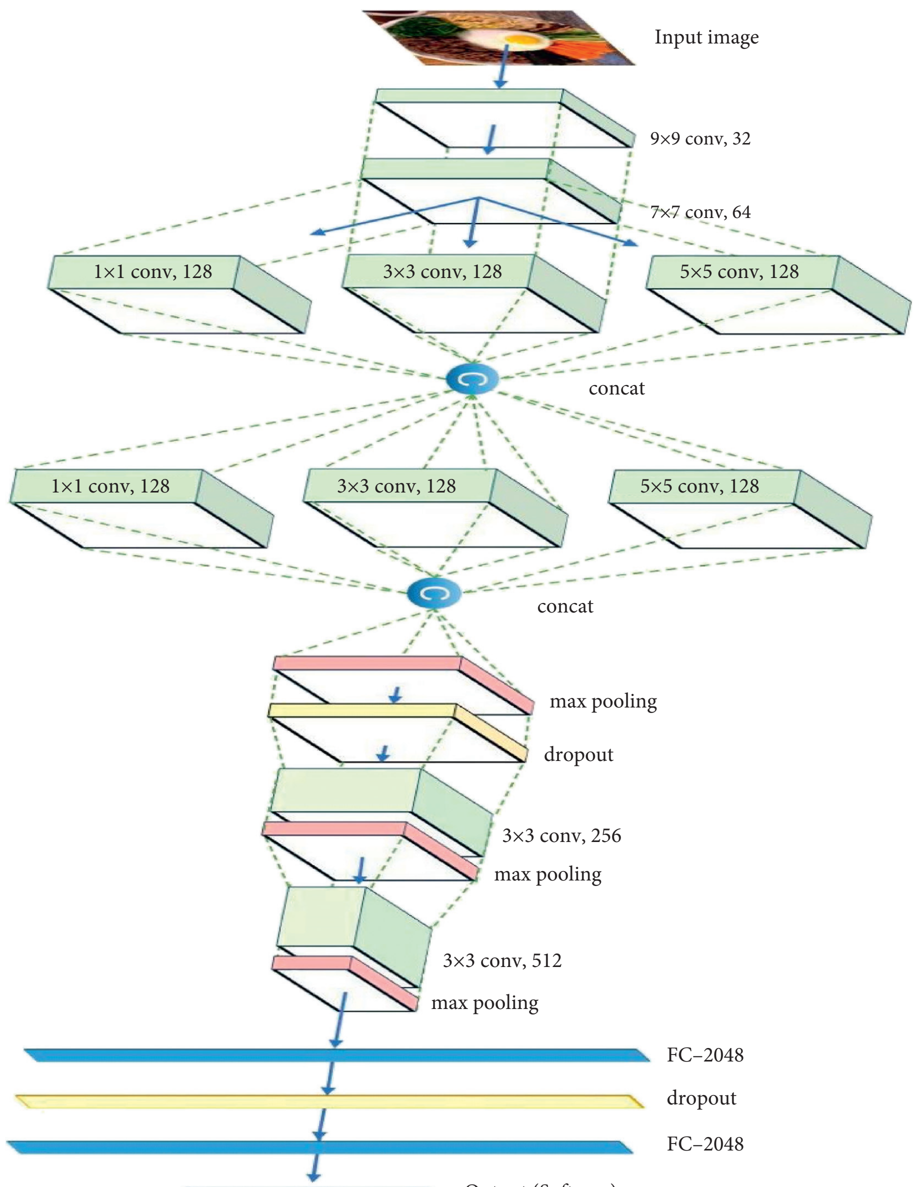

Figure 14: CNN model.

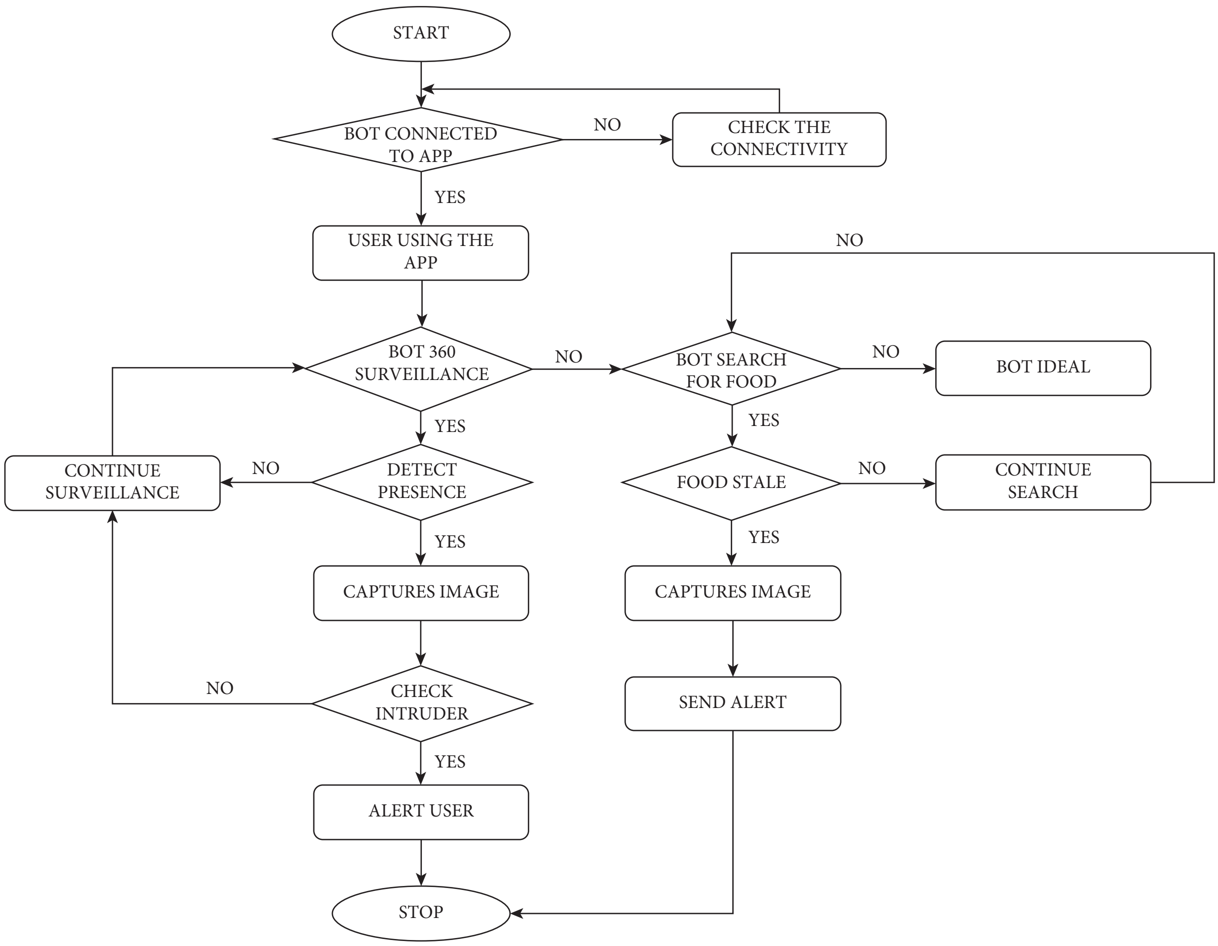

Figure 15: Flowchart of image processing.

Figure 16: The robot used for the safety of food and warehouses.

used to load the trained model on a bot, which is shown in Figure 10.

We had trained our machine learning model for detecting the food by using CNN. So, to train our model, we have used both kinds of images for food products, that is, fine quality and stale/rotten. Figure 10 shows the output of the images which are of fine quality. After training the model, it gives maximum accuracy of 96.30%, which is depicted in Figure 11.

Training the model used in the robot VIBHISHAN consists of 4 steps, used to ensure the safety of food by detecting the food (using image processing). The 5 steps are as follows:

Step 1. image acquisition.

Images were taken from a dataset with an image having a 1024×1024 resolution, which was then reduced to 512×512 resolution. Dataset consists of images analysed: apple, banana, beetroot, paprika, onion, peas, pear, orange, potato chip, mango, hawthorn, tomato, doughnut, peanut, and so forth.

When the image is captured through the camera installed on the robot, then it will help in further steps to identify the food captured and draw useful insights from it.

Step 2. image segmentation.

Once the images are picked up, we explore different regions of images (containing objects and background). RGB images are used in real applications but the color components of the images are converted to black and white for training purposes, that is, monochrome images. Figure 12 demonstrates the conversion of coloured image to monochrome image.

Step 3. shape detection.

Shape detection was the keep step while training our model because describing the features (shape) of an object plays an important role in object classification. The simple shape detection method which detects the complete shape of the food was used. It was based on binary morphological

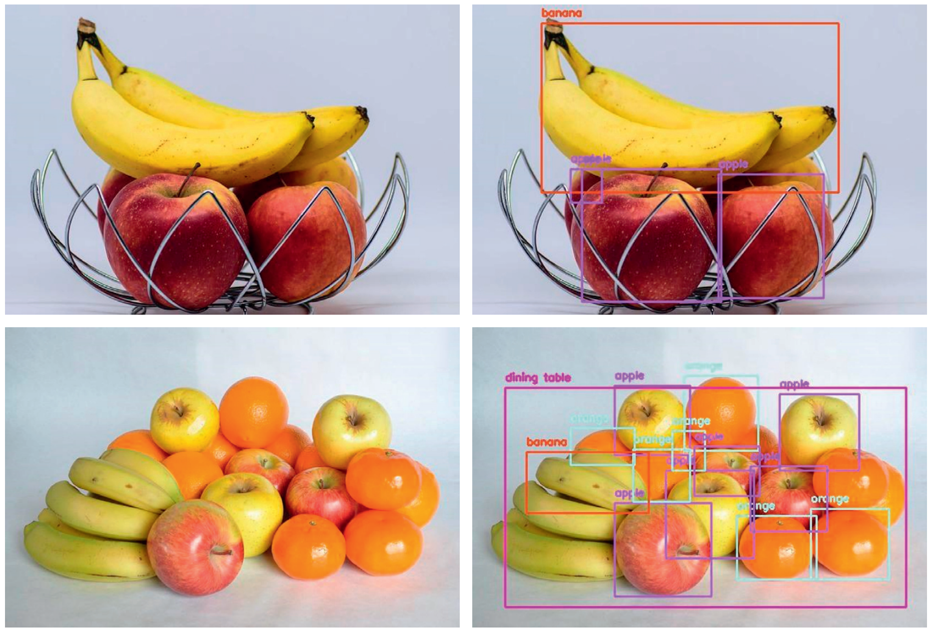

FIGURE 17: Result for image processing.

operations. Figure 13 demonstrates how the shape is detected.

Step 4. food recognition.

Once all the above steps are completed, the last step is to recognize the food, which can be tested by the validation dataset. Once it recognized the food correctly, then it was also tested on the robot which captures the images. Figure 14 shows the CNN model.

Figure 15 depicts the whole methodology on which the bot works. The bot is used for both the purpose, that is, intruder detection (safety of warehouse), and food safety.

6. Result

VIBHISHAN is an automated robot that can recognize the intruder and also identify the food condition (of stale or rotten food), which ensures the safety of the warehouse as well as the food stored in it. Figure 16 illustrates the picture of a robot (VIBHISHAN 2.0) which we had made for safety purposes. In addition, it is an efficient and cost-effective robot, which can be used to solve the issue of safety of warehouses and food. It is very small in size yet it performs all the tasks necessary to ensure safety.

As shown in Figure 16, the robot has a camera installed in front of it, which will capture the images of the surrounding of the warehouse; they will be sent to the owners on their mobile apps with the help of Wi-Fi which is present inside the body of the robot. With these wheels attached to the robot, it helps it move and do proper surveillance of the food warehouse and food.

Figure 17 is an output of how this robot identifies the food by using a machine learning algorithm with the help of a camera installed on it. This process will help in reducing the wastage of food or preventing the food from getting stale in large warehouses which get unnoticed by humans.

7. Conclusion

As the food industry heavily depends on warehouses to meet the demand of the increasing population in the world, the safety of food warehouses and food is an essential aspect in industry, to ensure that the quality of the food remains intact, because the slightest breach in safety may lead to contamination of the food present in the warehouses. So, the robot VIBHISHAN 2.0 could be one of the possible solutions to set the seal on the safety of both warehouses and the food present inside it, which could be an alternative to a manual way of ensuring safety or it can also be used with a blend of manual and robot techniques. By this, we can ensure security that would not leave any scope for breach in the safety of food. This robot is cheap and efficient as it can work in all possible scenarios and contribute towards the goal of giving fine quality food to people across the world at minimum cost. It will be the one stop solution to ensure safety of food warehouses and food.

Data Availability

The data used to support the findings of this study have been deposited at https://drive.google.com/drive/folders/1YuKAxOtAggSKn5ap7GI2VQqePgzG07R4?usp=sharing. Coding is available for this article whenever required.

Conflicts of Interest

The authors declare that they have no competing interests.

Authors' Contributions

All the authors contributed equally and significantly in writing this article and read and approved the final manuscript.

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Review Article

Modelling Techniques to Improve the Quality of Food Using Artificial Intelligence

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Artificial intelligence (AI), or AI/machine vision, is assuming an overwhelming part in the realm of food handling and quality affirmation. As indicated by Mordor Intelligence, AI in the food and refreshments market is required to enlist a CAGR of 28.64%, during the conjecture time frame 2018–2023. Artificial intelligence makes it workable for PCs to gain as a matter of fact, investigate information from the two data sources and yields, and perform most human assignments with an improved level of accuracy and proficiency. Here is a concise gander at how AI is expanding sanitation and quality activities. This exploration has along these lines tried to furnish policymakers with a way to assess new and existing strategies, while likewise offering a reasonable premise through which food chains orders can be made stronger through the thought of the executive's practices and strategy choices. This survey centers on the AI applications according to four mainstays of food security that is food accessibility, food availability, food use, and strength.

1. Introduction

Quick development of populace, reducing characteristic assets, environmental change, contracting rural grounds, and unbalanced business sectors are making the worldwide food frameworks rather unreliable. In this manner, current farming and food frameworks ought to be more gainful regarding yield, effective in activity, tough to environmental change, and maintainable for the people in the future. Therefore, the need of an innovative change is more prominent than any time in recent memory. Being a new headway in computer sciences, artificial intelligence (AI) has the ability to address the difficulties of this new worldview. Subsequently, understanding the significance and relevance of AI in farming and food area could be essential in the excursion towards accomplishing worldwide food security [1]. The major goal of this study is to create artificial intelligence and methodology for assessing and optimizing food quality and safety initiatives in the food sector. The cost-effectiveness of the approaches examined in this study is as follows:

(a) Aspects of general technical and economic importance to consider when evaluating food quality and safety improvements
(b) Quantification of the relative efficacy of various AI techniques for increasing food quality with growth focus on the farm stage
(c) Optimal (lowest cost) AI techniques for enhancing food quality at various stages
(d) The impact of farm scale on additional expenses associated with implementation of AI techniques to improve the food quality and their distribution throughout various stages of the supply chain

This audit centers around the AI applications corresponding to four mainstays of food security (food accessibility, food availability, food use, and strength) as characterized by FAO, in detail. The AI innovations are being applied worldwide in every one of the four mainstays of food security despite the fact that it has been one of the more slow received advancements contrasted with the rest. On the other hand, it warrants investigating the abilities of AI and their present effect on the food frameworks. It is prominent that AI innovation has a critical task to carry out later on the cultivation area. The overall AI in cultivation market is required to arrive at USD 2,075 million by 2024. Present article uncovers how AI innovations could profit worldwide farming and food area and looks at the ways by which AI can address the noticeable. Quality affirmation is acquiring conspicuousness since quality ascribes are by and large more exceptionally esteemed by governments, buyers, and organizations. Some food handling ascribes incorporated the accompanying terms described in Table 1. This higher valuation is inciting more deliberate quality affirmation by food organizations and more guidelines by government. Simultaneously, guidelines are under nearer investigation both locally and universally [2]. As requests for administrative responsibility have expanded, governments are progressively needed to utilize hazard appraisal and advantage cost investigation to assess whether existing or proposed food guidelines improve public government assistance.

The first necessary dimension in order to achieve food security is availability, which indicates the presence of food in a country through all forms of domestic production, food stocks, imports, and food aid [4]. The availability and access to food alone is not adequate, as people need to have a “safe and nutritious food.” Sufficient energy should be there in order to engage the daily physical activities after consumption of foods. Adequate sanitary facilities to avoid the spread of diseases, safe drinking water, and the awareness of food preparation and food storage are also included. Utilization, which is the third dimension, therefore, covers the diverse aspects by combining consumers’ understanding on which food to select, how to prepare it, and store them [5]. Food stability must be present at all times to exist the availability, access, and utilization of the food security. This fourth dimension highlights the importance to reduce the possibility of adverse effects on the other three dimensions [6].

Being a huge field with numerous applications, AI is likewise perhaps the most confounded innovations to chip away at. Machines characteristically are not more brilliant; a great deal of registering force and information are needed to engage them to reproduce human reasoning. A bunch of innovative and logical advances have prompted the development in the utilization of AI in genuine applications in different fields because of the huge increment of information with high computational force and huge stockpiling to enable them to reproduce human reasoning [7]. It is conceivable that a machine gains from its experience by changing their reactions dependent on new data sources given, playing out the human-like undertakings. The machines can be prepared to deal with a lot of information and perceive an example in them. At long last, AI is a data processing framework or computational framework that accepts information as data sources and interacts with them to prompt an easy to understand yield [8].

Table 1: Quality affirmation handling different attributes of food quality.

Foodborne microorganisms
Pesticide deposits
Food added substances
Naturally happening poisons
Veterinary deposits
Nutrition attributes
Fat
Calories
Value attributes
Purity
Compositional uprightness
Convenience of arrangements
Package attributes
Package materials
Other data
Process attributes
Animal government assistance
Worker well being
Pesticide use
Worker safety

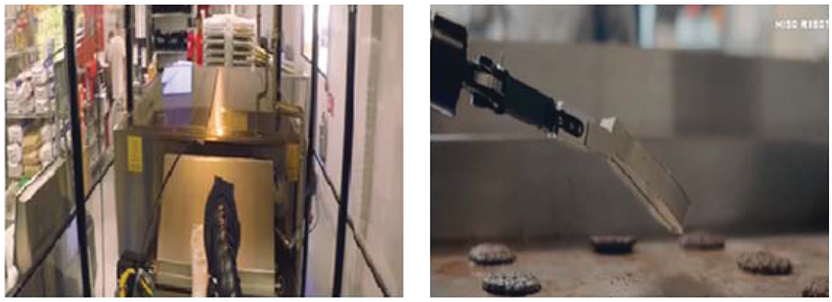
Source: Hooker and Caswell [3].

2. Role of Artificial Intelligence Robotics in Food Safety

By using the technology of artificial intelligence robotics, the agriculture sector would need to increase its productivity by about 70%. To successfully achieve this, in Figure 1(a), a robotic technology will need to be a core unit to secure the quality of food in the food industry. AI has a vital role to play in future food production as shown in Figure 1(b). The robotics are also the part of artificial intelligence [9].

Food and refreshment organizations are moving quick utilizing innovation for activities and calculated efficiencies and onto how to meet user’s requirements [10]. The prominent players in the industry have embraced artificial intelligence to maintain strong empathy with their audience. Rarely, has a crisis pushed the adoption of a technology in the way that AI in the food business is doing right now. The business of cultivating and selling high-quality food to consumers is being disrupted to a degree that has not been seen since the last pandemic, which occurred over a century ago. It is becoming increasingly clear that our food system was not adequately prepared (“antifragile”) for the COVID-19-induced disaster. No germs and high-quality food has been prepared by this artificial intelligence robotics scheme, as shown in Figure 1(b).

The continuing deconstruction and automation of the food supply process demonstrates that we are entering a new normal and that returning to the old reality would be impossible. Robots, augmented reality, virtual reality, three-dimensional printing, sensors, machine vision, drones, blockchain, and the Internet of things are all altering the food industry, but they all have one thing in common:



(a) (b)

Figure 1: (a) A robotic workforce to secure the food quality. (b) AI role to bake cookie.

artificial intelligence is the secret code or sauce underlying them all. As the world develops post-COVID, the application of AI to increase food production is quickening, and demands of speed, efficiency, and sustainability are rising in tandem with the quickly growing population.

3. Applications of Artificial Intelligence with Its Drawbacks and Solution to These Challenges

Artificial intelligence is transforming several sectors, including government, medicine, advert, and finance to name a few that have adopted this technology. By learning the intricacies involved with big data analytics and AI, the food and beverage industry has begun utilizing the numerous predictive analysis applications offered by this technology. A fascinating certainty we found is that the worldwide AI market in food and drink organizations is assessed to develop yearly at an accumulate development pace of 42% before 2021. This has become evident by the increasing amount of food companies that are using artificial intelligence to generate more revenue and improve their productivity [11]. For the first time, the light of technology has dawned dramatically on the food industry and has been implemented without any hesitation. Artificial intelligence is now known to be impacting many aspects of the industry such as financial, production, distribution, marketing, consumption, packaging, and storage. To give a better explanation of the extensive usage of AI in food manufacturing, processing, and distribution, here are a few notable highlights [12].

4. Sorting

Sorting food requires extra attention that is paid to the specific details of the product, for example, size or colour. These factors help food companies to make well-guided decisions on the processing of various foods that will ultimately increase the purchase rate of consumers.

Figure 2 shows the companies in the food industry, such as TOMRA sorting food (tomatoes), are among the few that take the advantage of artificial intelligence to develop machines that significantly improve the sorting of food [13]. These technology-inclined systems are sensor based and use features such as cameras and near-infrared sensors to visualize food products with human perception.

Figure 2: AI-based robot sorting the quality of tomato.

5. Algorithm for AI-Based Robot Sorting the Quality of Tomato

Step 1: capture image and capture the softness value

Step 2: predict type of tomato using image processing AI technique

Step 3: confirm prediction of AI with the softness value.

Step 4: if confirmed, perform steps 5–7

Step 5: if tomato is damaged, pick it and discard it

Step 6: if tomato is not prepared, leave it

Step 7: if tomato is prepared, pick it and store it

6. Execution of Individual Cleanliness Propensities by Workers

The significance of guaranteeing that workers in food and refreshment organizations take important individual cleanliness careful steps could not possibly be more significant. Computerized reasoning empowers organizations to rapidly identify any failures in this facet and kill them for improved food handling. In Figure 3, several CCTV cameras are installed in the restaurant; this is just the advanced feature of the artificial intelligence. With this feature of artificial intelligence, the use of special cameras equipped with facial recognition and object recognition feature to ascertain if workers are committed to keeping the laws of food safety [14, 15].

7. Reducing Equipment Repair and Maintenance Cost

Any professional in the food industry knows how much of their company's resources go into cleaning processing machines and also repairing them. Ongoing research

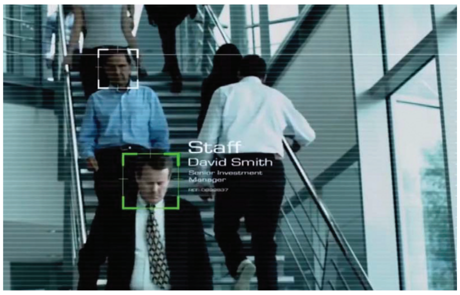


Figure 3: Investigation done via AI.

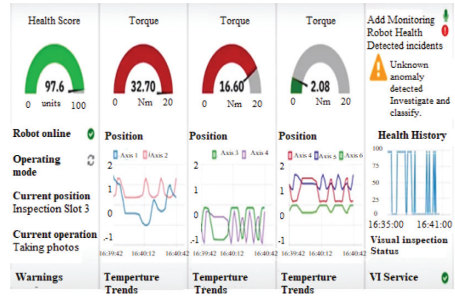


Figure 4: Application of artificial intelligence.

projects suggest that a system known as the self-optimizing-clear-in-place (SOCIP) which can improve cleaning time and drastically reduce resources used for cleaning including water [16]. In Figure 4, the artificial intelligence technology uses features such as ultrasonic sensing and optical fluorescence imaging to detect the tiniest amount of food leftover and microbial debris present in the equipment. This aids the optimization of the cleaning/maintenance process. Organizations can likewise use man-made brainpower in the part of machine fix and intermittent ideal working. It can rapidly identify any piece of hardware that is defective and separate them for instantaneous substitution of its corrupted apparatus. This will ultimately lead to improved employee efficiency and human resource management as there is a much better system in place to provide early detection of any fault [17].

8. Optimized Supply Chain Management

The food industry can use artificial intelligence to minimize delays and maximize profit margins by providing close monitoring of energy supply chain operation. This also helps companies to forecast for better management of pricing and stock products accurately. With growing concerns about transparency, artificial intelligence has also been utilized to track products from the farm to consumers to ensure transparency [18]. The flow of products will be cost-effective and streamlined in the best way possible with the adoption of this technique into food production and distribution.

9. Revolutionizing the Whole in Store Shopping Experience with New Products

Based on the available demographic data and statistics available, many food companies have been able to provide location-specific varieties of food flavour combinations that are targeted at a preferred group of consumers. By intently observing discussions via web-based media and utilizing man-made reasoning to break down burns through information and distinguish notions or conduct that are pivotal, in building positive encounters and in the turn of events and plan of new product offerings. This has proven to be an immense contribution to the food industry because companies can now offer unlimited forms of flavour combos, spices, and ingredients [18, 19].

10. Personalized Customer Service

The consumer favour a more customized insight as they shop utilizing visit boxes or voice aide fuelled by characteristic language handling, and organizations can tap buyer shopping information and history to give a hypercustomized and computerized client assistance experience. Using these predictive analysis technology provided by artificial intelligence solution providers, food companies can monitor on what decisions customers do overtime and what food they always reorder [20]. This ensures that the consumers are provided with a personalized feed containing their preferred food option.

11. Better Farming Conditions

It would be every heart-warming that the farmer could cultivate better food under optimal growth factors. Companies have already begun to research how they can apply this feature of artificial intelligence technology to better suit the farmers [20]. One of company known as Sentiment aims to invent a system that can create growing conditions where the effects of factors such as light intensity, temperature, salinity, and water stress on basil can be carefully checked (Figure 5). As of yet, progress only being made in the lab is looking to come up with specific "ingredients" for making perfect foods. Modern applications of artificial intelligence in the food sector include achieving significant reductions in the downtime, reducing consumer friction at the point of sale, speed up of manual tasks, and improving worker-overtime ratio to name a few [21].

12. Challenges of Artificial Intelligence and Available Solution

So, with all the diverse ways listed above on how artificial intelligence is improving the food industry, it might hit you like a ton of bricks to hear that this amazing technology has also got its coins. While there are many benefits, there are just as many challenges. Companies have to decide whether to buy or build this technology, and ideally, food companies would develop their own unique in-house technology systems. However, to be pragmatic, a lot goes into acquiring these systems. A portion of the difficulties that join utilizing man-made consciousness in the food business include the following.

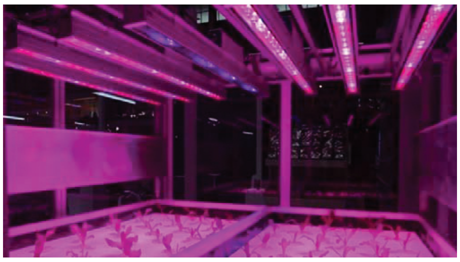


Figure 5: Farming done via AI.

12.1. Cost. Potential adapters face numerous difficulties with the price being the biggest among them and getting buy-in for these types of tech systems.

12.2. Integration Issues. It is never easy to integrate new technologies. This also works similar for the integration of artificial intelligence in food companies.

12.3. Proprietary Date. With the right proprietary date, food and beverage companies may not be talented to construct artificial erudition models that can execute. Given the above fundamental challenges, we will provide two solution ideas, especially for large companies with much capital that can be invested into adopting artificial intelligence technology. Food organizations that have effectively settled information investigation and a group of expert engineers can go on to securely fabricate their own man-made consciousness stage. You do not want to jump into making this decision if your company's team of developers lacks the required competency to match up with the in-house artificial intelligence system. They should be skilled enough to keep this system always updated to avoid any future troubles.

Various companies that lack such resources should find food and beverage solution providers that have already established artificial intelligence systems which will improve the front-end process and back-end process in your company. A few examples of these solution providers are SAP and bundled solutions built for food and beverage distribution. 75% of millennial in the US and UK would desire to utilize artificial intelligence innovation to get better help with arranging and preparing strong meals. Artificial intelligence is growing at a rapid pace and we have witnessed more companies within the food and beverage industry that are investing in artificial intelligence solutions for better performance. The predictive analysis provided by this cutting-edge tech is being used to resolve various critical problems in this industry. A lot of these companies have gone a step ahead to combine other areas of artificial intelligence with predictive quality analytics to create new opportunities to develop more potential products for the future [20, 21].

13. COVID-19 Pandemic and the Food Security in the Country

The recent COVID-19 pandemic has also reiterated the importance of food security particularly for developing nations. It has brought the global economy to a precarious position where Sri Lanka also has been impacted considerably at all levels. Almost all industries were negatively affected, apart from some essential services, such as water, electricity, fuel, and those producing food (farming) and medical supplies. Continuation of food production as an essential service was a crucial decision taken by the authority in order to assure food availability and accessibility [22]. However, the doss distribution took a longer time to return to normalcy. Under new normal situation, the working culture has now changed to the mode of "Work from Home." Hence, there is a need to redefine the agriculture profession, and technological needs to achieve food security based on the new needs. In such context, we firmly believe that AI applications together with recent advancement in technology have a bigger role to play. As the world develops post-COVID, the application of AI to increase food production is quickening, and demands of speed, efficiency, and sustainability are rising in tandem with the quickly growing population. Here are six instances of food sector players that have implemented AI and demonstrated how it has boosted their growth or even revolutionized the way they operate [23].

13.1. Processing. Food processing is a labour-intensive enterprise, but one where AI can increase production and minimize waste by replacing employees on the line whose sole job is to detect products that are not appropriate for processing. This form of fast decision-making necessitates the use of the senses of sight and scent, as well as the capacity to adjust to changing conditions. AI adds even more value to the table with augmented vision, which analyses data streams that are either accessible to human senses or where the volume of data is overwhelming.

13.2. Food Hygiene. AI can help to reduce the presence of diseases and identify poisons in food production.

13.3. Efficiency in the Supply Chain. While smart devices are being used to replace human labour, technology is also being used to replace human work. Food apps, drone and robot deliveries, and self-driving cars are all new methods to bring information and food to customers, and they all rely on AI.

13.4. Predicting Consumer Trends and Patterns Is a Difficult Task. AI enables businesses to stay competitive in the market by responding to diverse popular waves of diverse trends and creating market predictions.

Restaurants: following this year's COVID-19 epidemic, the future of eateries is in risk. The rise of online-based meal delivery services has shifted the focus away from the physical experience of dining establishments.

Creating more nutritious foods: for a long time, many people have believed that food equals health, but now, that we have a better understanding of human, plant, and animal genomes, it is becoming a reality. As the world progresses toward precision nutrition, changes in consumer tastes are providing potential for AI in food. One example is the increased desire for plant-based alternatives to animal protein. Creative AI

Table 2: A summary of AI applications in the four pillars of the food security.

Pillar	Application	Author	Technique	Remarks	Practical use of the application
Availability	Paddy land leveling system	Si et al. [1]	Fuzzy logic	Fuzzy system in the controller judges the land level	Land preparation
	Contaminated soil classificatory tool	Lopez et al. [2]	Fuzzy logic	Greater accuracy over typical computer-based models	Land and crop selection
	Stem water potential estimator	Valdes-Vela et al. [29]	Fuzzy logic	Greater approximation power compared to other models	Water management
	Soybean aphid control system	Peixoto et al. [6]	Fuzzy logic	Predict the timing and release of predators for the biological control	Pest management
	Image-based AI management system for wheat	Li et al. [7]	ANN (BPNN)	Uses pixel labelling algorithms for image strengthening	Fertilizer application time decision
	Soil moisture monitoring system	Athani et al. [8]	IoT-enabled Arduino sensors	Vastly decreases the manufacturing and maintenance costs	Reduction of COP
	System for detecting mature whiteflies on rose leaves	Boissard et al. [10]	ML	Reliable for rapid detection of whiteflies	Pest management
	AI-assisted weed identification system	Tobal and Mokthar [30]	ANN	Minimize the time of classification training and error	Weed control
	Weed identification system in paddy fields	Barrero et al. [11]	ANN	Based on areal image analysis	Weed control
	Novel weed management strategy	Pérez-Harguindeguy et al. [31]	ML	Combines UAVs, image processing, and ML	Weed control
	Field weed identification system	Ebenso et al. [32]	ANN	Improves crop/weed species discrimination	Weed control
	Expert system for diagnosis of potato diseases	Boyd and Sun [33]	Rule-based computer program	Can diagnose eleven pathogenic diseases and six nonpathogenic diseases	Disease management
	Expert system for diagnosing diseases in rice plant	Sarma et al. [34]	Rule-based computer program	Based on logic programming approach	Disease management
	Leaf image classification system	Sladojevic et al. [35]	ANN	Uses deep convolutional networks	Disease management
	System for diagnosing diseases of oilseed-crops	Chaudhary et al. [36]	Fuzzy logic	Much faster inference compared to earlier models	Disease management
	System for rice yield prediction	Ji et al. [37]	ANN	More accurate than linear regression models for the yield predictions	Yield prediction (decision making)
	System for cotton yield prediction	Zhang et al. [38]	ANN	More realistic trends versus input factors and predicted yields	Yield prediction (decision making)
	System for wheat yield pre	Ruß et al. [39]	ANN	Uses cheaply available in-season data.	Yield prediction (decision making)
	System for jute yield prediction	Rahman and Bala [40]	ANN	Could be used to predict production at different locations	Yield prediction (decision making)

Table 2: Continued.

Pillar	Application	Author	Technique	Remarks	Practical use of the application
Accessibility	Food desert identifier	Zhao [41]	Big data analytics and ML	Locates areas with low food access	Decision making
	Food desert identifier	Amin et al. [42]	ML	Detects food deserts and food swamps with a prediction accuracy of 72%	Decision making
	Decision tool to evaluate the performance of agriculture food value chain	Liu et al. [43]	Fuzzy logic	Integrates TFN, AHP, and TOPSIS	Decision making
	Forecasting of food production	Sharma and Patil [44]	Fuzzy logic	Forecast the production and consumption of rice	Decision making
	Forecasting of food production	Yan et al. [45]	ML	Uses ANN, SVM, GP, and GPR to forecast future milk yield	Decision making
	Supply chain optimization	Cheraghalipour et al. [46]	Evolutionary ML	Reduce held inventory and cost in supply chains	Efficient food distribution
	Supply chain optimization	Ketsripongsa et al. [47]	Evolutionary ML	Used for transportation scheduling of seafood and milk products	Efficient food distribution
	Supply chain forecasting	Olan et al. [48]	ANN	Forecast the results of perishable food transportation	Decision making
	System for preparing and dispensing food	Sharma et al. [49]	Robotics	Extremely useful in pandemic situations like COVID-19	Efficient food distribution
Utilization	Cassava roots storage system	Babawuro et al. [50]	Fuzzy logic	Uses an intelligent temperature control technique	Postharvest quality control
	Fruit storage system	Morimoto et al. [51]	Fuzzy logic and ANN	RH inside the storage house is controlled	Postharvest quality control
	Potato storage system	Gottschalk [52]	Fuzzy logic	Highly energy efficient	Postharvest quality control
	Mechanical damage detection of fruits	Vélez Rivera et al. [53]	Hyperspectral images and ML	Used as a tool for the automatic inspection and monitoring of internal defects of fruits and vegetables in postharvest quality control laboratories	Postharvest quality control
	Assorting of fruits and vegetables	Valdez [54]	Computer vision and deep learning	Fast, reliable, and labor inexpensive methods	Reduce labor requirement
Stability	Water resource management	Sadeghfam et al. [55] Zahm et al. [56]	ANN	Minimize the ground water overexploitation and groundwater remediation through pump-treat-inject technology	Increasing water availability
		Zahm et al. [56]	ANN	Identify the reasons for spring flow decrease	Increasing water availability
	Supply chain quality data integration method	Wang [18]	AI integration method of block chain technology	Supply chain of agriculture products	Increasing water availability

AI, artificial intelligence; ANN, artificial neural networks; BPNN, back-propagation neural network; IoT, Internet of things; ML, machine learning.

applications have risen in response to challenges such as establishing consumer-acceptable flavour and texture features.

14. Synthesis and Way Forward

The synthesis and way forward towards the artificial intelligence plays the vital role in the examination. To achieve the high quality in food is the major agenda nowadays. The powerful techniques have to be applied. As discussed in this study, achieving food security is the ultimate objective of future agricultural and allied sectors. A thorough review on the applications of AI in food security indicates promising signs in this regard. Within the food sector, AI could uplift existing practices and strategies in order to achieve productivity and sustainability goals efficiently and effectively [24].

As FAO [25] clearly states, achieving food security relies on top of four key pillars. This article primarily focused on the applications of AI in these four vital areas of the food sector. There are many benefits of AI, which has been applied in the form of different tools and techniques that are user friendly and providing optimum results. These techniques are combined with other technological advancements and being applied into agricultural practices along the food value chain. Many different AI technologies have been adopted over a wide range of applications in the agriculture sector in many countries. Among those, as expected, fuzzy logic systems, ANN, and ML could be identified as the most frequently used technologies while being the pioneer concepts of this innovative branch of computer science. With the anticipated changes in trends in AI technology, we could expect differences in its complexion in applications in the future. As indicated in Table 1, many applications can be identified on the use of AI in the area of food availability. This is directly related with the objective of improving food production. As it provides direct benefits to all the stakeholders, most of the AI technology developers seem to have concentrated their efforts in this direction [26]. It would provide both short-term and long-term benefits. However, achievement of future food security does not depend solely on ensuring food availability. One of the key findings of this review is the lack of AI applications in other three pillars of food security. Nevertheless, many recent developments indicate the use of AI applications towards other three pillars of food security as well. If this promising trend continues, there is an expectation on the achievement national level food security [27]. The AI and agriculture seem two vastly different sciences. However, the evidence provided in this article suggests that the marriage between these two fields of study could yield huge positive impacts in meeting the global goal of food security [9, 28]. Table 2 presents the four pillars of the food security based on artificial intelligence applications.

From Table 2, showing the most appropriate researchers ideas about the plant tracking system is being developed using a particular AI methodology. To construct a plant surveillance system for sensing and managing a plant development parameter, namely, relative humidity, a specific AI approach is being used. The system's performance is extremely predictable and accurate, according to the data collected. Plant humidity sensors are used to monitor changes in moisture and to adjust irrigation methods. These simple adjustments in irrigation procedures increase productivity while saving water. Effective irrigation management with plant water sensors requires focused monitoring of the sensors to get the water level when the data received is within the set range for the specific growing conditions. We can utilize neural networks to anticipate seasonal fluctuations and rainfall in a region, which will aid farmers in planning their future yield.

Asymmetric sensor node deployment, gathering of insufficiently useable information and data for food deserts, and a gap between the right dataset (of which blocks are true food deserts) [42] and surveyed data based on limited/inaccurate real-world data making decisions without AI is a difficult task.

The use of computer vision and deep learning technology in agriculture seeks to improve the quality of harvests and farmers' production. Assorting fruits and vegetables has an impact on the export market and quality evaluation at postharvest. TOMRA industry sorts the good quality tomatoes from defected tomatoes during harvesting or/and during the postharvesting phase, as shown in Figure 2. The goal of this article is to assist farmers with postharvest processing by determining whether modern AI approaches may assist in distinguishing healthy tomatoes from tomatoes with flaws [57–60].

15. Conclusion

The artificial intelligence approach provides efficient solution that helps to increase the lifetime of farming activities. Therefore, in farming, the concept of artificial intelligence is implemented which makes the task so effective and simple. One benefit of these computerized frameworks is that they offer consistent data across a scope of timescales, from hours to months, accordingly working with the advancement of models of cycles which might be explicit to a specific time span. Besides, these frameworks can promptly be utilized in business nurseries, so the inferred intelligent models are moderately simple to convey to a business setting where they can consequently be improved over the long moment.

Data Availability

No data were used to support this study.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

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Research Article

Opportunities of Artificial Intelligence and Machine Learning in the Food Industry

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The food processing and handling industry is the most significant business among the various manufacturing industries in the entire world that subsidize the highest employability. The human workforce plays an essential role in the smooth execution of the production and packaging of food products. Due to the involvement of humans, the food industries are failing to maintain the demand-supply chain and also lacking in food safety. To overcome these issues of food industries, industrial automation is the best possible solution. Automation is completely based on artificial intelligence (AI) or machine learning (ML) or deep learning (DL) algorithms. By using the AI-based system, food production and delivery processes can be efficiently handled and also enhance the operational competence. This article is going to explain the AI applications in the food industry which recommends a huge amount of capital saving with maximizing resource utilization by reducing human error. Artificial intelligence with data science can improve the quality of restaurants, cafes, online delivery food chains, hotels, and food outlets by increasing production utilizing different fitting algorithms for sales prediction. AI could significantly improve packaging, increasing shelf life, a combination of the menu by using AI algorithms, and food safety by making a more transparent supply chain management system. With the help of AI and ML, the future of food industries is completely based on smart farming, robotic farming, and drones.

1. Introduction

It is well known that food or ration is a necessary for human beings and can be described as the best outcome of farming, fashioned after handing out the various foodstuffs shaped by farmers. For any country's development, the food industry's products play a crucial role [1]. It also has a significant role in the development of the country's economy as well as the world economy. Therefore, the quality of food industry products and their safety with proper distributions are much needed. In the last few decades, newly developed technology such as artificial intelligence (AI) achieved good results to attain the desired objectives [2]. Therefore, it is essential to investigate the AI-based smart agriculture and advanced food industry aspects. Such techniques fulfill social requirements and deliver quality products on time. By using these modern technologies, the food industry can produce a large number of food products in less time that will increase the economy of the company in exponential manner [2].

AI-based systems or autonomous systems are extensively applied in approximately every portion of the technology. It enables the world to efficiently optimize the problems, computerize the food industry, and transfigure food industries products [3]. By using a computerized system, the industry can examine and make sure the most favourable circumstances such as seed selection, crop monitoring, watering, and temperature monitoring can be improved, which will provide excellence of the food industry products

[4, 5]. The use of AI is not limited to these things only. It can also be helpful in food processing, storage, and delivery of food items. Intelligent gadgets such as robotics and intelligent drones can also play a very crucial and significant role in minimizing the packaging cost. It will also help in delivering the food products, completing the task in perilous surroundings, and also providing very-good-quality products [6–8]. The important roles of AI in food industries can be broadly classified into two classes: one is food security management, and another one is food quality management. The area under each class is given in Figure 1. By keeping every aspect of AI in the food industry, this study provides a literature study of machine learning and AI in the food industry.

The rest of the manuscript is organized as smart farming followed by AI in the food processing industry. After this, the role of data analysis in the food industry is discussed; then, ML in the restaurant business is discussed. As per the food safety concern, AI is also important; therefore, the next section will describe the AI in food safety. At last, but not the least, the future scope of AI and ML in the food industry is covered. Finally, the conclusion of the manuscript is included in the last section.

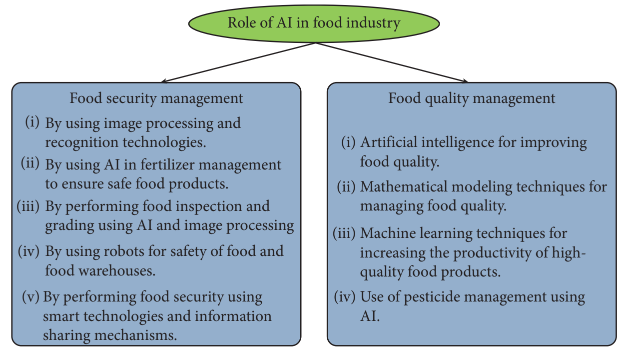

Figure 1: Role of AI in food industry.

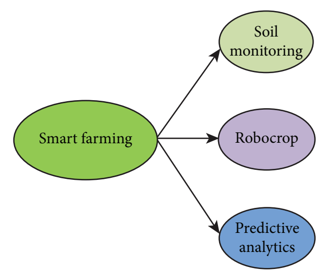

Figure 2: Smart farming.

2. Smart Farming

In the food industry, AI also has some important applications such as soil monitoring, robocroping, and predictive analysis [9–11]. Figure 2 shows the trendy applications of AI in the food industry. The description of each application is given in the forthcoming section.

2.1. Soil Monitoring. In the current scenario, food industries are considering the benefits of AI-based systems. Under the AI-based system, computer vision and deep-learning algorithm is very important and used to investigate the sequence of information or data received by the AI-based agents to trace the progress of crop and soil health [10, 12–22]. The computerized systems are used to make available clients with a sagacity of their soil's strengths and weaknesses. The prime objective behind the building of the developed system is to identify defective crops and identify the probable approach for healthy crop development.

In the recent scenario for Soil Monitoring (SM), once a farmer submits a sample of their farm soil to the monitoring body, afterwards, the customer will get a detailed summary of their field soil contents. After the drawn results, an adequate decision has been taken for bacteria, fungi, and wide-ranging microbial progression.

The first AI-based drone was used in Japan in the year 1980 for crop dusting. Today, most companies are taking advantage of agriculture AI and aerial technology to keep an eye on crop health [15]. The company's primary endeavour is to decrease the costs and improve crop growth. Users preprogram the drone's route and then will integrate with the device. After that, the computer vision will record some pictures that will be used for examination purposes.

Now, further technology moved to the new era of advancement is called the Internet of Things (IoT). The IoT plays an important role in decision on crop and soil monitoring [16]. SM with IoT is the application of AI that supports farmers and food industries to capitalize on their economy, diminish the chances of ailment, and optimize uses of available assets. In these, sensors are deployed to sense the temperature of the soil, amount of nitrogen, phosphorus, and potassium (NPK) in soil, moisture level, the content of water, potential in soil, amount of photosynthetic radiation, and oxygen level in soil [17]. The collected data from the various sensors are again forwarded to the data centre point or the cloud for a proper decision so that adequate action can be taken timely. The outcome of the analysis, visualization of received data, is helpful in resource utilization. The identification of the behaviour of the system requires identifying the trends of soil and making the delicate decision to circumstances to get maximum crop yield and excellent products [16, 17]. The agriculture-based IoT is called smart agriculture. The IoT-based food industry is called the smart food industry.

IoT-based agriculture is completely based on soil monitoring, weather forecasting, and crop monitoring. As it is known, weather and irrigation play a very crucial role in IoT-based agriculture. The smart agriculture elucidations are also attached with an elegant atmosphere such as good air quality and a well-groomed watering system. The commonly applicable sensors and types of measures considered by the respective sensors are given in Table 1.

In the literature, so many studies [13–20] were found on smart farming and noticed that by using these modern tools, resources can be utilized in an optimized manner and the income can be maximized. Also, there are some specific

Table 1: Sensors and types of measures considered by the respective sensors.

Sr. no.	Type of sensor	Measurement
1	Temperature sensor	Soil temperature Noncontact shell temperature
2	Moisture sensor	Soil wetness Conductivity Volumetric water content Water potential
3	Solar radiation	Active radiation UV radiation Solar-shortwave
4	Weather	Rainfall Warmth Moisture Air pressure Speed of wind Flow direction of wind
5	NPK soil sensors	Nitrogen level Phosphorous level Potassium level pH level Temperature level Moisture level

areas such as cannabis and hemp, soybeans, potato, almonds, cherries, apples, and grapes yielding promising production by using smart farming.

2.2. Robocrop. With the advancement in technology, the food industry is also using modern-technology-based tools so that production can be increased. One of the tools developed by the various research groups is called robocrop [18]. It is an AI-based robotic system that advances the yielding process by maximizing usefulness and uniformity. It conducts line up crop tools accurately and at a high rate. The food industry product shrubbery forward of the system is monitored by a high-resolution and precise system. The captured image is processed by a high-performing workstation to attend the maximum attentiveness of green band pixels relating to the crop line. Due to the outsized region captured by the input devices and the numerous processing line, an outstanding typical crop centre-line tracking is accomplished [19]. It evaluates the resultant image to a ground truth gridiron pattern with the crop line area. The obtained information is then employed to align the instruments in the row via a hydraulic-based shift. The pattern-based attribute builds the system very healthy besides backdrop pick over infestations. It improves the performance and production rate just because of multicameras and multiple sensors.

In robocroping or agricultural automation, outstanding work has been carried out by various authors in the field of harvesting robots [23–25] that has increased productivity considerably in recent decades. These systems became popular due to advancement and additional benefits which are improved productivity and reduced labor force. The previously published article [23] described the dual-arm harvesting robot which consists of dual arms arranged in an optimized manner. This dual-arm robot is suitable for fruit harvesting and based on SVM. In agricultural automation, robotic weeding facilitates weed control near or within crop rows automatically and effectively. An image-processing-based system [24] was designed for identifying crop plants at various growth levels for robotic weeding control. In the list of existing systems, a specific system was developed for strawberry flowers known as Adaptive Robotic Chassis (ARC) [25]. In that system, strawberry flowers are captured by the installed camera and then processed. Finally, the desired coordinate has been obtained and the significant actions are taken by the robot.

The performance of the robocrop completely depends on input image features. If the input image contains more dominant features, then it shows outstanding results. In every sample of an input image, the crop must present more shrubbery than the wildflower and the crop shrubbery should be near to the mean of the RGB colour band. A typical robocrop system consists of a robocrop console part, a hydraulic-based shaft, a three-point linkage frame, a high-definition camera, various types of speed sensors, an ADC adapter, and so on. Figure 3 shows one sample of robocrop picking fruits [19].

2.3. Predictive Analytics. Learning models are developed to trail and forecast various environmental effects on crop yield such as weather changes. For this, ML algorithms account for a very significant role. ML algorithms in association with the satellites investigate crop sustainability, predict the weather, and assess farms to know about the existence of pests and diseases. The model is very good at delivering high-standard data or information that is perpetually updated at a quick rate. Also, the organization is very much confident about the data it provides for its customers with admittance to more than one billion stacks of agronomic data regularly. The data sources such as precipitation, wind speed, solar radiation, and temperature along with historical values are important for predictive analysis. The obtained analysis accounts an important role for adequate scheduling and crop selection for particular agricultural land [20].

FarmShots is a Raleigh, North Carolina-based AI start-up that focuses on analysing agricultural information derived from the pictures taken by drones and satellites. The primary focus of the company is to detect pests, diseases, and reduced plant nutrition on farms [21]. In April 2017, the firm limited the free access of its products for John Deere's customers via June 2017. With this collaboration, it is very much clear that John Deere is showing more interest in entering into agricultural tech freedom.

3. Artificial Intelligence in Food Processing Industry

In this section, authors are going to discuss the importance and application of different areas of artificial intelligence such as pattern recognition, data science, deep learning, machine learning, and robotics in the food processing industry. Along with food processing, the food handling

Figure 3: Robocrop picking fruits [20].

industry is also important where AI plays a key role in handling the entire processing unit task. There are some important applications taken from the food processing and handling industry, as shown in Figure 4.

3.1. Product Sorting and Packaging. In the food processing industry, the proper ordering and packaging of food products is one of the tedious tasks and time-taking processes for manufacturing units. Therefore, such a tedious task can be handled by AI-based systems so that the chance of error is minimized, and the production rate of the industry is rapidly increased. The development of AI-based systems is a challenging task due to the irregularities in shapes, colour, and sizes of vegetables and fruits. For developing an AI-based sorting and packaging system, a large amount of data is needed so that the system is properly trained and performs the task in an efficient manner [26, 27]. Various research groups designed different systems for the same task. One of them is TOMRA, which performs the sorting task in a very efficient manner. It improved the production rapidly with the accuracy of 90%. In current situations, most of the product sorting and packaging tasks are performed by the automated system. By using such types of systems, industries gained some advantages such as faster production rate, high-quality yielding, and labor cost cutting. Figure 4 shows important applications taken from the food processing and handling industry.

The AI-based intelligent decision-making systems consist of various tools and methodologies, i.e., high-resolution cameras, laser-technology-based systems, X-ray-based systems, and IR spectroscopy. These tools and technologies are used to analyze each and every aspect of the food products such as fruits and vegetables at the input channel. Conventional systems are only able to characterize good and bad products according to their appearance. By using TOMRA, it has been observed that the detaching and ordering problem can be improved by 5–10% in the case of potatoes only [28, 29]. The same type of problem was also handled by a Japanese company that uses a TensorFlow ML-based system and also achieved a remarkable outcome and gained significant benefit in their assembling unit. This system achieved remarkable results for other food processing industries also. In addition, each organization found that the AI-based system works more precisely. The performance achieved for potatoes encourages the expansion of AI-based

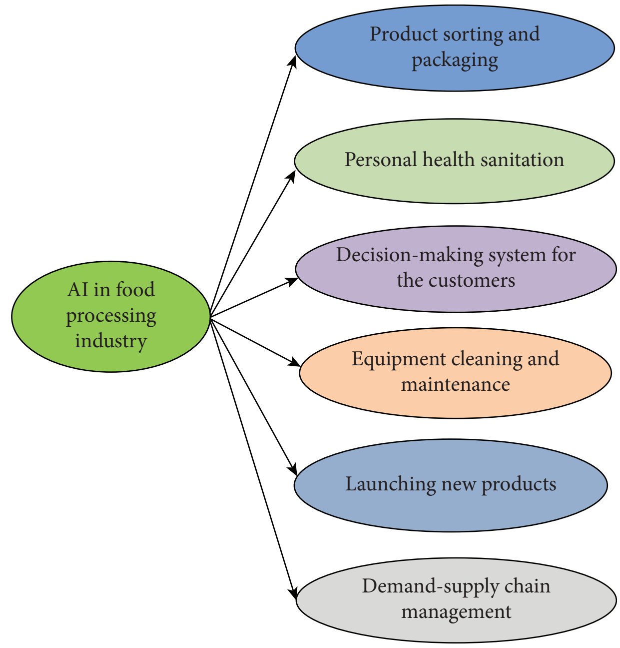

Figure 4: Important applications taken from food processing and handling industry.

systems for others also. It can be further expanded for different sections or departments of the food processing industry.

3.2. Personal Health Sanitation. In the literature, it has been also found that different countries across the globe such as the USA launched the food processing unit sanitation guideline. Such guidelines have also been taken care of by the AI-based systems. Initially, the KanKan and Shanghai municipal health agency worked together to develop an AI-based system. The first AI-based system is designed to grant object and facial recognition for an anonymous quantity. The system is used to monitor individuals who are not following the guidelines [30]. If anything matches, then it can be resolved in real time without any delay. The designed system shows very good results; therefore, it has been planned to expand the system for more and more organizations.

3.3. Decision-Making System for Customers. In different organizations, it is found that AI is not only helping food processing industries in developing various flavor amalgamation but also assisting the customers in picking innovative essences [31]. In 2018, Kellog launched Bear-Naked-Custom that is most favorable for the customers to make their adapted granola from more than 50 constituents. With taking care of every individual, it records their flavors, customer taste selection, and much more information. Such type of information is playing an important role for launching a new product into the market [31, 32]. Therefore, AI again played a good role in developing decision-making systems for customers.

3.4. Equipment Cleaning and Maintenance. In food processing industries, proper cleaning and maintenance of processing tools are very much essential. Such a task can be easily handled by AI-based systems [33]. For implementing this, various sensors and cameras are deployed to perform the task. One product of Whitwell and Martec muscularly suffers that it can decrease to only 50%, which permits large efficiency and a lesser amount of time. Presently, Martec is trying to justify its AI-based cleaning place model. For this approach, Martec employs ultrasonic sensing imaging methods and optical fluorescence methods to cultivate the obtained information to the AI system development [34]. It measures the remaining amount of food and microbial debris inside the machine. After releasing the entire report of the testing phase, the system will take stand.

3.5. Launching New Products. The launching of new products for any production unit is a tedious task. Especially, in the case of food industries, it totally depends on the consumer's interests. Therefore, the information collected by the various decision-making systems for customers is helpful for the launching of new products. The collected information is processed by the ML-based module and then takes the proper decision for the product [2, 35]. By using an ML-based approach, questions such as "what customers are exactly looking out for" has been answered. Presently, nearly all the food processing industries and food product packaging industries are utilizing the power of artificial intelligence to expand and launch new products into the market. Previously, this work has been carried out through a case study or survey. Therefore, the success rate for the system is very low. Now, the entire scenario is changed, and AI and ML are prominently used for such types of tasks.

In the entire region of the USA, a self-service soft drink corner has been installed by Coca-Cola. By using this, customers have the option to make thousands of drinks by adding minor variations in flavors. Such type of activity has been recorded by the machine, and the rest of the analysis is performed by the ML and deep learning algorithms. By using these data, new products can be launched. Cherry sprite is the real time example of a product. It has been also suggested that, in the next coming decades, most of the food industries will take advantage of the recommendation system for developing new products.

3.6. Demand-Supply Chain Management. As long as food industries are more worried about food safety policies, they are required to materialize more translucently regarding the pathway of food products in the supply chain system. To monitor every stage of the process AI is deployed [1]. It manages everything such as price control to inventory management. It also takes care of forecasting and monitoring the pathway of possessions from where they are grown to the location where customers collect it. AI-based Symphony Retail provides the facility to book transportation, billing, and inventory management [36]. It also maintains the discipline and avoids getting plenty of commodities that end up in exhausted material.

4. Data Analysis at Food Industry

The food-based industry is stuffed with a large number of well-established brands as well as food outlets. Due to the growing competition, this industry is losing its attraction for establishing a new business [37]. In the food industry, using technology, especially data science, is the only way which can make anyone stay upfront in the competition. Figure 5 gives the information regarding data analysis in the food industry.

4.1. Customer Satisfaction. Ooshma Garg, the founding father of Gobble, shared a thought that a food industry can be phrased as a tech company. It was a disputable assertion for the rest of the world, but there's some truth behind this [37, 38]. Data science has become a prerequisite in current technology-driven industries for elevating and maneuvering their diverse business practices. Gobble is a great example industry which completely relies on data science for predicting the supplies as well as the demand of its customers. It offers its customers with ten-minute dinner kits and has more than thousands of regular customers with different menu choices. It collects the data such as buying history, customer behavior, and feedback and food preference of different time frames to ensure the readiness to meet the demands [39]. Gobble is a demand-driven example of a company that utilizes the artificial intelligence within the food industry and can surely serve as a blueprint for other businesses in their domain.

4.2. Introducing New Recipes. A single recipe can be cooked in numerous ways by combining the ingredients. In addition, the fact is that those ingredients can be cooked in some other ways which creates an area of endless possibilities to make cooking dishes. On the web, multiple recipes are available online and contain a huge dataset that allows the exploration of components in several cuisines from common man to professionals. The researchers can determine the differences as well as the similarities between the different cuisines [40]. For example, North American and Western European cuisines are totally based on the ingredients which contain the same flavor of compounds that East-Asian and Southern-European cuisines avoid.

In conclusion, the technologists can appraise which food components have a decent savor and mark a cuisine that is trendy in a few provinces. This basic understanding also permits artificial-intelligence-based algorithms to recommend the chefs with different types of ingredient combinations that will surely result in broadening the menu as well as the profits of a food industry.

4.3. Reinventing Food Delivery. Online food outlets such as for Swiggy, Zomato, and Uber-eat have a large amount of data based on ordering patterns of their customers and dish preferences. Data science and AI can be utilized by the food-based professional for creating simpler, cost-effective, and time-efficient methods for delivering the product [41]. AI is beneficiating some existing industries with some valid chances for market domination. But still, it is nascent in the

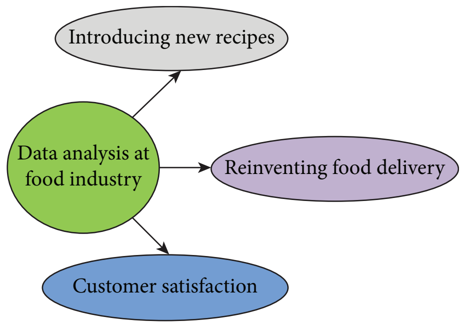

Figure 5: Data analysis at food industry.

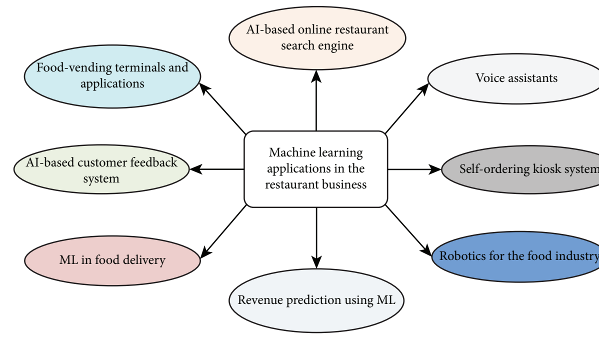

Figure 6: ML application in the restaurant business.

food industry and, therefore, needs more proficient optimization by food companies as well so people can get their food with better services.

5. Application of ML in the Restaurant Business

The application of ML and AI techniques is not limited to only making the automated system, robocrops, soil monitoring, and new product launching. It can be also useful in the restaurant business for many numbers of services [42, 43]. The list of applications of ML in restaurant business is given in Figure 6.

5.1. AI-Based Customer Feedback System. Nowadays, there are many kinds of applications within the domain of food services which help in predicting the number and type of food being ordered as well as the relevant inventories. This information can be utilized for statistical analysis of visitor traffic and food items that would be needed during a period of time [43]. Such information is collected by combining the data of previous engagements with the customers, their food preferences, habits, and complaints, as well as supply of the required items during that period. The result of collecting and analysing the information helps the food-service-based applications to secure more food orders from old as well as new customers, thus securing the consumer loyalty. Moreover, it also helps in removing the loopholes and complaints that make these applications more fail-safe and reliable [44]. There are some other applications which assist with the functionalities of the food-service-based applications such as the restaurant management framework, payment gateway applications, cloud-based big-data applications, and even the restaurant table booking platforms.

5.2. Food-Vending Terminals and Applications. It has become the need of a food-selling firm to build a reliable system for providing its services online to the people after it decides its menu and marketing strategy. This system can be an online site that can provide the benefit of fast ordering and recommendations or a mobile application that comes with added advantages such as incorporating an artificial-intelligence- (AI-) based system. Due to the emerging food-based e-commerce applications, it is a wise decision to enlist one's food-selling firm to their repository [44]. It allows the firm to have best functionalities of these e-commerce applications without spending more money in developing the same for itself, although the amount of commission charged by the e-commerce can still lead the firm to develop it. AI can help in developing an automated customer-service segment that enables the firm to efficiently perform administrative tasks such as consumer grievance redressal, dispatching crews, and creating reports.

5.3. AI-Based Online Restaurant Search Engine. It is observed that consumers often prefer a cafe, bar, or restaurant by comparing its ratings with competitors. Thus, it becomes important for an organization dealing in the food and beverage industry to know about the experience, either good or bad, from its customers to attract new customers or to avoid losing the old ones. These days, a large majority of customers are introduced to a food place via Google searches or another online medium. This fact is being utilized while recommending a customer with a preferred restaurant or cafe based on their locations and ratings with the help of AI [45]. These AI agents also help in notifying the customers about the offers, events, or sales in their favorite food places.

5.4. Voice Assistants. It is estimated that about 27% people preferred voice searching over conventional searching by typing. Due to this fact, the option of voice-based searching is being introduced into every food or other e-commerce industry, while an entirely new area of voice commerce such as Alexa by Amazon has been developed. This feature can now be utilized by the restaurants to enable these voice commerce applications to make quick orders from them even without looking into details, and this is helpful for new restaurants [46].

5.5. Self-Ordering Kiosk System. The point-of-sale systems (or self-service systems) are popular among the customers, especially in well-established restaurants. These systems assist the customers with the ordering process by giving them detailed information about the flavors or spices used, their preferences, and even the newly added items. These systems are now being adopted by every restaurant which incorporates automated systems. This technology has helped the restaurants in dealing with problems such as manpower shortages, customer engagements, and inaccurate orders.

5.6. Robotics for the Food Industry. With the advancements of AI, it has become possible to utilize the efficiency of robotics in the food-based industries, although it has not been adopted on a large scale yet. There are a wide range of robotics that are being used in various areas of the food industry such as drones in food delivery and robotic arm on processing the food [18, 19]. However, as the cost of introducing these technologies in the food-based industry is higher than employing the manpower, these technologies are not being adopted. Some recent innovations in robotics are delivery drones and bots being used by "7-Eleven" convenience stores, "Flippy": a two-arm robot for frying and packing the burger patties.

5.7. Revenue Prediction Using ML. For a running business such as a restaurant and food outlet, the quality of food and services given by the owners is very important. Apart from the service and food, the prediction of sales output of the restaurant is also an essential part of the business. The owner of the food chains or restaurants needs to compile a strong business plan for their future operations for better business growth and more profit. In artificial intelligence, multiple fitting algorithms can be used to create a sales forecast [47]. In the food industry, finding a suitable fitting algorithm for the sales prediction, i.e., for five months' sales prediction or 14 months' sale prediction, requires a huge time and seamless efforts. In this era of data science, it is possible to get sales predictions on fingertips. Data science allows finding the best suitable algorithm for a particular business and easy deployment of the algorithm in the same business with a perfect AI development team.

5.8. ML in Food Delivery. Machine Learning (ML) can help in efficiently solving the problems such as deciding the delivery routes, supply of raw materials, predicting the demands of certain food items, and planning the logistics [48]. The delivery route problems can be solved with ML by optimizing the location of the delivery agent with current or upcoming traffic situations and then notifying them about the best route in a synchronous manner. By ensuring the efficient and timely delivery, it becomes easier to provide constant orders and to even deal with problems such as running out of delivery agents or late deliveries. Moreover, by incorporating the ML, the scale of collected data increases with time which can later be analyzed using other artificial-intelligence-based algorithms for developing a more intelligent system. Such analysis could be performed using more advanced AI-based techniques such as deep learning (DL) that provide an added advantage over the competitors.

6. Artificial Intelligence in Food Safety

Due to the sterile nature of robots, it is widely acceptable in food processing industries. This feature is a huge factor in decreasing the number of foodstuff-related diseases. The Food Safety Modernization Act (FSMA) has drafted stricter hygienic necessities, which is applicable for complete supply chain systems. The cause behind it is cereals, spices, and other food products that do not need refrigerators and they are in the most prone area of contamination. Formerly, such food products were free from contamination, but now, the scenario is entirely changed. For these types of problems, AI-based systems can surely help to resolve the problem. They are free from transferring illnesses as a human can do. However, the maintenance of an AI-based system is simple and easy [2, 49]. According to the report published by Technavio, the implementation of robots in food processing industries will lift up by 30% and also fulfill the government's demands. There are also some new revolutionary inventions by using artificial intelligence in food safety approaches that are anticipated to become well-known soon. They have the major objective to plummeting the frequency of food-borne diseases. Figure 7 shows artificial intelligence in food safety.

6.1. Next-Generation Sequencing and Electric Noses. The two most promising inventions in the food industry are next-generation sequencing (NGS) and electric noses (ENs). NGS replaces the DNA approach in the food security region very quickly. The introduction of AI-based automated systems and workflows helped formulate data acquisition and laboratory trials much quicker and more accurately than ever. The NGS can find hazardous inclination very quickly and efficiently. It can also prevent the infection epidemics before the impairment of an ample amount of people. ENs are mainly the surrogate for a person muzzle in fabrication surroundings. Some sensors are placed that can precisely identify a diversity of smells. These sensors just sense the smell around the surroundings, and sensed data are transferred to a data center where ML algorithms access these data [49, 50]. According to the decision made by the ML-based system, an alarm signal is transferred to the manufacturing units. Therefore, EN can be the upcoming future of food products safety.

6.2. Food Waste Management. The report published by the Department of Agriculture, USA, declares that, "In the United States, food waste is estimated at between 30 and 40% of the food supply. This estimate, based on estimates from the USDA's Economic Research Service of 31 percent food loss at the retail and consumer levels, corresponded to approximately 133 billion pounds and $161 billion worth of food in 2010. This amount of waste has far-reaching impacts on the society."

According to McKinsey, AI can resolve such type of issues and disengage huge amount of opening by dipping food waste by the 2030. Such surprising statistics can be accomplished by launching supplementary regenerative leisure farming practices [51]. It shows that humans are not utilizing the available resources efficiently. The traditional methods of farming can be replaced by the smarter farming methods. In this, various sensors are deployed and collect the information. The collected information is processed with ML algorithms, and then appropriate decisions are taken. By using these, farmers can make decisions the fastest and accurate. Here are some suggested ways to reduce the food waste with AI:

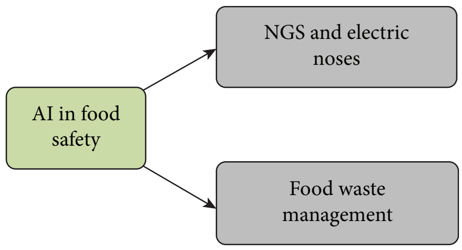

Figure 7: Artificial intelligence in food safety.

(i) While several elucidations examine the maturity of the fruits, others stature out what microorganisms can boost fruits and vegetables development not including the participation of artificial fertilizers.
(ii) Manufacturers can acquire purge of ground examination, gaining from compensation of the artificial intelligence that will keep a considerable amount of capital.
(iii) The farm-based food supply chain management uses computer vision technology to manage and examine each process; then, the food waste will be decreased rapidly.
(iv) Artificial-intelligence-based food tracking systems will enable us to sell food ahead of it turning into waste. By using this, more farmers and people can connect for buying the food products.

The major challenges to execute such types of ideas in reality cannot be conveyed by one organization and one body of the system. The entire food industry needs to be altered. A complete association of associates is required to work together to make an efficient system which significantly blows on the entire globe.

7. The Remuneration of Artificial Intelligence in the Food Industry

There are a few advantages of artificial intelligence in food industries listed as follows:

(i) In recent times, almost all food processing industries are unquestioning AI to advance the demand-supply chain management, meticulous logistics, and predictive analysis, as well as to add precision in the system.
(ii) Digitization of the demand-supply chain management systems eventually compels returns and offers a superior appreciation of the circumstances. Artificial intelligence can examine massive amounts of data that are far from human potential.
(iii) AI helps industry to diminish the time to marketplace and improve agreement with suspicions.
(iv) Automated ordering will positively decrease labor expenses, enlarge the pace of the manufacturing, and advance the excellence of products.

8. The Future Application of AI in Food Industry

After the investigation of the literature in the food industry, it can be observed that there is a need for a significant amount of investment in the food processing and manufacturing industry. By applying AI, systems can easily identify various issues in food production than man-based systems. It has also been noticed that researchers are prominently working on this sector. Gayama, an agrotech firm based in Switzerland, is an excellent example of one such firm that has raised a sum of $3.2 million for an artificial-intelligence-driven project. The project is based on hyperspectral cameras that are able to distinguish a minor fluctuation in water intensities, nourishment, vermin, and crop yields. Then, the artificial intelligence process finds possible intimidation and generates alert signals to farmers so that they can plan accordingly. The artificial intelligence process will also recommend convincing measures that farmers must get to preeminent use of available resources. By using ML and deep learning methods [52, 53], Earth's surface can be also analyzed by satellite data. The main intention is to discover spaces that would use some facility from the government or its shareholders for improving the crop that can improve the outcome.

It has also been observed that the farming is immobile and old fashioned in many sections of the entire globe. It could be replaced with smart farming in the near future. AI has a possibility to implement smart farming and solve the existing crisis somehow in the coming future. Successful implementation of smart farming could enhance the yields by at least 60%. ML and AI are promising techniques, but there will be prosperity of solutions to eradicate waste in food production industries.

For example, 77 Lab has previously launched elegant bots that can select food stuff directly from the plant, eradicating the uselessness of manual labor. There were so many self-assisted pickers in history, but these elegant bots are using machine learning or deep learning and can decide the height of maturity of any fruit, recognize fruits from different plants in a healthier manner, and handle fruits more precisely. So, these are the future of upcoming farming or food processing industries.

9. Conclusions

This study presented the various facts to indicate the advantages and implementation of AI for the food businesses in a precise manner. In the current scenario, the food industry is utilizing the basic level of artificial intelligence. Every day the role of AI is becoming vital due to its capability to escalate hygiene, food protection, and waste management system. In the future, AI is going to transform the food processing industry because it has so much potential to generate reasonable and healthier productivity for clients and employees. The employment of AI and ML in food production and eatery businesses is already taking the business to a new level by minimizing human mistakes in manufacturing and to a lesser extent leftover copious product. It enables low costs for packing as well as conveyance, increment in customer pleasing, rapid services, voice searching, and more personalized orders. These business advantages can also be benefited for big food factories which will bring an obvious benefit in the long run.

Data Availability

The data used to support the findings of this study are available from the corresponding author upon request.

Conflicts of Interest

All authors have no conflicts of interest to report.

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Review Article

Usage of Artificial Intelligence and Remote Sensing as Efficient Devices to Increase Agricultural System Yields

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Artificial Intelligence is an emerging technology in the field of agriculture. Artificial Intelligence-based tools and equipment have actually taken the agriculture sector to a different level. This new technology has improved crop production and enhanced instantaneous monitoring, processing, and collection. The most recent computerized structures using remote sensing and drones have made a significant contribution to the agro-based domain. Moreover, remote sensing has the capability to support the development of farming applications with the aim of facing this main defy, via giving cyclic records on yield status during studied periods at diverse degrees and for diverse parameters. Various hi-tech, computer-supported structures are created to determine different central factors such as plant detection, yield recognition, crop quality, and several other methods. This paper includes the techniques employed for the analysis of collected information in order to enhance the productivity, forecast eventual threats, and reduce the task load on cultivators.

1. Introduction

Actually, in the agricultural sector, various agricultural producers are fighting to deal with the dangers and risks posed by the usage of pesticides in their crops to combat pests and other illnesses. All these components combine and present the farmers with a new challenge. Since agriculture relies on natural forces for most of its produce and rain uncertainties, every year, farmers are placed under great pressure because of a shortage of available employees, and the increasing desire to achieve greater yields [1]. This means that agriculture needs to expand substantially in the coming years, and farm efficiency needs to be doubled virtually so that ranchers can achieve their objectives. The automation industry in agriculture remains at the forefront of the rising issues and concerns worldwide. The population is increasing enormously and the need for food and jobs is expanding with this increase. Presently, farmers' traditional methods are not able to satisfy these purposes. Consequently, modern automated procedures have been implemented to make things simpler and more successful [2]. For various technological developments, artificial intelligence can be applied in agriculture. These include consultancy services for artificial intelligence, data analysis, the Internet, the use of cameras and other sensors, etc. Artificial Intelligence in agriculture will become sufficiently competent to offer improved, predicted insights by studying the various sources of data, such as weather, terrain, crop productivity, and temperature [3]. Such artificial intelligence-powered technology can assist the farming sector to make greater crops in the food supply chain and enhance a broad range of agricultural chores. These new approaches have helped to boost food requirements and have supplied billions of individuals throughout the system with work opportunities. The application of artificial intelligence in agriculture has defended crop productivity from several causes (such as population expansion and climate change). In the agricultural sector, there are key challenges:

(i) Every day, the decision to prepare soil, seeds, and harvest is increasingly challenging for farmers. Agriculture is strongly related to the variation of different climate elements such as temperature, precipitation, and moisture. The increase in pollution and degradation also leads to climate change [4]. For farmers, it is a great issue.

(ii) Each plant requires precise soil nourishment. Phosphorous, potassium, and nitrogen are the three basic nutrients needed in soil. The lack of any of these elements can result in poor crop productivity [5].

(iii) Protection of plants or weeds is also an important function. It may result in an increase in costs in addition to absorbing soil nutrients, which, if not regulated, leads to a lack of nutrition in the soil [6].

Although many applications in agriculture are available, there is still limited knowledge about the latest technology worldwide. Artificial Intelligence supports various segments to improve yield and effectiveness. Artificial Intelligence results are helping to surmount the conventional difficulties in each domain. Similarly, Artificial Intelligence in agriculture assists cultivators to increase their proficiency and decrease natural unfriendly effects [7]. The farming business transparently grasped Artificial Intelligence into their training to modify the general result. Artificial Intelligence is assisting ranchers in staying up to date with climate predicting information in a propelled manner. The forecasted information assists ranchers with expanding production and benefits without hazarding the harvest [8]. The examination of produced information assists the ranchers to avoid potential risk by comprehension and learning with Artificial Intelligence [9]. Actualizing such an exercise assists to formulate a smart assessment on reasonable delay.

Moreover, using Artificial Intelligence is an effective method to distinguish potential imperfections and component deficits in soil. With the picture identification approach, Artificial Intelligence recognizes potential imperfections through pictures caught by the camera [10]. Deep learning appliances are being developed with the assistance of Artificial Intelligence to investigate vegetation models in agriculture. Such Artificial Intelligence-enabled appliances are helpful in understanding ground deficiencies, plant nuisances, and illnesses [11]. Ranchers can utilize Artificial Intelligence to supervise weeds through executing computer visualization, robotic technology, and machine learning [12]. With the assistance of Artificial Intelligence, information is assembled to keep verification records on weeds, which aid the ranchers to use pesticides exactly where the plants are located [13]. This diminished the use of the synthetic product splash in a desired sector [14]. As a result, Artificial Intelligence reduces herbicide use in the area relative to the amount of synthetic substances regularly sprayed [15].

Remote sensing has distinctive benefits over other types of ecological measurement techniques [16]. These advantages include the ability to evaluate factors and ground/land characteristics without having a direct connection to the region of study; the ability to build remote observances, thereby avoiding risks for the user and lowering field measurement fees; and the ability to return at any time and perform repeated data study progresses for the purposes of observing and conditioning evaluations [17]. The domains related to remote sensing are numerous: marine, risk assessments, and natural resource supervision. Technology is continuously progressing and offers the foundation for abundant amounts of innovation and development.

Remote sensing refers to the identification of electromagnetic power from a given surface with the assistance of satellites or airplanes [18]. Spectral detectors can be separated into two categories relying upon the quantity of wavebands with which they evaluate spectral reflectance: (a) multispectral detectors, which get the reflectance data in limited (from 3 to 10) broad wavebands only in the perceptible and near-infrared spectral zones (from 400 to 1100 nm) with small impact of atmospheric dispersing [19] and (b) hyperspectral detectors, which obtain the reflectance data virtually incessantly (numerous hundred wavebands) in the perceptible to infrared spectral zone of the electromagnetic range (from 400 to 2500 nm).

The improvement of novel technologies, for example, high spatial and hyperspectral detectors, made it important to build up an assortment of new techniques, for example, multivariate statistical techniques, to explore this kind of information [20].

2. Applications of Modern Technologies in Agriculture

Like many industries, agriculture has profited from the effects of technology. Farmers rely on information technology for a variety of tasks, not just farm management. Indeed, the way farmers manage crops and livestock has been altered by information technology [21].

Farmers may employ Cloud computing to improve the management of their crops and businesses. They may develop budgets and operating schedules based on their production plans using some of these programmes. Work plans can be drawn up and progress tracked in relation to the weather prediction. Machine activities and production may be measured with the use of mobile task management systems and data integration techniques [22].

Furthermore, Radio Frequency Identification (RFID) is the technology used for agricultural tracking and security. Livestock, for example, may be tracked using RFID-enabled “livestock tracking tags.” This can be beneficial for tracking cattle on a daily basis, as well as for health monitoring and preserving a database of each animal’s health history. Furthermore, through its security tagging, this technology aids in the reduction of counterfeiting/impure food shipments during crop shipping, particularly certified organic crops [23].

Besides, precision agriculture contains a variety of tools, including data analytics. This is known as "smart farming," and it is now being used by many food producers to reduce costs and boost yields. The following describes how it works: Crop yields, fertiliser applications, soil mapping, weather events, and animal health are among the data that farm offices gather. Even small producers may collect data from a variety of sources to aid in decision-making that will help them reduce expenses and enhance yields. The use of water sensors, which may be used to plan future crops and water use, is of great importance here. This is especially beneficial in drought regions [24].

The introduction of Artificial Intelligence algorithms in cultivated areas as well as in farming products has been advanced in agriculture. Cognitive information technology in agriculture has become inventive, knowledgeable, and efficient. Artificial Intelligence can also help producers to estimate needs via providing data such as the trends of historical data in food commodities, regional main food preferences, etc. [25]. The Artificial Intelligence scope in farming is large and can serve, for example, in the pesticide spraying via sensors and other devices installed in drones and robots. These technologies contribute to preventing the overuse of pesticides, water, and herbicides; maintain soil fertility; and, at the same time, increase personnel productivity and efficiency while improving quality [26]. Artificial Intelligence-powered solutions present many benefits for the agricultural sector.

2.1. Environmental Challenge Management Using Weather Forecasting. In the increasing domain of precision agriculture, weather data play an essential function, as an agricultural technique that assists control and precise cultivation. Nevertheless, Artificial Intelligence-powered systems and information employ smart resource allocation, which helps farmers to negotiate shifts under changing environmental conditions, as a result of many environmental issues, such as climate change and other risks to agricultural productivity [27].

2.2. Surveillance System for Soil and Crops. With new solutions and the installation of Internet of Things (IoT) sensors on farmland, ranchers can immediately detect the moisture content of the soil and know its chemical structure and composition. These implanted sensors can be adjusted so that farmers are automatically informed of insufficient soil content of substances such as potassium, nitrogen, phosphorus, or humidity [28]. Remote sensing complemented by a 3D laser scan also helps to provide agricultural land plant metrics that ensure crops are grown according to the correct soil conditions. Drones additionally play a major role in identifying and quantifying agricultural health issues sooner via offering significant insights into improving production and minimising input costs with professional multispectral cameras and sensors [29].

2.3. Farming and Predictive Analysis. Predictive analysis by using innovations acquires the facts and information necessary to decide how production may be improved and to take all corrective measures to attain the objective. Smart agriculture, on the other hand, includes a range of strategies and skills that allow farmers to maximise the yield and improve soil fertility. When using these technologies, it becomes possible to interfere properly at the correct time, in the correct location, in order to respond with excellent precision to the specific needs of individual crops and different sections of the farm [30].

2.4. Artificial Intelligence-Enabled System for Agricultural Data Evaluation and Insect Detection. By applying Artificial Intelligence in agriculture, producers can now evaluate a number of things in real time. Sensors can detect the emergence of insects in their territories, and the sensors can determine what sort of insects they are. It quits and does nothing if it is a helpful or neutral insect. However, it provides information from the Cloud if it is a significant pest or a deadly disease. The Artificial Intelligence-driven solutions therefore enable producers to optimise their plans to generate greater returns through adequate use of resources, management of crop selection, and much more [31].

2.5. Adequate Irrigation and Sustainable Farming. The growing demand for food has led to farmers improving their productivity by using various techniques, resulting in soil abuse. Increasing returns over time reduces land quality, which generates too low returns to pay even for seeds. Irrigation is a process that is human-intensive. Different automated systems may now influence Artificial Intelligence and machinery to evaluate soil fertility, historical weather patterns, and seed quality to help farmers manage their water supplies effectively [32]. Through seeding the optimum-planting crop, minimising water waste, and enhancing yields, the use of Cognitive IoT solutions can contribute to enhancing water management.

3. Application of Remote Sensing in Agriculture and Vegetation Inventory

Strategies utilized for investigating vegetation characteristics with remote detecting can be separated into physical techniques, empirical techniques, and a combination of both [33]. Generally, physical techniques are founded on the radiative exchange hypothesis, and they reproduce plant-light connections with the assistance of simulation designs [34]. Empirical techniques depend on the statistical connection involving *in situ* estimated vegetation properties and the vegetation reflectance data [35].

Generally speaking, an applied methodology for discovering empirical connections between vegetation characteristics and spectral reflectance includes joining the reflectance data of at least two individual spectral wavebands to deduct an indicator called vegetation index (VI). For example, the Normalized Difference Vegetation Index (NDVI) utilizes the data from the reduced reflectance in the red region and elevated reflectance in the near infrared region [36]. NDVI has been utilized for many years to gauge different vegetation factors; for example, biomass and yield,

Table 1: Remote estimation of crop fractional vegetation covers: the main remote sensing vegetation indicators.

Application	Symbol	Name	Formula	Reference
Assessment of the general state of vegetation	TVI	Triangular Vegetation Index	TVI = 0.5 × [120 × (R750 − R550) − 200 × (R670 − R550)]	[40]
	GNDVI	Green Normalized Difference Vegetation Index	GNDVI = (R860 − R550)/(R860 + R550)	[41]
Assessment of the amount of photosynthesis	REPI	Red Edge Position Index	REPI = 700 + 40 × {[(R670 + R780)/2 − R700]/(R740 − R700)}	[42]
	CTR2	Carter	CTR2 = R695/R760	[43]
Assessment of nitrogen content	NDNI	Normalized Difference Nitrogen Index	NDNI = [LOG(1/R1510) − LOG(1/R1680)]/[LOG(1/R1510) + LOG(1/R1680)]	[44]
Assessment of the amount of light used in photosynthesis	PRI	Photochemical Reflectance Index	PRI = (R531 − R570)/(R531 + R570)	[45]
	ZMI	Zarco-Tejada and Miller Index	ZMI = R750/R710	[46]
Assessment of the amount of dry biomass	PSRI	Plant Senescence Reflectance Index	PSRI = (R680 − R500)/R750	[47]
	NDLI	Normalized Difference Lignin Index	NDLI = [LOG(1/R1754) − LOG(1/R1680)]/[LOG(1/R1754) + LOG(1/R1680)]	[44]
	CAI	Cellulose Absorption Index	CAI = [0.5 × (R2000 + R2200)] − R2100	[48]
Assessment of water content	WBI	Water Band Index	WBI = R970/R900	[49]
	NDWI	Normalized Difference Water Index	NDWI = (R857 − R1241)/(R857 + R1241)	[50]
	DSWI	Disease water stress Index	DSWI = (R802 + R547)/(R1657 + R682)	[51]

from restricted to exhaustive degrees [37, 38]. Likewise, physically based vegetation indicators identified with vegetation biophysical characteristics have been built up [39]. Table 1 presents the principal remote sensing vegetation indicators used in the remote estimation of crop vegetation.

Among these indices, the Enhanced Vegetation Index (EVI) is similar to the Normalized Difference Vegetation Index (NDVI) and can be used to quantify vegetation greenness [52, 53]. However, EVI corrects for some atmospheric conditions, canopy background noise, and is more sensitive in areas with dense vegetation. In addition, the Soil Adjusted Vegetation Index (SAVI) is structured similar to the NDVI but with the addition of a soil brightness correction factor [54]. Moreover, the NDRE (Normalized Difference Red Edge) is an index that can only be formulated when the Red edge band is available in a sensor. It is sensitive to chlorophyll content in leaves (how green a leaf appears), variability in leaf area, and soil background effects [55].

Another strategy includes mixing numerous spectral wavebands into a unique empirical prototype utilizing multivariate statistical methods [56, 57]. The empirical designs can be additionally separated into linear (for example, partial least squares regression) and nonlinear (for example, support-vector machines) designs.

Empirical techniques are computationally rapid and recapitulate local information efficiently; however, they also have some weaknesses [58]. These processes frequently lack cause-and-effect relationships, making it more difficult to move a design to a new location, study it at a different time, or even to a different spectral detector without systematically recalibrating it. The restrictions of empirical techniques can be partially overcome by utilizing physical techniques [59]. Nevertheless, physical techniques are computer-intensive, occasionally necessitate several input variables for calibration, and need rigorous parameterisation before they can be employed [60].

4. Earth Observation Satellite Systems

Globe inspection satellites fluctuate in accordance with their orbit, and from the position of the imaging device, the information categories, spectral traits, and the swath size of detectors [61]. These variables are set at the start of operation and are part of the satellite's installation. For instance, with the aim of observing the weather conditions at a big scale and elevated frequency, it is suitable for a satellite to be on a geostationary trajectory. Nevertheless, as the trajectory is a significant length above the globe, it is complicated to attain an elevated spatial resolution. On the other hand, for appliances such as the passing of clouds over land, an elevated spatial resolution is not needed [62].

An elevated spatial resolution device would be required for projects that require high-resolution images of a specific region, such as the observation of a glacier river or the inspection of structures damaged by a natural disaster [63]. Such a detector would usually have a thin swath and be on an orbiter at Low Earth Orbit (like, for example, the QuickBird satellite). In such an orbit, it is not feasible to observe constantly the identical district, due to the continuous movement of the satellite around the globe [64]. Pictures can just be obtained on the satellite. For instance, moderate-resolution Imaging Spectroradiometer (MODIS) pictures have been employed to plot water bodies at general and local levels. For local tasks, pictures supplied via the Enhanced Thematic Mapper Plus (ETM+), the Thematic Mapper (TM), and the Operational Land Imager (OLI) from Landsat satellite series are extensively employed [65].

Hui et al. [66] designed, using multi-temporal Landsat TM and ETM + pictures, the temporal and spatial modifications of a studied Lake. OLI pictures were employed by Du et al. [67] to remove water body charts in subareas. While evaluated with MODIS, the Landsat TM, ETM+, and OLI pictures have much greater spatial resolutions (30 meters) and can extract entities with higher aspect and precision. Table 2 shows principal spectral properties of Landsat TM/ETM.

Nevertheless, spatial resolution pictures of Landsat are still insufficiently elevated to recognize satisfactorily little-sized masses [68]. Trade satellite structures, such as IKONOS, SPOT6, SPOT7, and Quick-bird, allow these small entities and bodies to be plotted, though they can be expensive.

Besides, the European Space Agency initiated a novel satellite technology with elevated optical spatial resolution, identified as Sentinel 2 at the end of June 2015. This satellite can offer automatic and general previews of detailed spatial resolution and multispectral pictures with an elevated temporal motion, satisfying the needs of the following genesis of functional products, like for example, soil cover plots, ground cover detection plots, and transformation as well as geophysical attributes [69, 70]. The Sentinel-2 pictures have the possibility of representing an immense importance for local mapmaking of entities, according to its interesting characteristics (such as the spatial resolution of ten meters for 4 different bands and the ten days of frequency expedition) and accessible free records. The Sentinel-2 multispectral picture has third-teen bands, in which four bands (blue, red, green, and near infrared) have a spatial resolution of ten meters and six bands have a spatial resolution of twenty meters. Figure 1 illustrates the geospatial analytics process.

4.1. The Electromagnetic Spectrum. Electromagnetic radiation could be described as the power that moves with the rapidity of brightness in a harmonic wave model. Visible brightness is only one class of electromagnetic radiation; other categories comprise radio signals, gamma rays, as well as infrared rays. All of these include the electromagnetic spectrum; the diverse types of electromagnetic radiation differ across the electromagnetic range regarding frequency and wavelength [72]. Wavelength can be defined as the length involving the positions in two wave successions, whereas frequency is described as the amount of wave sequences delivering the identical point in a specified time phase (1 cycle per s = 1 Hertz, or Hz). The numerical association between frequency and wavelength is indicated via the equation: $S = wf$, where w is the wavelength, f is the frequency, and S is the brightness speed (which is constant at 300×10^3 km per second in a vacuum). Visible brightness symbolizes just a small fraction of the electromagnetic spectrum. It varies in wavelength starting with 3.9×10^{-7} m (violet) to 7.5×10^{-7} m (red), and has corresponding frequencies that vary beginning with 7.9×10^{14} to 4×10^{14}.

In remote sensing, an instrument (i.e., sensor or scanner) is attached to a satellite or aeroplane that collects data and information concerning specific entities or districts on the land. Generally, the data list the stage of electromagnetic power that the objective has. The degree of the selected geographic region is dependent on the captor's scientific requirements and the elevation of the navigation vehicle in which it is equipped. When electromagnetic radiation comes into contact with any object or material, such as water, trees, or atmospheric gases, a variety of interactions can occur, including the emission, reflection, scattering, or absorption of electromagnetic radiation by the substance, or the diffusion of electromagnetic radiation through the substance. Usually, remote sensing is related to the data transcription and recognition of returned and released electromagnetic radiation. Each entity or matter has a specific release and/or reflectance characteristic, jointly identified as its spectral endorsement, which differentiates it from other entities and matters. Remote detectors are adjusted to assemble these spectral endorsements. Spectral records can be collected in two configurations: analogical, as aerial photographs, or digital configuration as two-dimensional matrix, or picture compiled with pixels that accumulate electromagnetic radiation rates collected by means of a satellite-fixed assortment [73]. In addition, sensors can be divided into two groups: active and passive sensors. The passive sensors, the most known class of sensors currently in function globally, study naturally happening electromagnetic radiation that is either returned or released from districts and entities of importance. Whereas active sensors, like microwave systems such as radar, transmit artificial electromagnetic radiation toward the elements of importance and subsequently register what quantity of that electromagnetic radiation is returned to the system [74].

4.2. Data Resolutions. A remotely sensed record is principally defined via four kinds of resolutions:

4.2.1. Temporal Resolution. The temporal resolution indicates the revisiting frequency of a satellite detector for an objective location. The temporal resolution is associated with numerous features, as well as swath overlap, satellite aptitudes, and latitude. The period of day or month has an immense effect on satellite pictures [75]. Particular target organisms can fluctuate quickly at any time, such as the lunar time periods that influence the oceans, continuously mounting and diminishing, or else fruit trees can lose their leaves in winter involving a supplementary difficulty to differentiate precisely green foliage.

4.2.2. Spectral Resolution. The detector's spectral resolution provides the quantity of spectral groups (red, blue, green, near-infrared, mid-infrared, thermic, etc.) in which the detector can register electromagnetic radiation. Nevertheless, the number of bands is not the unique basic attribute of spectral resolution [76]. The band frequencies in the electromagnetic field are valuable. The sensibility of detectors to unimportant modifications in electromagnetic power is significant. The better the detector's radiometric resolution,

Table 2: Spectral properties and principal applications (example, in Landsat TM/ETM).

Band	Wavelength (μm)	Principal applications
B-1	0.45–0.52 (blue)	This band is practical for mapping coastal water areas, differentiating between soil and vegetation, forest-type mapping, and detecting cultural features.
B-2	0.52–0.60 (green)	This band corresponds to the green reflectance of healthy vegetation. It is also practical for cultural feature identification.
B-3	0.63–0.69 (red)	This band is practical for discriminating between many plant species. It is also practical for determining soil boundary and geological boundary delineations as well as cultural features.
B-4	0.76–0.90 (near-infrared)	This band is especially responsive to the amount of vegetation biomass present in a scene. It is practical for crop identification and emphasizes soil/crop and land/water contrasts.
B-5	1.55–1.75 (mid-infrared)	This band is sensitive to the amount of water in plants, which is practical in crop drought studies and in plant health analyses. This is also one of the few bands that can be used to discriminate between clouds, snow, and ice.
B-6	10.4–12.5 (thermal infrared)	This band is practical for vegetation and crop stress detection, heat intensity, insecticide applications, and for locating thermal pollution. It can also be used to locate geothermal activity.
B-7	2.08–2.35 (mid-infrared)	This band is important for the discrimination of geologic rock type and soil boundaries, as well as soil and vegetation moisture content.

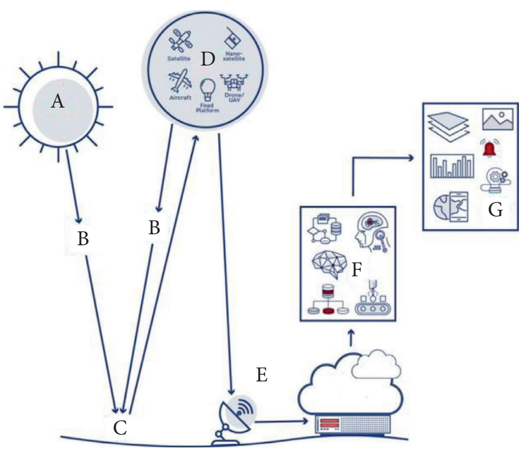

Figure 1: The geo-spatial analytics process [71].

the more receptive it is in order to perceive low differences in returned or released energy.

4.2.3. Spatial Resolution. The spatial resolution provides the pixel measurements of satellite pictures representing the globe's surface. In aerial imagery, it is related to picture characteristics and the stage at which small entities can be identified within the picture [77]. The spatial resolution of airborne images in white and black (only one band) ranges from 40 to 800 row pairs per millimetre. The greater the resolution of a sensing structure, the more efficiently the draft of entities can be monitored on the soil. The spatial resolution of a picture turns on:

(i) The picture dimension coefficient: spatial resolution diminishes as the dimension coefficient rises
(ii) The amount of the optical structure
(iii) The type of assemblage of the photographic motion
(iv) The disparity of single entities and objects
(v) Atmospheric dissemination consequences: can provoke lower resolution and contrast
(vi) Picture motion: the relative activity involving soil and detector can provoke distortion

Moreover, it is important to note that the most unpredictable feature is the atmosphere, which is hard to predict and usually fluctuates [78].

4.2.4. Radiometric Resolution. The radiometric resolution is defined as the quantity of data in one pixel and is determined in bits. One bit of data indicates a binary decision of "no" or "yes," accompanied by a numeric value of 0 or else 1 [79]. White and Black pictures, called grayscale pictures, from digital photographic devices are generally in 8 bits, with estimation between 0 and 255 to designate the data. Coloured pictures often have three canals in 8 bits; every canal has a specified value for blue, green, and red. Simultaneously, they generate the viewed colour and the intensity of every canal manages the darkness. It is a method of additive colour merging.

As an example, a radiometric resolution of 11 signifies that the pixel has 2048 (equivalent to 2^{11}) probable shades of red, 12 bits symbolize 4096 (equivalent to 2^{12}) shades of red, and 14 bits correspond to 16384 (equivalent to 2^{14}) shades of red. While amplifying radiometric resolution results in a larger interval for the pixel, this does not imply that it is the best option.

5. Machine Learning in Remote Sensing

Firstly, machine learning techniques were employed in remote sensing in the nineties. It was founded primarily on remote sensing as a method to computerize cognition-based construction. The work by Huang and Jensen [80] explained how a cognition-foundation was built with minimum input from users, and afterwards, decision trees were grown to understand the commands from an individual input for the specialist structure. They concluded that machine learning-assisted methodology provided greater precision when compared to traditional techniques. Consequently, analogous improvements in machine learning were made and were rapidly approved as an essential instrument by remote sensing experts and scientists. It is presently being employed in a large assortment of varied tasks, from an unsupervised satellite picture view categorization to the organization [81].

5.1. Machine Learning Categories. Machine learning can be allocated to three types, as seen in Figure 2:

(i) Supervised machine learning: the machine learns via labelled data. The prototype is prepared on existing records before it begins formulating decisions through the novel records. The output in supervised machine learning is measured. The target variable can be continuous as Linear, Polynomial, or Quadratic Regressions or categorical as Logistic Regression, Support Vector Machine, Decision Tree, Gradient Boosting, Bagging, Random forest, etc. [82].

(ii) Unsupervised machine learning: the machine is trained on nonlabelled data and with no suitable control. It mechanically deduces models and associations in the records through constructing clusters. The prototype learns by measurements and presumed constructions in the records. Target is absent as in principal component analysis, factor analysis, etc. [83].

(iii) Reinforced learning: the prototype learns by means of test and error technique. This type of learning implies an operator that will interact with the environment to make reactions and subsequently determine errors or reaction consequences [84].

The distinction involving supervised and unsupervised learning is present when employing supervised prototypes, where the operator has constructed a preestablished marker with a set of traits. While the unsupervised algorithm deduces the data set via information classification into various categories constructed upon the connexion it has identified among various data [85], reinforcement learning is quite dissimilar. The operator gives the algorithm a setting and the algorithm formulates choices within that setting. It is constantly enhancing itself with every decision supported by the outcome of the previous decision.

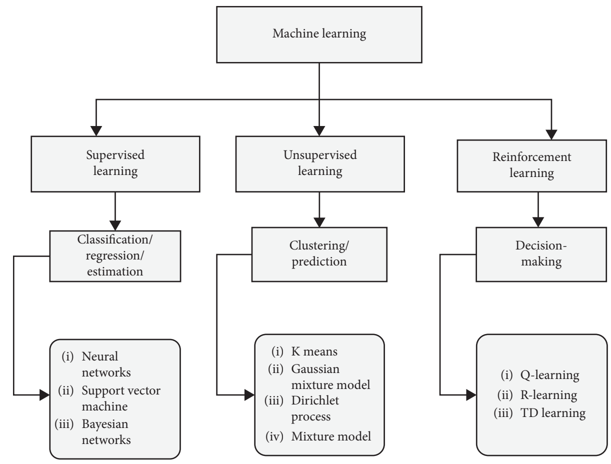

Figure 2: Machine learning categories.

5.2. Image Processing and Map Production. The process of obtaining land surface data from remotely sensed records depends on a succession of complex steps, for the reason that radiance calculated via sensors (expressed in watt per m^2) does not permit for immediate inference of soil cover. Previously, numerous functional cartographic structures were established on monitoring interactive ocular analysis of some pictures obtained at particular periods of the year, and principally depended on specialist explanation. Picture processing devices have gradually sustained this way.

Any plan creation of ground cover includes a succession of major operating stages. For every stage, numerous algorithmic and theoretical options are feasible. Waldner et al. [86] have exposed that crop mask precision differs more from one farming district to another rather than from one modern technique to another. Obviously, some technological selections might be more suitable than others. Nevertheless, in the majority of situations, the quality and amount of the remote sensing input and adjustment data set participate in a significant function. The solution to achievement is nearly the sufficiency of technological choices chosen for the quality and quantity of input globe inspection and in situ adjustment records, as well as in relation to the site features to be plotted. Four major levels in the territory cover sequence making might be recognized noticeably: (1) picture segmentation; (2) characteristic extraction; (3) categorization; and finally (4) postprocessing, counting, filtering, and/or combination.

5.2.1. Picture Segmentation. The soil is divided into pixels through satellite descriptions, while visual monitor analysis defines standardized models. A picture raster composed of pixels and a vector composed of objects are identified as the two most important conceptual patterns established in order to illustrate the spatial aspect of the globe. While the spatial resolution is more or less than the dimension of the soil cover components to be represented, ground cover data are usually treated at the pixel degree and then the segmentation stage is not required. For high-spatial-resolution captures offering pixels much less important than the ground cover components, the prototype of vector is generally desired and the picture should be segmented into entities through picture segmentation algorithms. Picture segmentation collects adjoining pixels into spatially continuous entities in accordance with the spectral traits and their spatial perspectives, with the objective of registering significant spatially isolated ground entities and objects. The entity-based principle is effectively adjusted to picture structure extraction, has essential appropriate information, and accepts multiscale analysis because of hierarchical or multi-degree segmentation [87]. From another point of view, this stage is an additional origin of error when evaluated with the pixel-based methodology. In fact, it is mainly suggested to work with object-based categorization while the pixel dimension is much less important than the landscape constituents. Regularly, metric and decametric pictures are frequently fragmented into objects, while hectometric-resolution pictures are undeniably not fragmented. In unusual cases, pixel- and object-based making of chains have been planned, and interactive construction of ground cover plan is carried out

[88]. Picture segmentation can be performed according two different methodologies: the angle-based strategies, which depend on a restricted recognition of edges, and the district developing techniques, which distinguish spatial groups of ordered pixels. One of the most known district-developing calculations in remote sensing comprises the act of assembling objects as long as the standardized variance of pixel values within mixed object persists under a specified threshold [89]. Besides spectral homogeneity, the mixing of objects can likewise be controlled by object form, in order to increase the coordination with spatial ground cover objects.

5.2.2. Attribute Extraction. The attribute extraction stage entails estimating the most discriminant factors to be used as contributions for categorization calculation from remote sensing images or time cycles. These attributes might be of different natures: (1) spectral, such as multispectral reflectance, or acquired indexes, such as the NDVI or some other vegetation, chlorophyll, or soil indices; (2) temporal, such as the lowest, highest, or amplitude of a variable over a specified time epoch; (3) textural, such as local disparity, entropy, or some other variable obtained from a co-occurrence matrix; and (4) a spatial or relevant variable that is especially suitable for the object-based methodology. Presently, three principal procedures might be seen in the field of land cover plotting. Firstly, usual methodologies depend fundamentally on spectral traits and, eventually, some basic temporal traits dependent on NDVI time arrangement, taking into account that these are the origins of all other traits in any circumstance. Considering progressively high calculating performances and the propagation of Artificial Intelligence algorithms, numerous remote sensing experts presently judge that "more is better" and depend on classification calculations to choose the most discriminant ones. Moreover, information-based approaches intend to incorporate external specialist cognition through structuring unarranged attributes as indicated by the classification target and also via holding just those attributes considered important as per specialists' principle [90].

5.2.3. Categorization. This stage comprises one or numerous numerical steps to finally assign each pixel or object to one of the classes of the ground cover configuration. The large diversity of categorization algorithms can be divided into two major groups: the supervised group, which utilizes a training data set to align the algorithm *a priori*, and the unsupervised group, which creates bunches of pixels to be named *a posteriori* as soil cover category considering *in situ* or auxiliary records. Currently, predicting steps of supervised categorization are extremely valuable. They comprise programmed cleaning of *in situ* training data set, or dynamic learning to construct a more proficient training data set through repeatedly increasing the effectiveness of the classifier design. The arrangement of techniques employed to distinguish pictures in ground cover categories is continually extending. A survey of these techniques was resumed by Nitze et al. [91] and is incorporated as follows:

(1) Categorization Based on Maximum Likelihood. Until lately, the Maximum Likelihood categorization technique was considered as the most utilized approach for the supervised categorization of remote sensor information [92]. The Maximum Likelihood principle depends on probability. In this methodology, preparing information is utilized to explain statistically the target categories through their multivariate probabilistic density capacities. Every density capacity corresponds to the probability that the spectral model of a class drops inside a specified district in multidimensional spectral space. The spectral reference of every pixel is subsequently allocated to the category of which it has the most elevated probability of being an element [93], whilst the essential benefit of the Maximum Likelihood approach is the complete control that a user has over the soil cover classes to be utilized in the last categorization. Its application is constrained by its dependence on the Gaussian distribution of input records, an assumption that is frequently ignored when employing multitemporal records of numerous spectral traits and multimodal distributions [94]. Furthermore, categorization through Maximum Likelihood employs the equivalent set of traits for all categories and needs an elevated number of calculations to categorize the picture information totally. Especially, this is evident when an elevated number of attributes is employed as input to the categorization step, or where a large number of spectral categories must be separated. In such cases, the usage of the Maximum Likelihood classifier can be considerably faster than other supervised categorization methods. The different restrictions related to Maximum Likelihood categorization convert into the dynamic improvement of new categorization calculations for the field of remote sensing. Of these novel techniques, artificial neural networks [95], support vector machines [96], Decision Trees [97], and groups of classification trees such as Random Forest [98] have shown enormous hope.

(2) Artificial Neural Networks. The utilization of Artificial Neural Networks for remote sensing categorization is incited by the fact that the human brain is proficient at handling high amounts of information and records from a wide range of sources [99, 100], and that scientific renderings of this methodology might be valuable for preparing and analysing picture information. While applied to picture categorization, an Artificial Neural Network is a hugely equal allocated processor made up of basic handling items that gains information from its environment via a self-learning operation, to adaptively build linkages involving the input records, as for example, satellite imagery attributes, and the output records, as for example, target cover groups [101]. Prominent Artificial Neural Networks are the Multilayer Perceptron (MLP) [102], and Kohonen's Self-Organizing Feature Map [103] and Fuzzy ARTMAP [104]. While these methodologies change as far as their definite usage is concerned, they necessitate training and organization to separate important data from remotely detected picture information [105]. Figure 3 represents the Artificial Neural Network structure [106].

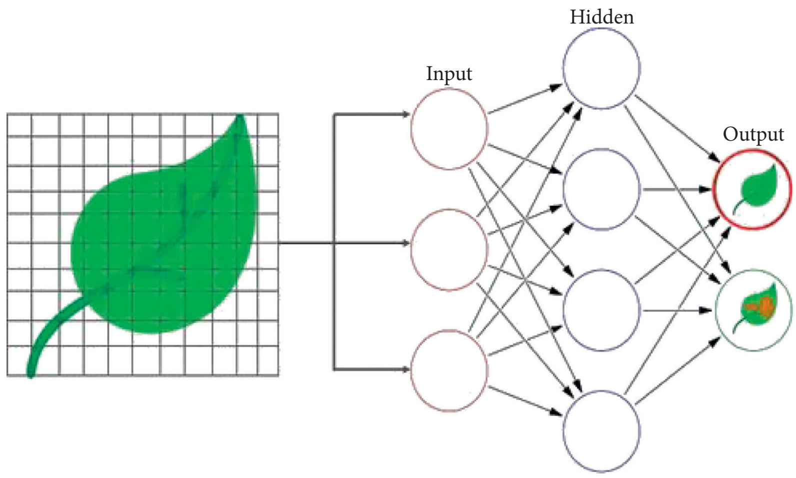

Figure 3: Artificial Neural Networks [106].

During the training phase, image data from areas whose features (or classes) are used as inputs to the system is collected. These data are used by the system in an iterative methodology that characterizes the rules that produce the best organizational outcomes. Showed rules are then utilized in the organization phase to designate attribute information to the training class of which it has the most significant probability of being a component.

The benefits to Artificial Neural Networks integrate their capacity to: (1) perform more precisely when input data involve numerous large data sets that are estimated at various scales and the frequency distributions of which are uncommon; (2) learn and constantly update complex models, as for example, nonlinear connections among input information and output groups, as more information is given in a varying domain; (3) give, via generalization, strong answers in the presence of partial or inaccurate information; and (4) consolidate *a priori* understanding and logical physical restrictions into the investigation [107, 108]. However, the inconveniences to Artificial Neural Networks have restricted their appropriation to basic applications [109]. On the other hand, the most important disadvantage of Artificial Neural Networks is that they are a "black box" for explanation [110]. In fact, it has habitually been hard to clarify in a significant manner the procedure through which the output has been gotten, because the guidelines for picture organization and analysis learned via the system are not simply reachable or describable [111]. Therefore, other organization strategies with more prompt logical clarification abilities will be utilized in general.

(3) Support Vector Machines. Support Vector Machines, defined as a supervised nonparametric statistical learning procedure for solving categorization problems [112], show incredible potential for the categorization of remotely detected picture information [113]. Support Vector Machines resolve a quadratic optimization problem to decide the ideal separating limits (hyperplanes) involving two groups in multidimensional element space [114]. Support Vector Machines do this task by concentrating on the training data that lie at the edge of the group disseminations. While groups cannot be isolated, the training data are assigned into a higher-dimensional space utilizing core methods, where the novel record distribution allows the greater fitting of a straight hyperplane [115]. This method is replicated for each pair of groups to split the information into the pre-selected number of groups. The guidelines for best group division are then utilized to assign all picture information into the preselected target groups. Figure 4 illustrates the Support Vector Machine principle [116].

The basis of the Support Vector Machines' principle of categorization is, hence, the idea that just the training samples that lie on the group limits are required for discrimination [117]. The benefit of utilizing Support Vector Machines is their capacity to surpass conventional organization techniques when just little training data sets are accessible [118]. The fundamental rule that promotes Support Vector Machines is that the learning procedure depends on basic hazard minimization [119]. Under this idea, Support Vector Machines limit organization errors on hidden information without making any *a priori* suppositions on the statistical distribution of the information [120]. The significant weakness in utilizing Support Vector Machines concerns the choice of the most adequate core function type and its related parameters. Even if various choices exist, some core functions cannot give the best Support Vector Machines' design for remote detecting uses [121]. This is significant because inadequate decisions may prompt overfitting, which may have a huge negative effect on Support Vector Machines' execution and precision of organization [122]. Furthermore, Support Vector Machines have not been improved to manage heterogeneous information, such as the outlier impacts commonly encountered in remote sensing data, the addition of which can

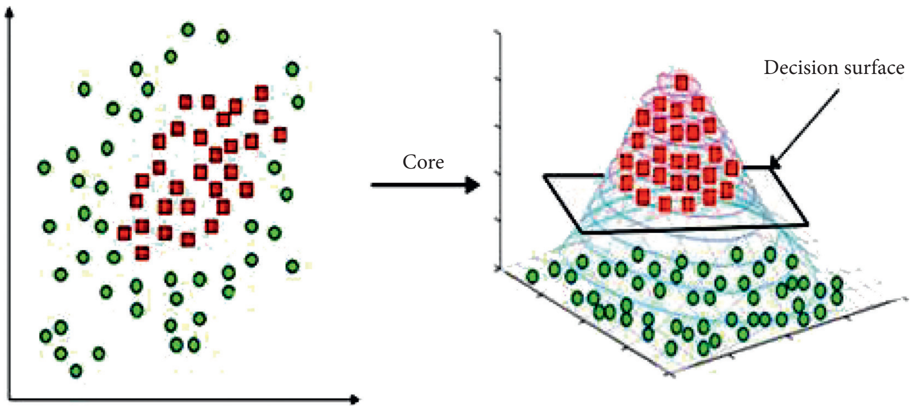

Figure 4: Support Vector Machine.

significantly reduce classifier influence [123]. Regardless of these issues, Support Vector Machines are a prominent alternative for land cover organizations.

(4) Decision Tree Classification. Decision Trees, supervised organization strategies dependent on recursive binary divisions agreeing to many upgraded guidelines, have become an alluring alternative for separating discrete class data for land cover classification [124]. A Decision Tree accepts many elements as input, and comes back with an output via an arrangement of tests [125]. Trees construct the instruction by recursive binary dividing areas that are progressively homogeneous concerning their class variable [126]. Decision Tree classifiers make multivariate designs dependent on many decision instructions characterized by mixes of parameters and many linear discriminant equations that are applied at every test node [127]. Ordinarily, after an adequate number of training tests have been gathered, a Decision Tree learning calculation utilizes the training information to create Decision Trees that are then changed into another illustration of information representation, called production instructions. Since production instructions are uncomplicated, they can be analyzed by specialists and can be represented easily [128].

The utilization of Decision Trees for picture organization has many benefits, for example, the capacity to collect information at various estimation scales [129], nonordinary (nonparametric) input information frequency distributions [130], and nonlinear connections between input information and groups [131]. These are analogous to those explained by Artificial Neural Networks. Nevertheless, Decision Trees are simple to use because fewer numbers of factors are required to be determined [132] as demonstrated in Figure 5; they give a hierarchical construction that is clear and simple to interpret [133]; and they can be trained via making instructions and settings directly from training information with minimal operator collaboration [134].

One of the most important features of decision trees is that they can adjust when new learning information is provided and that the system's output can be evaluated to see how a deduction was reached [135]. The disadvantages of using Decision Trees include their inability to include spaces

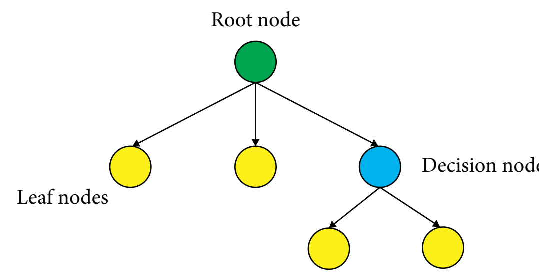

Figure 5: Decision Tree.

with high dimensionality [136], noisy data [137], and overfitting [112]. A better comprehension of impacts on Decision Tree organization performance is a part of remote detecting that is presently experiencing further investigation [138], and has prompted the advancement of ensemble Decision Tree-based strategies, for example, the Random Forest technique, which enhances organization performance through the mixture of numerous individual Decision Trees.

(5) Random Forests Classification. Random Forest, an improved form of Decision Tree, is an ensemble learning calculation that consolidates different organizations of similar information to generate higher arrangement precisions than different types of Decision Trees [98]. Random Forest works by fitting numerous Decision Tree-based organizations to a data set, and afterward utilizing a guideline-based approach to deal with joining the forecasts from all the trees as illustrated by Figure 6 [139].

During this procedure, singular trees are developed from differing subsets of training information utilizing a procedure entitled bagging. Bagging includes the irregular subsampling (with substitution) of the original information for developing each tree. Usually, for each developed tree, 66% of the training information is utilized to develop the tree, while the remaining 34% is left unused for later error evaluation [140]. A classification is subsequently fit to each bootstrap model; nevertheless, at every node (split), just a few randomly specific indicator factors are utilized in the binary dividing [141]. The parting procedure proceeds until supplementary

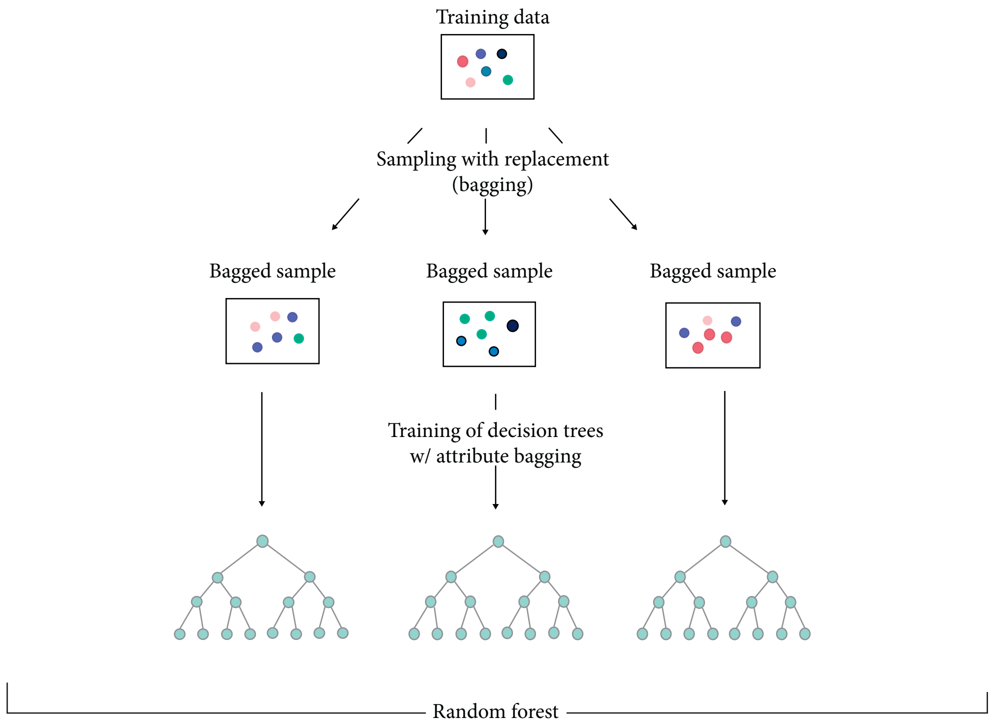

Figure 6: Random Forest principle [139].

subdivision no longer diminishes the Gini indices [142]. With only one vote, each tree contributes to the task of the most common class to the input data [143]. The common vote of an observation determines the forecasted group, with binds division determined at random [144].

The most important benefit of Random Forest is that it is conceivably more precise and reliable than usual parametric or Decision Tree Artificial Intelligence techniques [143]. This is because the classifiers' category executes more precisely than any unique classifier, while dodging classifier limitations [145]. Furthermore, Random Forest needs the description of only two factors to construct the forecast model (that is, the quantity of classification trees required and the quantity of forecast factors utilized in every node to develop the tree), and is accordingly judged to be moderately simple to parameterize [143]. Further points of interest result from the Random Forest's utilization of bagging to cause singular tree development from training information subsets. Completely developed trees are utilized to estimate precision and error rates for every sample utilizing the Out-Of-Bag forecasts, which are then standardized over all tests. Since the Out-Of-Bag records are not employed to fit the trees, the Out-Of-Bag estimates are basically cross-validated precision estimates [143]. Random Forest is additionally ready to evaluate the significance of only one variable. For this reason, Random Forest switches one of the input factors, preserving the rest invariable, and determines the reduction in precision that has occurred by methods for the Out-Of-Bag error [143]. This is helpful when it is critical to realize how each predictive variable influences the organization design [145]. The disadvantage of using Random Forest is that with a large number of trees, it becomes more difficult to analyse individual trees and comprehend their configuration [146], leading to a black box environment that complicates decision instructions [147]. Table 3 presents the advantages and limitations of algorithms employed for area classification of satellite images.

(6) Postprocessing. These processes can develop the categorization outputbecause of the option to employ diverse filtering methods or otherwise to combine diverse categorization outputs. Initially, macroscopic deficiencies are modified interactively because they are clearly identified via regular optical examination. Basic filtering parameters over sliding section of 3 pixels × 3 pixels or 5 pixels × 5 pixels, such as a majority filter, eliminates the salt-and-pepper result provoked through pixel-based categorization. Such a majority filter could moreover be employed for pixel-based categorization output by objects acquired through multispectral reflectance picture segmentation, therefore offering a much smoother land cover plan. Fusion methods are needed to combine outputs from the classifier group. With majority voting, a unique output chart can be obtained either when the ensemble selects the category to which all classifiers agree or when at least half of the classifiers agree. Weighted majority voting can be employed whilst a number of classifiers are supposed to execute better than others, or are weighted via the connected possibility or membership of the categorization output. It is imperative to remark that the diverse stages explained above are mostly correlated, and every choice must consider the total land cover cartography creation sequence to guarantee that a suitable solution is realized.

Table 3: Advantages and limitations of algorithms employed for wide-area classification of satellite picture records [147].

Algorithm	Advantages	Limitations
Maximum likelihood	(i) Easy application (ii) Simple to comprehend and interpret (iii) Forecasts category membership probability	(i) Parametric (ii) Supposes normal distribution of records (iii) Elevated training sample needed
Artificial neural networks	(i) Manages big attribute space well (ii) Shows strength of class membership (iii) Normally high classification precision (iv) Challenge to training records deficiencies—needs less training records than Decision Trees	(i) Requires factors for network modeling (ii) Tends to overfit records (iii) Black box (rules are unidentified) (iv) Computationally powerful (v) Time-consuming training
Support vector machines	(i) Manages large feature space well (ii) Insensitive to Hughes consequence (iii) Works well with little training data sets (iv) Does not overfit	(i) Requires factors: regularization and core (ii) Reduced performance with limited attribute space (iii) Computationally powerful (iv) Created as binary, even though variations are present
Decision trees	(i) No requirement for any sort of factor (ii) Simple to use and understand (iii) Handles absent records (iv) Handles records of diverse types and degrees (v) Handles nonlinear connexions (vi) Not sensitive to noise	(i) Susceptible to noise (ii) Are inclined to overfit (iii) Does not perform as well as others in big attribute spaces (iv) Big training test needed
Random forests	(i) Ability to establish variable significance (ii) Strong to data diminution (iii) Does not overfit (iv) Generates unbiased precision estimate (v) Higher precision than Decision Trees	(i) Decision guidelines undefined (black box) (ii) Computationally powerful (iii) Needs input factors

6. Conclusion

Today, these Artificial Intelligence-powered solutions are used to solve several industrial objectives, such as transport, banking, medicine, and agriculture. The use of this Artificial Intelligence technology has revolutionised the entire food process with enormous benefits. In addition to supporting producers in automatic farming and culture, Artificial Intelligence in agriculture also leads to precision farming with better crop yield and better quality while using limited resources. Moreover, remote sensing uses advanced methods, which assist ranchers to watch their crops without having to watch the farm physically. Today, several companies look forward to Artificial Intelligence-enabled agriculture development. Artificial Intelligence, combined with remote sensing, redefines the usual patterns of agriculture and thus reclassifies the conventional model of farming. In agriculture, the future of Artificial Intelligence is increasingly evolving with many sophisticated strategies through comprehensive transformation.

Conflicts of Interest

The authors declare that they have no conflicts of Interest.

Authors' Contributions

KE designed the review plan and wrote the text; SS contributed to writing of the text; YG, MC, and OBB contributed to figure and table preparations and writing of the text; ME and MAT contributed to reviewing of the text. All authors have read and approved the final manuscript.

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Research Article

Open Data Release and Privacy Concerns: Complexity in Mitigating Vulnerability with Controlled Perturbation

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The benefits of open data were realised worldwide since the past decades, and the efforts to move more data under the license of open data intensified. There was a steep rise of open data in government repositories. In our study, we point out that privacy is one of the consistent and leading barriers among others. Strong privacy laws restrict data owners from opening the data freely. In this paper, we attempted to study the applied solutions and to the best of our knowledge, we found that anonymity-preserving algorithms did a substantial job to protect privacy in the release of the structured microdata. Such anonymity-preserving algorithms argue and compete in objectivethat not only could the released anonymized data preserve privacy but also the anonymized data preserve the required level of quality. K-anonymity algorithm was the foundation of many of its successor algorithms of all privacy-preserving algorithms. l-diversity claims to add another dimension of privacy protection. Both these algorithms used together are known to provide a good balance between privacy and quality control of the dataset as a whole entity. In this research, we have used the K-anonymity algorithm and compared the results with the addon of l-diversity. We discussed the gap and reported the benefits and loss with various combinations of K and l values, taken in combination with released data quality from an analyst's perspective. We first used dummy fictitious data to explain the general expectations and then concluded the contrast in the findings with the real data from the food technology domain. The work contradicts the general assumptions with a specific set of evaluation parameters for data quality assessment. Additionally, it is intended to argue in favour of pushing for research contributions in the field of anonymity preservation and intensify the effort for major trends of research, considering its importance and potential to benefit people.

1. Introduction

Open data have proved its importance in the field of research, open governance, development versus analysis, and business initiatives. The release of public open data has emerged as a critical need for the overall development of humanity as one nation. In the COVID-19 pandemic, the world as one entity has recently accepted the relevance of open data and its potential to help curb the spread and come up with a range of solutions. Researchers worldwide used open COVID-19 data to help governments and organizations like WHO enforce measures and suggest policies. However, the threat to individuals to whom the data refers is shown up intensely because of the fear of identity recognition or reidentification of it. In fact, this has always been a rising concern and is being criticized since long back throughout the world, not just in the COVID-19 data but in all such released data where the identity disclosure attack is possible. Researchers have been trying to find a balance between the quality of open data released and the possibility of identity revelation from attacks.

However, in the current pandemic crises, all major policy decisions have their critical base on the open data shared worldwide, which is an important lesson learned that should not be allowed to be lost. At the same time, the inability to contain privacy threats has put nations and individuals in a weird defensive position. The concern of misuse is genuine in case the identity of individuals is released or regenerated from other existing sources of information which might be available. This has also resulted in regaining the focus towards anonymity concern [1–6].

Open data in a broader sense is defined with generosity in terms and conditions that do not limit people's right to see, use, investigate, and share data [7] although the work is relevant to all such releases which have limitations or controlled access to a small group of researchers.

Some of the important early initiatives which were mass encouragement towards public open data release are listed below for reference in yearwise ascending chronology [8–11].

The US [12], UK [13], and Canada [8, 14] government bodies pioneered and contributed to substantial commitments and efforts.

Open data for researchers with background from different business domains results in a complete critical analysis as well as exploring the hidden benefits from the data at each level. It leads to solutions for medical, technical business, and most important of all, the good and open governance [11, 15–19].

Food industry is the backbone of the health of the citizen in every country. Open data in the big picture is often talked about in health care. In the food technology domain, it generally marks its importance in terms of food quality assessment, regulatory measures, and genomics and to find the correlations between the food people consume with the overall health data of an area as well as consumer's preference analysis. There is enormous data that directly or indirectly comes from the ambit of food technology.

While the perception prevails that privacy concern is mostly about direct health care or defence data, the reality is that it is a barrier in the research and growth of almost every prominent industry. In the context of food technology also the open data struggles with privacy threats. The requirement to analyse consumer awareness and concerns is one such area that has privacy as a major concern and must be dealt with to protect the interest of consumer's personnel information.

Artificial intelligence plays a key role in recommendation systems, quality assessment, and deriving solutions that could improve the overall health of people in a particular locality and in government policy-making. Such AI powered systems need to include the best possible, privacy protection techniques and strengthen them transparently, to gain the trust of the people to whom the data actually refers.

2. Materials and Methods

2.1. Anonymity Algorithms. There has been a substantial effort by the researchers to mitigate the anonymity barrier of structured data release. Numerous anonymity-based algorithms have been proposed till date to preserve the anonymity concerns of the data. However, these algorithms work with suppression and generalization as the key techniques to prevent identity in the data [9, 20]. The sole purpose of these algorithms is to suggest the right balance between "data suppression and generalization" and "the anonymity preservation need" [21, 22]. These algorithms formulate and quantify the trade-off in their best possible ways. However, as they still depend on suppression and generalization as the key techniques, in fact, it means that the quality loss is bound to happen [21, 23].

2.2. Baseline Assumptions of K-Anonymity Algorithm. The K-anonymity algorithm establishes baseline assumptions which are followed by its successor algorithms in general. These assumptions are as follows and extracted from [24]:

(1) The value K emphasizes the minimal number of tuples of all combinations of quasi-identifiers to be exactly the same to make it impossible to be reidentified

(2) All explicit identifiers are assumed to be either suppressed or encrypted for the input data set. Hence, they are ignored completely

(3) Quasi-identifiers are attributes whose combination could be exploited for linking and reidentification in external data sets

Thus, keeping the distortion of the data at the bare minimum level with the least impact on the data distribution, similar parameters are assumed in enhancement to the K-anonymity. However, other statistical techniques like scrambling, swapping, or adding noise to the data values are not employed that can make the data unfit for investigation.

Baseline definition: the first assumption is derived from the definition of K-anonymity requirement; that is, in the released microdata, the combination of a tuple of a quasi-identifier must match at least k-1 tuples.

2.3. Vulnerabilities That Can Be Exploited in the Baseline Assumptions in the Context of Open Data. Although anonymity-based algorithm has been a success since the last decade, many platforms have been developed around them [25, 26]. However, we cannot deny the fact that the literature puts forth many reasoning that anonymity algorithms are not foolproof techniques and bypassing them is possible, and it also becomes much easier in today's data-age [27–29].

This section highlights the gaps that we found in the basic assumptions of the K-anonymity algorithm.

Consider the fictitious open data set of a hospital that is assumed to be released on a daily basis in Table 1.

Assume this release is done with $K = 2$. A generalization of level 1 is good enough on "Date of Birth" and "Zip" fields. Generalization of level 1 for "date Of Birth" field could be defined with the suppression of "dd" in "dd/mm/yyyy" and a generalization of level 1 could be defined as the suppression of the last two digits of the six-digit "Zip".

The table after applying K-anonymity algorithm for $K = 2$ will be as in Table 2.

Now, to illustrate vulnerability, we consider a voter's data as follows, say from an external database.

Table 1: Medical data released as anonymous data.

Date of birth (dd/mm/yyyy)	Zip	Sex	Medical symptoms
07/10/1982	233001	Male	Shortness of breath
18/01/1983	233001	Female	Obesity
23/10/1982	233022	Male	Shortness of breath
11/01/1983	233001	Female	Obesity
26/01/1983	233001	Female	Hypertension
09/09/1982	233052	Male	SLE
15/07/1982	233052	Male	SLE
03/09/1983	233005	Female	Hypertension
05/09/1983	233005	Female	Hypertension

Table 2: Medical data released as anonymous data with 2-anonymity applied.

Date of birth (dd/mm/yyyy)	Zip	Sex	Medical symptoms
XX/10/1982	2330 XX	Male	Shortness of breath
XX/01/1983	2330 XX	Female	Obesity
XX/10/1982	2330 XX	Male	Shortness of breath
XX/01/1983	2330 XX	Female	Obesity
XX/01/1983	2330 XX	Female	Hypertension
XX/09/1982	2330 5X	Male	SLE
XX/07/1982	2330 5X	Male	SLE
XX/09/1983	2330 XX	Female	Hypertension
XX/09/1983	2330 XX	Female	Hypertension

Name	Address	City	Zip	DOB	Sex	Party
Amit Kumar	E-31, Varanasi Road	Ghazipur	233001	07/10/1982	Male	Congress

The above record could be linked to two records in our medical data as depicted by the underlined rows in Table 3 provided someone attempting to figure out the medical symptom of "Amit Kumar" with external information that he visited the hospital that day for a consultation. The target for this reconstruction is to know the medical symptoms of the patient "Amit Kumar." Now as the data set releases satisfy K-anonymity for $K = 2$, it is guaranteed to be at least two such records which will be identical. However, the issue here is that the attacker might be interested in symptoms which are also identical in this case. Thus, the attacker could reidentify the data of the patient "Amit Kumar" in terms of medical symptoms, irrespective of the fact that the released data has been anonymized using K-anonymity.

Now, looking back at the mathematical foundation of the definition of K-anonymity requirement, see the following.

2.3.1. Definition (K-Anonymity). Let $Tab_X(X_1, X2, \ldots X_N)$ be a table and QI_{TabX} be the quasi-identifier associated with Tab_X. Tab_X is said to satisfy K-anonymity iff, for each quasi-identifier QI-QI_{TabX}, each sequence of values in Tab_X [QI] should at least occur K times in T[QI].

Table 3 satisfies the above definition successfully and is compatible with $K = 2$; still, it could be deidentified for a particular critical field.

Thus, a possible way to handle this situation is the modification of the mathematical foundation requirement of the anonymity algorithm, which is an addon restriction imposed by the l-diversity algorithm. We have rephrased key aspects of it as follows.

2.3.2. (K-Anonymity) Leading to l-Diversity. A well-known improvement to tackle the gap in the K-anonymity algorithm's assumption is provided by the l-diversity algorithm [30]. Below is the discussion on the gap and implications of the solution provided by the l-diversity algorithm.

Let $Tab_X(X_1, X2, \ldots, X_N)$ be a table and QI_{TabX} be the quasi-identifier associated with Tab_X. Tab_X is said to satisfy K-anonymity iff, for each quasi-identifier QI-QITab_X, each sequence of values in Tab_X [QI] should at least occur K times in T[QI]. And the critical field values should be such that they have at least *'l'* enumeration or diversity in the group with k-anonymity.

There, the critical fields are those fields which could have high chances of attack.

Thus, to apply the modified definition of K-anonymity requirement, we need a generalization of level 2 to "Date of birth" field. Generalization of level 2 for "Date of birth" field could be defined with the suppression of "dd" and "mm" in "dd/mm/yyyy" So, Table 4 satisfies the modified definition.

Therefore, as we can see that, with this modified definition, there are four matching records in Table 4 with values of medical symptoms = {"shortness of breath", "SLE"}, which makes the record protected from reidentification. That implies the anonymized data that we get after applying 2-anonymity, 2-diversity on our data has left the granularity of the information to decrease substantially in exchange for improved privacy. A closer analysis reveals that the "Zip" column itself is left with just one piece of information which is "2330XX", which, however, may not be necessarily true for all such released data. However, in most cases where the records are collected in close geography, such occurrences may not be surprising as the "Zips" in the context of India are distributed accordingly in a range-based order. Similarly, but on all records, there is a visible loss in the "months" part of the "Date of birth" field. By assuming an equal weightage of "days," "month," and "year," we just lost $1/3^{rd}$ of the information fields.

Thus, the result of the application of k-anonymity and l-diversity, as it obliviously appears to be simply in black and white. That is, applying l-diversity over k-anonymized data with the identification of at least one sensitive field results in the released data more robust to the attack and course granule, hence clearly leading to quality loss. It further means that the analysis ability is more restricted and we are

Table 3: Medical data released as anonymous, with venerable records.

Date of birth (dd/mm/yyyy)	Zip	Sex	Medical symptoms
XX/10/1982	2330 XX	Male	Shortness of breath
XX/01/1983	2330 XX	Female	Obesity
XX/10/1982	2330 XX	Male	Shortness of breath
XX/01/1983	2330 XX	Female	Obesity
XX/01/1983	2330 XX	Female	Hypertension
XX/09/1982	2330 XX	Male	SLE
XX/07/1982	2330 XX	Male	SLE
XX/09/1983	2330 XX	Female	Hypertension
XX/09/1983	2330 XX	Female	Hypertension

Table 4: Medical data released as anonymous with 2-anonymity and 2-diversity applied.

Date of birth (dd/mm/yyyy)	Zip	Sex	Medical symptoms
XX/XX/1982	2330 XX	Male	Shortness of breath
XX/XX/1983	2330 XX	Female	Obesity
XX/XX/1982	2330 XX	Male	Shortness of breath
XX/XX/1983	2330 XX	Female	Obesity
XX/XX/1983	2330 XX	Female	Hypertension
XX/XX/1982	2330 XX	Male	SLE
XX/XX/1982	2330 XX	Male	SLE
XX/XX/1983	2330 XX	Female	Hypertension
XX/XX/1983	2330 XX	Female	Hypertension

losing on data quality. With real data, we will try to validate this apparent and obvious conclusion in the below section to understand the contradiction with the chosen standard set of evaluation parameters.

3. Application of Two Anonymity Algorithms to Nonfictitious Data from the Domain of Food Technology

We have used "ARX data Anonymization Tool" which is distributed under the "Apache License, Version 2.0". It is an open-source tool with a wide range of data anonymization techniques implemented for professional use.

We have used an attribute subset of the approved food establishments for November 2018 of the UK government [31]. The attribute selection is done with the purpose of analysing locationwise activities of the plant to provide skills training for job opportunities of local man power. However, no rows are reduced from the actual data. The fields are as shown in the tabular structure below. For better understanding, we have shown the top five rows in Table 5. The total number of records in this data set is 6455, which is sufficiently large data for practical analysis and evaluation purpose. We also want to address the privacy concern in recognition of the business owners, so the "App No" and the "Trading Name" fields are treated as identifiers and hence suppressed during the application of the anonymity algorithms.

For illustration purpose, Table 6 shows the 2-anonymized data sample of the records in the data set.

The quality evaluation is done with the following standard parameters:

(i) Gen. intensity
(ii) Granularity
(iii) N.-U. entropy
(iv) Discernibility
(v) Record-level squared error
(vi) Attribute-level squared error

The following strategy is used to anonymize data using the ARX tool with the following values of *k* and *l* as defined in k-anonymity and *l*-diversity algorithms and the observed results in the "Result and Discussion" which is the next section:

(i) 2-anonymity
(ii) 4-anonymity
(iii) 6-anonymity
(iv) 2-anonymity, 2-diversity
(v) 4-anonymity, 2-diversity
(vi) 4-anonymity, 3-diversity
(vii) 4-anonymity, 4-diversity
(viii) 6-anonymity, 2-diversity
(ix) 6-anonymity, 3-diversity
(x) 6-anonymity, 4-diversity
(xi) 6-anonymity, 5-diversity
(xii) 6-anonymity, 6-diversity

The value of *l* as in *l*-diversity is limited to be not greater than the value of *k* as in *k*-anonymity to let diversity not dominate the uniqueness of record in order to control data quality.

4. Results and Discussion

Table 7 presents the quality parameters evaluation in each column with ascending value of *k* as in the k-anonymization algorithm. We have not introduced the diversity factor in this part of the experiment to observe the behavior of the

Table 5: Attributes-subset of approved food establishments for November 2018 by the UK government, top five rows.

App. no.	Trading name	Town	Postcode	Country	All activities
AR 001	Monteum Ltd.	Shoreham	BN43 6RN	England	Dispatch centre (LBM), processing plant (fish)
AR 003	Southover Foods Ltd.	Southwick	BN42 4EN	England	Processing plant (meat)
AR 008	Higgidy Ltd.	Shoreham	BN43 6PD	England	Processing plant (meat)
AR 009	Little Tums	Shoreham-By-Sea	BN43 6NZ	England	Processing plant (meat)
AR 010	Malpass Markets	Shoreham	BN43 6RN	England	Mincemeat establishment, meat preparation establishment
...	...	...	...	...	...

Table 6: Record-samples of the food establishment data set after applying 2-anonymity.

App. number	Trading name	Town	Postcode	Country	All activities	Processing plant	Geographic local authority
*	*	Shetland	NA	Scotland	Auction Hall (fish)	NA	Shetland Islands
*	*	Shetland	NA	Scotland	Auction Hall (fish)	NA	Shetland Islands
*	*	Aberdeen	NA	Scotland	Cold store	NA	Aberdeen City
*	*	Aberdeen	NA	Scotland	Cold store	NA	Aberdeen City
...	...	...	...	...	...	...	...

Table 7: Results of quality parameters of the food establishment data set after applying 2-anonymity, 4-anonymity, and 6-anonymity.

Model	2-anonymity	4-anonymity	6-anonymity
Gen. intensity	15.42343	6.69984	6.69984
Granularity	16.12703	7.25019	7.25019
N.-U. entropy	13.06863	4.91985	4.91985
Discernibility	16.11756	7.2399	7.2399
Record-level squared error	14.99271	6.26457	6.26457
Attribute-level squared error	18.14774	8.74009	8.74009

k-anonymity algorithm independently as a sole factor. There are two interpretations that could be made with the following data:

(1) With the increase of the value of k, the data quality dips and so does the record-level and attribute-level squared error. However, both error metrics are reducing decisively due to strong generalization.

(2) There is a certain point where the data quality metrics stop descending and stabilize with the increase in the k-values.

Table 8 is an interesting abnormal behavior which is observed when both k and l values are too low and equal. The quality metrics results not only suggest a jump in data quality but also strangely high values of the record-level and attribute-level squared errors. In particular, the record-level squared error shoots close to 100%.

This is a false indicator as the quality improvement is driven by small but equal diversity leading to very high error quantification. It is presented just to conclude that it could be preferred to ignore such values while choosing the combination of k and l values.

Table 9 shows the data quality improved from 2-anonymity, 2-diversity which we chose to discard as an anonymization strategy in our case, with a higher value of $k = 4$. Thus, we observe steady and gradually. This gradual descending in quality is driven by l-value. The error metrics

Table 8: Results of quality parameters of the food establishment data set after applying 2-anonymity, 2-diversity.

Model	2-anonymity, 2-diversity
Gen. intensity	21.73349
Granularity	22.83501
N.-U. entropy	19.25503
Discernibility	22.81606
Record-level squared error	99.96683
Attribute-level squared error	21.27768

still remain high due to the high level of generalization even with a small value of k.

Results in Table 10 are in line with the results in Table 9. The small and steady data quality fall continues with the increase in l-value, but the increase of k-value from 4 to 6 has a comparatively larger impact on data quality decline.

Figure 1 presents a single-frame observation to relate the above discussion. As it is observed from the stacked plot of all anonymization strategies, put together that the k-value is the more dominant factor in reducing the anonymized data quality compared to l-value. That is, in other words, generalization deteriorates the data quality more compared to diversity. Hence, diversity is good for privacy control and less evil for data quality. With this data sample, we reached stability in quality with a very less value of k both at $k = 4$ and $k = 6$ leading to unchanged values of quality metrics. The crux is that we reached an early and sharp data quality

Table 9: Results of quality parameters of the food establishment data-set after applying 4-anonymity, 2-diversity; 4-anonymity, 3-diversity and 4-anonymity, 4-diversity.

Model	4-anonymity, 2-diversity	4-anonymity, 3-diversity	4-anonymity, 4-diversity
Gen. intensity	14.21253	13.13973	11.91992
Granularity	15.52285	14.4694	13.27653
N.-U. entropy	11.54522	10.60076	9.35309
Discernibility	15.49844	14.44529	13.24972
Record-level squared error	99.90506	99.89778	99.87712
Attribute-level squared error	13.2648	12.21016	10.94421

Table 10: Results of quality parameters of the food establishment data-set after applying 6-anonymity, 2-diversity; 6-anonymity, 3-diversity; 6-anonymity, 4-diversity; 6-anonymity, 5-diversity; 6-anonymity, 6-diversity.

Model	6-anonymity, 2-diversity	6-anonymity, 3-diversity	6-anonymity, 4-diversity (%)	6-anonymity, 5-diversity	6-anonymity, 6-diversity
Gen. intensity	11.87162	11.34489	10.94	10.34937	8.76683
Granularity	13.27653	12.74981	12.36	11.71185	10.22463
N.-U. entropy	9.14062	8.70266	8.34	7.76506	6.37721
Discernibility	13.24748	12.72163	12.33	11.68218	10.19514
Record-level squared error	99.84593	99.84606	99.84	99.82315	99.78056
Attribute-level squared error	10.64448	10.16837	9.79	9.2042	7.41376

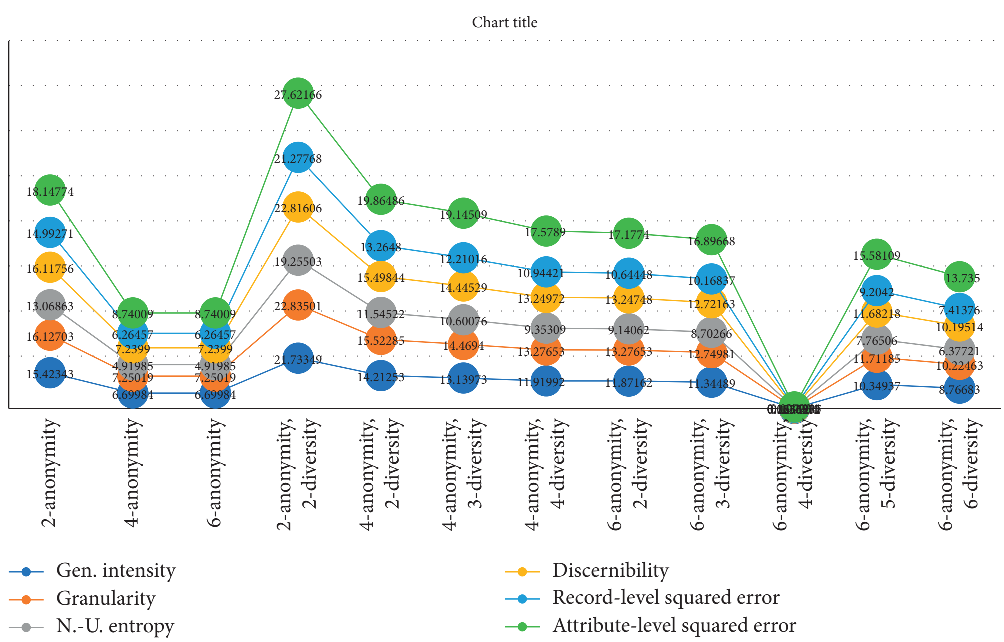

Figure 1: Single-frame result as stacked line plot of quality parameters.

decline before stability. That means a large amount of data loses its analytical opportunity with less anonymization. Quality loss appears overweighing to the privacy gains in our experiment. And if we try to control the quality loss with less generalization, that is, low value of k, then introducing diversity would result in abruptly high data quality loss.

5. Conclusions

This paper discusses the open data movement and its benefits in brief. It illustrates the need for opening public data that could give transparency to the citizen towards governance for the purpose of research, transparency, and fair opportunity to involve in governance to all its citizens.

It also identifies "anonymity" as one of the key barriers of open data. Although privacy for opening the data has been a concern for more than two decades, when there was very limited data compared to the data, the world holds today. There have been attempts to solve this barrier technically which had been a success at a major level. The K-anonymity algorithm and its successor algorithms borrow the basic assumption set established by the K-anonymity algorithm.

However, many critics focus on the aspect that the data which are claimed to be privacy-preserving after applying such algorithms, in fact, do not guarantee protection. Such critical reviews break open the loopholes to prove broken promises. On one side, this paper aims to provide a review with a simple example that could make readers understand that, on one side, algorithms compete to achieve better anonymity, on the other side they tend to compromise on data granularity. This makes it less usable for the analysts. It is just that the vulnerability has been fixed to break the usability of the released data. This makes more sense when imagining how important the granularity of the data was at the initial phase of the COVID-19 pandemic. As the leaders worldwide are worried about quick mitigation and fire-fighting in any such future unfateful circumstances, they must also be worried about doing more to open data to the maximum possible level and invest in finding solutions to the opposing force that is "privacy concern" while opening the data to the world. We studied a controlled strategy of k-value and l-value combinations and their impact on data quality. When the anonymity algorithms are needed to be applied on data with varying sizes, nature, and release purpose, the objective of choosing the right fit algorithm becomes an extremely difficult job with a range of algorithms and their individual variations. Moreover, the level of privacy control is a separate dimension, which applied with quality metrics parameters over a wide range of solutions would result in large 3-dimensional matrics or more that would be required to be translated to a one-dimensional result set to pick one suitable algorithm as a solution for that category of data set. Such a complex problem needs aggressive employment of machine learning and artificial intelligence, because of the complexity in finding the final most optimal solution for data anonymization.

Data Availability

Monthwise data for approved food establishments in the United Kingdom are available at https://data.food.gov.uk/catalog with many other food-related data sets. This data set is provided by "Food Standard Agency," UK. The link to the particular data we used is also provided in the reference section [31].

Conflicts of Interest

The authors declare that they have no conflicts of interest.

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Review Article

Application of Blockchain and Internet of Things in Healthcare and Medical Sector: Applications, Challenges, and Future Perspectives

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Internet of Things (IoT) is one of the recent innovations in Information Technology, which intends to interconnect the physical and digital worlds. It introduces a vision of smartness by enabling communication between objects and humans through the Internet. IoT has diverse applications in almost all sectors like Smart Health, Smart Transportation, and Smart Cities, etc. In healthcare applications, IoT eases communication between doctors and patients as the latter can be diagnosed remotely in emergency scenarios through body sensor networks and wearable sensors. However, using IoT in healthcare systems can lead to violation of the privacy of patients. Thus, security should be taken into consideration. Blockchain is one of the trending research topics nowadays and can be applied to the majority of IoT scenarios. Few major reasons for using the Blockchain in healthcare systems are its prominent features, i.e., Decentralization, Immutability, Security and Privacy, and Transparency. This paper's main objective was to enhance the functionality of healthcare systems using emerging and innovative computer technologies like IoT and Blockchain. So, initially, a brief introduction to the basic concepts of IoT and Blockchain is provided. After this, the applicability of IoT and Blockchain in the medical sector is explored in three major areas—drug traceability, remote patient-monitoring, and medical record management. At last, the challenges of deploying IoT and Blockchain in healthcare systems are discussed.

1. Introduction

The Healthcare sector is an essential concern for all the developing as well as developed countries because this sector is directly concerned with the social welfare and lives of people. Research and development in the Healthcare sector should be an ongoing process, as it will help to improve the quality of living by fighting various health issues and diseases. With the advancement and recent developments in technology, the improvement in the Healthcare sector can be seen easily. The existing capabilities of the Healthcare and Medical Sector can be further improved by the introduction of the latest and innovative computer technologies in the Healthcare sector. These advanced computer technologies can assist doctors and medical practitioners in the early diagnosis of various diseases. The accuracy of detecting diseases in the early stages can also be improved considerably using these advanced computer technologies.

Various emerging and revolutionary computer technologies are already being used in other sectors with miraculous results. These technologies include the IoT, Blockchain, Machine Learning, Data Mining, Natural Language Processing (NLP), Image Processing, Cloud Computing, and many more.

IoT means connecting everything with the Internet. Everything here includes vehicles, home appliances, and other items embedded with electronics, and software, sensors, actuators, and connectivity that enable these things to connect, collect, and exchange data. Kevin Ashton is considered the father of IoT [1], which involves Internet connectivity beyond standard devices, such as desktops, laptops, smartphones, and tablets, to any range of traditionally dumb or noninternet-enabled physical devices and everyday objects. The leading technologies used in the Internet of things are sensors, cloud, wireless technology, and security.

The basic life cycle of IoT consists of four parts: (1) to gather the data through devices with the help of sensors; (2) the gathered data are stored in the cloud for the analysis; (3) the analyzed data are then sent back to the device; and (4) the device acts accordingly [2]. IoT is applicable in many domains, thereby making our life comfortable. The main applications of IoT are Smart Homes, Smart City, Agriculture, Smart Retail, Driverless Cars, and Healthcare. Security remains a crucial aspect of every technology and plays a vital role in the smooth functioning of IoT networks. Some ongoing projects for enhancing IoT security include methods for providing data confidentiality and authentication, access control within the IoT network, privacy and trust among users and things, and the enforcement of security and privacy policies. The security problem in IoT arises due to careless program designing that leads to vulnerabilities, which is an important reason for network security issues.

In IoT architecture, proper initialization of IoT is done at the physical level so that any unauthorized receiver cannot access the system. IoT architecture consists of five layers: the Perception layer, Network layer, Middleware Layer, Application layer, and Business layer [3]. Each layer has its objective and issues. The main security goals crucial in IoT are Confidentiality, Integrity, and Availability (CIA). Based on vulnerabilities, there are four categories of attacks in IoT: "Physical attack," "Software attack," Network attack," and "Encryption attack."

1.1. Physical Attack

(i) Node tempering: the attacker, by altering the compromised node, obtains the encryption key
(ii) Physical damage: this damage results in a Denial of Service (DOS) attack as the attacker physically harms IoT system components
(iii) Malicious code injection: by this attack, the attacker can get full control of the IoT system
(iv) RF Interference on RFID: the attacker sends noise signals over radio frequency signals, and these signals are used for RFID communication
(v) Social Engineering: the attacker obtains sensitive information from the user of an IoT system to achieve his goals
(vi) Sleep Deprivation Attack: shutting down nodes is the main aim of the attacker
(vii) Node Jamming in WSNs: this attack can disturb wireless communication by using a jammer

1.2. Software Attack

(i) Phishing attacks: this is a widespread attack. The attacker uses fake websites to obtain the private information of the user.
(ii) Virus, Worms, Trojan horse, Spyware, and Aware: arrival of these entities can damage the system by spreading the malicious code through e-mail attachments and from the Internet. The worm can replicate itself without the involvement of humans.
(iii) Malicious scripts: this attack is used to access the system.
(iv) DOS: the adversary's main aim is to block the users.

1.3. Network Attack

(i) Traffic analysis attacks: to obtain the network information, the attacker intercepts and examines messages.
(ii) RFID spoofing: an attacker spoofs RFID signals, changes the message, and gives wrong information to the system. The system accepts the wrong information, which is altered by the attacker.
(iii) Sinkhole attack: it is a very common type of attack. The primary purpose of this attack is to send fake information about the route to the neighboring nodes.
(iv) Sybil attack: the attacker inserts the malicious node inside the network, and that one node in the network takes the identity of multiple nodes.

1.4. Encryption Attack. The main aim of this attack is to obtain the private key, which is used by two devices while communicating with each other.

(i) Side–channel: in this attack, when the message is transferred from user to server or vice versa, then the attacker reveals some additional information
(ii) Cryptanalysis attacks: in this attack, attacker decodes the message from the nonreadable format to a readable format without knowing the key
(iii) Man in the middle attack: the attacker keeps on observing the communication between the nodes to steal sensitive information

There exist various security proposals in the literature. However, security is still the topic of concern in IoT networks because of existing challenges like centralization, single point of failure, etc. So, a new and emerging technology known as the Blockchain can be used along with IoT for enhancing the security of IoT. The strength of Blockchain technology can be introduced in IoT to enhance its security and make it a more secure network by removing the challenges and issues of centralization in the existing security techniques and introducing the concept of decentralization using the Blockchain.

Blockchain is a point-to-point distributed network in which no third party is required for the transaction and communication [4]. All the transactions are independent and isolated from other transactions. The technology behind the popular and revolutionary concept of cryptocurrency is the Blockchain. Cryptocurrency is believed to be highly secure and unhackable. This very same concept of Blockchain can be used in other networks for security enhancement. In the Blockchain, a public distributed ledger system is opened to everyone. Blockchain is a list of records that store data publicly and in a chronological order. Block is a container that holds transaction details. Each block contains data, the hash of the previous block, and the hash of the concerned block. It has two parts: Header and Transaction details. The header contains information regarding the block. "Timestamp" keeps a record of the time at which the block was created. "Difficulty level" decides how hard it will be to mine a block. "Merkle Root" represents the fingerprints of all the transactions stored in the block, and "NONCE" is the solution to the mathematical puzzle in the Proof-of-work algorithm.

1.4.1. Motivation. In this article, two emerging technologies, IoT and Blockchain, are integrated, and their possibility and application in the Healthcare sector have been explored. IoT technology in healthcare can be used for applications like remotely monitoring patients' health. The patients who require regular attention can be monitored by the doctors remotely using the IoT Sensors deployed on their bodies and surroundings. Similarly, Blockchain technology in healthcare can handle the issue of drug traceability, medical record management, etc. However, IoT is prone to security attacks like attacks on integrity, privacy, confidentiality, and availability. So, using IoT alone in the Healthcare sector for applications like remote patient monitoring can lead to patient data leakage, data manipulation during its transmission, etc., which, in the worst case, can claim the life of the patient. So, Blockchain technology can be brought into use along with the IoT in healthcare to enhance the capabilities of the Healthcare sector and ensure the security and privacy of the patients' records.

However, the introduction of new and emerging technology in any sector can give rise to some issues as well as challenges. So, it is crucial to identify those issues and challenges, especially in the Healthcare sector, where people's lives are directly associated. In this article, the possibility of deploying Blockchain and IoT in the Healthcare sector is explored, and various new healthcare applications that are possible using these innovative technologies are presented. Various challenges and issues in the deployment of these two emerging technologies in the Healthcare sector are then presented in detail.

1.4.2. Main Contributions of This Article

(1) The possibility and benefits of using Blockchain and IoT technologies for enhancing the Healthcare and Medical sector have been explored

(2) Various areas of application in healthcare where IoT and Blockchain can be applied are presented

(3) Various challenges in the use of IoT and Blockchain technologies in the Healthcare sector have been explored and presented

2. Review Technique and Strategy

This section elaborates on the motivating factors as well as the review strategy used for conducting this study on Blockchain and IoT in the Healthcare sector.

2.1. Review Plan. Stages that were involved in this literature review on the use of Blockchain and IoT technologies in the Healthcare and Medical sector includes building a review strategy, downloading research articles from different online sources, analyzing the quality of articles, interpreting and enumerating observed results of the review, recording the results of the review, and finally presenting various research challenges and future research directions.

2.2. Research Questionnaire. The initial step involved in conducting this survey was to frame the different research questionnaires and the motivating factors, and searching for different online research databases for relevant articles. Table 1 gives the set of research questions along with the motivation required to plan and conduct the survey on the use of Blockchain and IoT in the Medical sector.

2.3. Source of Information. For conducting this review, various possible relevant resources have been consulted for finding the required and related research resources required for this study. Various online sources like Springer (http://www.springer.com), Google Science Direct (http://www.sciencedirect.com), IEEE Explore (http://www.ieeexplore.ieee.org), Scholar (scholar.google.com), and online tutorials, such as Edureka, National Program on Technology Enhanced Learning (NPTEL) for understanding the concepts, etc., have been consulted in this study.

2.4. Search Keywords. This exhaustive search on understanding the possibility of using Blockchain and IoT technologies in the Medical and Healthcare sector includes qualitative and quantitative research papers from 2008 to 2020. However, it mainly includes the papers after the year 2016. The research on IoT was started long back, but the concept of Blockchain was introduced from 2009 onward. Research papers from journals, conferences, symposiums, college thesis, workshops, etc., were included in this review.

Initially, a total of 79 papers on IoT, Blockchain having their applicability in the Healthcare sector were retrieved using the keywords mentioned in Table 2, which after applying certain inclusion and exclusion criteria as filters based on titles, abstracts, full-texts, publisher value, etc.,

Table 1: Research questionnaire and motivation.

Questions	Motivation
1. What is IoT? 2. What is the current status of research in IoT? 3. What are the challenges and research opportunities in IoT? 4. What are the different applications of IoT?	IoT is an emerging network that allows communication among different objects that surround us. These objects include homes, refrigerators, air-conditioners, traffic lights, etc. IoT is being used in different sectors, including agriculture, healthcare, transportation, smart homes, etc. It is crucial to find the challenges of IoT. Security, privacy risk, and trust are some of the challenges of IoT that require consideration.
1. What is a Blockchain? 2. Can the Blockchain be used use with bitcoin only? 3. What are the areas where Blockchain can be used? 4. How can the Blockchain be integrated with IoT? 5. What are the different challenges in the integration of Blockchain with IoT?	Blockchain is another emerging technology that has various applications and domains for improved security, privacy, and trust, considering the peculiar feature that makes it robust and unhackable. The privacy and security issues of the IoT network can be handled using the Blockchain. However, the possibility of integration and deployment of Blockchain in IoT networks is required to be explored.
1. How Blockchain and IoT can be used in the medical sector? 2. What are the different application areas of healthcare where Blockchain and IoT can be used? 3. What are the challenges in the deployment of IoT and Blockchain in the healthcare sector?	The combination of IoT and Blockchain can be introduced in the Healthcare and Medical sector for improving the current issues in the Healthcare sector like drug traceability issues. This integration of two powerful technologies can enhance the capability as well as the quality of the current Healthcare sector.

Table 2: Search strings.

S. no.	Keyword	Synonyms	Content-type
1	IoT applications	Application of IoT	Journals, conference, symposium, online tutorial, university thesis
2	IoT, Blockchain in healthcare	IoT and Blockchain in Medical sector	
3	Blockchain for patient health	Blockchain for remote monitoring of patients	
4	Blockchain and IoT for Medical supply chain tracking	IoT and Blockchain in medicine tracking	
5	Blockchain applications	Applications of the Blockchain	
6	Features of the Blockchain	Blockchain features	
7	Challenges in Blockchain, IoT	Blockchain ongoing challenges	
8	Blockchain IoT healthcare	Blockchain healthcare framework	

Table 3: Parameters considered for shortlisting and exclusion of articles.

S. no.	Considered parameters	Shortlisting for inclusion criteria	Exclusion criteria
1	Period	Articles published on the use of the Blockchain, IoT for healthcare and medical-related applications between the year 2016 and 2020	Articles published before the year 2016 were excluded
2	Type of articles	Articles with implementation results	Review and survey articles, theoretical papers without implementation results
3	Language	Articles are written in the English language	Articles in languages other than English
4	Title, abstract, citations, and journal/conference value and indexing	Articles with their titles and abstracts that match the use of Blockchain and IoT in the Healthcare domain were selected Number of citations, value of journal/conference where the article is published is also considered	Firstly, based on the titles, articles were selected and excluded Then, abstracts of articles shortlisted based on titles were checked for inclusion and exclusion

got reduced to 22 quality papers. Various search strings like "Blockchain and IoT in Healthcare" have been used for searching papers. Table 3 shows the various parameters that were considered for shortlisting and exclusion of irrelevant articles. The exclusion criteria for shortlisting of quality and relevant articles are shown in Figure 1.

3. Blockchain Technology and Related Concepts

Blockchain is an emerging technology used in numerous different networks to ensure security and reliability in those networks. Blockchain technology is also given preference in various transaction management systems, and it is replacing the current existing transaction management system.

The issues with the current banking system are as follows:

(i) High transactional fees

(ii) Double spending

(iii) Banks have become synonymous with cries

With its decentralization feature, Blockchain has solved the issue associated with centralized banks and is the primary technology behind bitcoin. Blockchain is a public distributed database that holds the encrypted ledger [5]. There is a central coordination system in a centralized architecture, and every node is connected to that central coordination system. All information between the nodes will be shared, passed, and approved through this central coordination system. Under this platform, all of these individual dependent nodes will get disconnected if the central coordination platform fails. Therefore, the switch from the centralized system toward a decentralized system is the need of the hour. In the decentralized system, there will be more than one coordinator. In a decentralized system, each node is treated as a coordinator, i.e., there is no centralized authority. Each node is connected to other nodes, and this system is not dependent on any particular coordinator.

Blockchain consists of a chain of blocks, and each block is a collection of all recent transactions that have taken place and are verified. The detailed and general structure of the Blockchain is shown in Figure 2, where the sequence of blocks is shown, and each block is connected cryptographically. All these transaction details are stored on each block, and a consolidated hash code block-wise is computed and stored into the block. Once the transaction is verified, this block becomes the permanent part of the Blockchain, and the chain keeps growing.

Blockchain is a leading technology, only second to the popular bitcoin. The working of bitcoins using the Blockchain can help to understand Blockchain technology better. Bitcoin is the first decentralized digital currency that was introduced in 2009 by Santoshi Nakamoto [6]. Bitcoin uses various cryptography as well as mathematical concepts that ensure that the creation, as well as the management of bitcoin, is restricted and secured. The algorithms and the cryptography technologies are used to keep on updating regularly. The ledger system that keeps track of how much bitcoin gets transacted is electronic and highly secure, and this ledger is known as the Blockchain.

In the Blockchain, there are various key concepts. One of them is the Previous Hash Code. Every block has to specify the hash code associated with it, which is used as an identifying factor for that block. This hash is created with a very complex hashing algorithm. The hash details of every transaction that has happened have to be completed to be a part of that block. The transaction details of a block are contained in the header in a hex value known as Merkle Root.

Another important concept associated with the Blockchain is the value or proof of work of that block. This is the mathematical solution that is attached to the block to ensure that this is the valid block.

Let us take an example to understand how the Blockchain works. Suppose *A* wants to send money to *B*. The transaction is represented as a block, and the block is broadcasted to every node in the network. After that, there is a group of sufficient miners that have the authority to approve the transaction. After getting approval from miners who solve the proof of concept, the transaction is added to the Blockchain, and finally, *B* gets the money.

A block is the crucial part of a Blockchain that records all of the recent transactions and, once completed, goes into the Blockchain as a permanent database. Blockchain is built from three technologies. First is that the Blockchain uses private key cryptography to secure identities and hash function to make the Blockchain immutable. It uses a P2P, a network, which ensures complete consistency with the Blockchain [7, 8].

Suppose a person tries to make a slight change concerning the transaction or a block that is part of a Blockchain, then the changed block cannot be added or reflected in the Blockchain because most of the people in the network have the original Blockchain, and this changed block cannot be accepted.

The program in which the Blockchain is created has a lot of protocols and security features. Solidity is the most preferred language for writing the Blockchain program. In any Blockchain, every transaction that gets verified and validated in the creation of a new block is logged along with the information about time, date, participants, and the amount that gets transmitted across. Each user who is part of the Blockchain holds the complete Blockchain in itself. The miner verifies each transaction involved in the Blockchain after solving a complex mathematical puzzle, and once it is solved, the transaction is verified and maintained in the ledger.

3.1. Types of Blockchain

3.1. Types of Blockchain. Blockchain is of three types Public, Private, and Consortium. A public Blockchain is similar to bitcoin in which anyone in the world can be a part of. Anyone who is part of the Blockchain and is a miner can read as well as write data into this Blockchain.

Private Blockchain is, however, something that is quite restricted. Usually, one central person has the exclusive right to both verify the transaction as well as add a new block to the Blockchain.

A consortium Blockchain is something between public and private Blockchain. Instead of one person, there are a group of people who verify and add transactions.

In conclusion, Blockchain uses mathematics to create a secure, distributed ledger that enables transactions without a third party.

3.2. Decentralized Applications. Decentralized applications are the central part of the Blockchain. It promises to deal with all the problems that come with the centralized

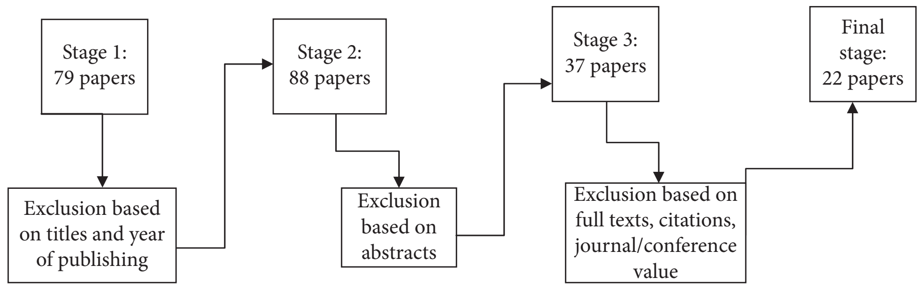

Figure 1: Exclusion criteria for shortlisting of quality and relevant articles.

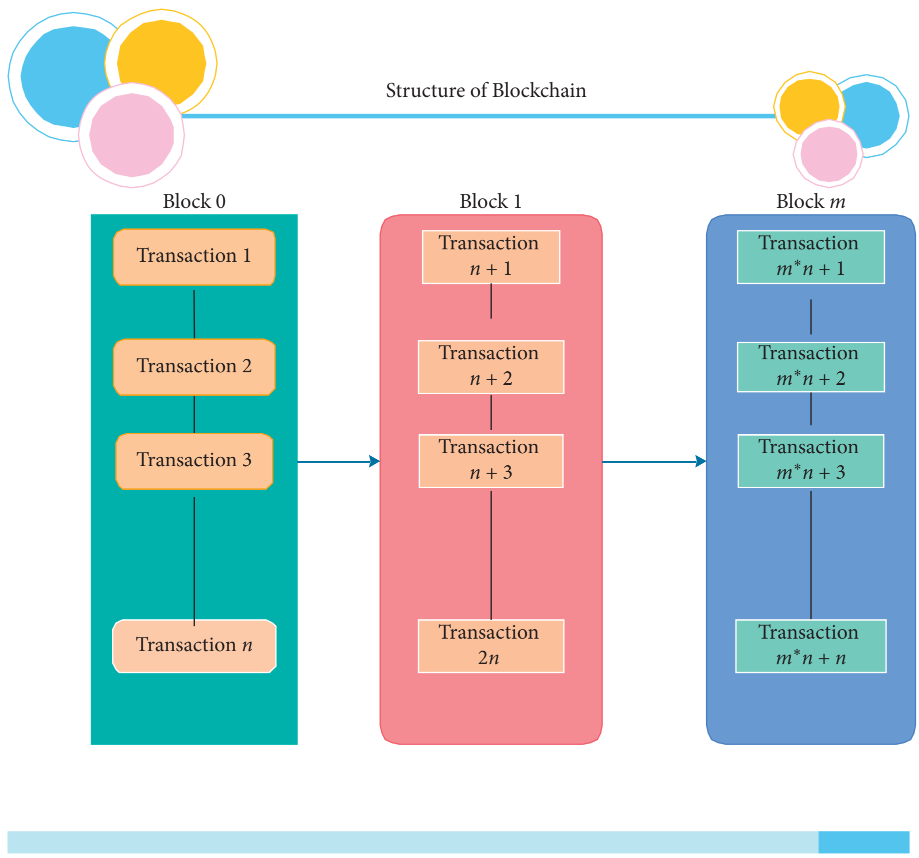

Figure 2: Structure of the Blockchain.

system. The decentralized architecture works as the user invokes the smart contracts. Ethereum is a decentralized platform that runs smart contracts. It was proposed in 2013 and released in 2015. The value token of the Ethereum Blockchain is called Ether, listed under ETH on cryptocurrency exchanges. The smart contract contains all the rules that are pertinent for the service that is provided to contain state information, which contains data for smart contracts [9]. Smart contract is an automated computerized protocol used for digitally facilitating, verifying, or enforcing a legal contract's negotiation or performance by avoiding intermediates and directly validating the contract over a decentralized platform. Nick Szabo, a computer scientist and cryptographer introduced the term in 1996. He claimed that smart contracts could be realized with the help of a public ledger.

The advantages of decentralized applications are the following

(1) *Autonomy*. You are the one agreeing; there is no need for a broker or a lawyer

(2) *Trust*. Entire documents and data in blockchain-based decentralized applications are encrypted using advanced encryption technologies, and all the data are distributed on a decentralized network that is being run by a shared Ledger. If the data are corrupted or altered, then it will be rejected by the members of the Ledger

(3) *Backup*. On the Blockchain, documents are duplicated and stored in many locations

(4) *Accuracy*. Smart contracts are faster and cheaper and avoid errors that arise from tedious manual work

3.3. Some Applications Supported by the Blockchain. A Blockchain wallet is similar to a bank account. It allows us to receive bitcoins, store them, and then send them to others. There are many Blockchain features, for example, security, instantaneous transaction, currency conversion, and accessibility. There are various types of Blockchain wallets:

3.3.1. Based on the Location of Private Key. This is where exactly our private key is being stored. The hot wallet is the Blockchain program where the private key is ultimately stored on a cloud-based server. Cold wallet: All the transaction details are going to get the first hash, and only the transaction hash gets prorogated throughout the network. With regard to the security feature, a cold wallet is more secure than a hot wallet.

3.3.2. Based on Device and Clients. In this category, there are desktop wallets, online wallets, mobile wallets, and physical wallets.

Apart from its use in cryptocurrency, Blockchain technology has its applicability in other domains like banking, payments and transfers, healthcare, law enforcement, voting, IoT, online music, real estate, and many more.

3.4. Peculiar Features of Blockchain. Blockchain has various peculiar and prominent features like decentralization, transparency, open source, autonomy, immutability, and anonymity that make it a unique and powerful technology for ensuring security, as well as reliability, in an IoT-inspired network for healthcare [10]. Many terms are required while studying the concept of Blockchain. Some of the key features supported by Blockchain technology are shown in Figure 3 and are as follows.

3.4.1. Public Distributed Ledger. The data within a Blockchain are accessible to everyone. With this, as long as you are part of the network, you could access the entire history of transactions that have taken place since the Blockchain was created. Any additions to Blockchain have to be approved by the user. A majority of the members within the network have to approve any additions to the Blockchain. This is the “public” part of the ledger [11]. Hyperledger can be thought of as a software that everyone can use to create one’s personalized Blockchain service. On the Hyperledger network, only parties directly affiliated with the deal are updated on the ledger and notified.

3.4.2. Hashing Encryption. In the Blockchain, security is ensured by hashing encryption. Blockchain utilizes the hash function to perform cryptography. The transaction details are contained in the header in a hexadecimal value known as Merkle Root. To ensure security, Blockchain also includes a digital signature. Users are provided their own private and public keys.

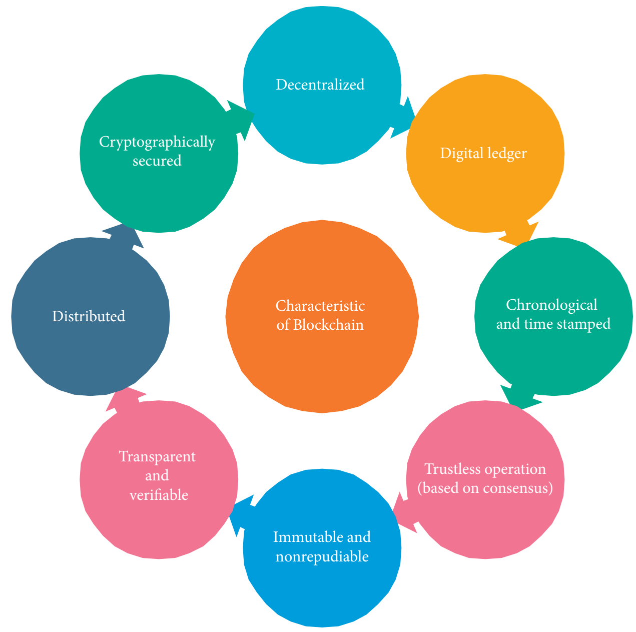

Figure 3: Characteristics of Blockchain.

3.4.3. Mining. Miners collect all transactions that people send to each other over the network, and only valid transactions are relayed to other nodes. Each miner takes several collected transactions and put them in a newly formed block.

3.4.4. Decentralization. One of the significant features of Blockchain is decentralization. Decentralization means data are not dependent or stored in the central part. Instead of this, data are stored in each block of the Blockchain. Transactions are not communicated to various nodes by the central authority. Every block acts as the verified digital ledger. Many research areas apply Blockchain to eliminate the concept of centralization and switch to the concept of decentralization, e.g., cloud, IoT, edge computing, and big data [12].

3.4.5. Immutable. Immutable means something which cannot be changed. It is an important feature of Blockchain in which blocks cannot be altered. Immutability is achieved by the concept of proof of work. Proof of work is achieved by mining and the work of miners is to change the nonce. A nonce is a varied value to create a unique Hash address of the block, which is less than the target hash value. The probability of proof of work calculation is very low. Many trials have to be done to acquire valid proof of work. There is only one possibility of changing the block when the attacker takes control of more than 51% of the node simultaneously [13].

3.4.6. Consensus Protocol. The word autonomy is based on Consensus Protocol. Consensus means agreement ensures the latest block has been added to the chain correctly [13]. For ledger consistency and user security purpose, consensus algorithms have been implemented [14]. There are many consensus mechanisms given in Table 4 [15].

3.4.7. Anonymity. Anonymity here means namelessness, and it also comes under the features of the Blockchain. The anonymity set is divided into two parts: First is the sender anonymity set, and the other is the receiver anonymity set. This example works when one user sends the data to other users; it does not reveal the user's real identity. Instead of this, it communicates with the other users by using Blockchain address. By this process, one user never knows the other user's real identity [13, 14].

3.4.8. Enhanced Security. Everything is public in the Blockchain, so the privacy solution is done by hashing encryption. Blockchain can bring increased security and have certain benefits as compared to conventional systems [15, 16]. To understand hashing encryption, we need to know about the contents of the block. A block is a container that controls the transaction detail. The block has two parts: Header and Transaction details. The transaction details of a block are contained in the header in the hexagonal value known as Merkle Root. Blockchain utilizes the hash function to perform cryptography [17].

3.4.9. Persistency. In the Blockchain, there is a major feature called mining. Mining is the concept of validating the transaction, with the invalid transactions being emitted quickly [14]. Miner is the first person who finds the nonce value that falls within the target requirement.

3.4.10. Traceability. Traceability is the distribution chain to find out the origin of the product and follow the sequence. Traceability is an arrangement of blocks in the Blockchain in which each block is connected with adjacent two blocks by means of the hash key [9].

3.4.11. Currency Properties. Blockchain is a point-to-point network. No third party is required for the transaction. All the transactions are independent of the third party. In cryptocurrency Blockchain, the transaction is used, and its circulation is fixed. All the activities of Blockchain 2.0 and 3.0 applications have the property of currency [9].

Table 4: Various consensus mechanisms.

Consensus mechanism	Examples
Proof-of-work	Bitcoin, Litecoin
Proof-of-stake	NXT
Delegated proof-of-stake	BitShares
Proof-of-activity (PoW/PoS-hybrid)	PeerCoin
Proof-of-burn	Counterparty
Proof-of-validation	Tendermint
Stellar consensus protocol	Stellar
Ripple protocol consensus algorithm	Ripple

4. IoT and Related Concepts

4.1. Architecture of IoT. The basic architecture of IoT is the same as the TCP/IP architecture. There are many factors in IoT architecture that need to be focused like Scalability, Interoperability, Reliability, and QoS. The basic architecture of IoT consists of many layers [18], and the general architecture of IoT is described in Figure 4.

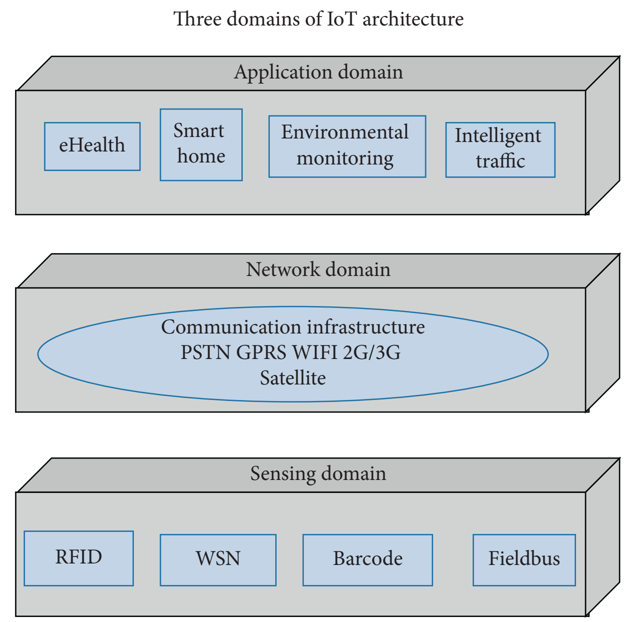

Figure 4: Domains of IoT architecture.

Perception layer: first is the perception layer, also known as the device layer. In this layer, sensors sense and gather information about the environment.

Transport layer: it transfers the sensor's data between different layers through networks such as wireless, 3G, LAN, and RFID.

Processing layer: this layer stores, analyses, and processes huge amounts of data. Modules and concepts like databases, cloud computing, and big data are used in this layer.

Application layer: this layer is responsible for delivering application-specific services to the user.

Business layer: it manages the whole IoT system, including applications, business and profit models, and user privacy. This layer also helps in future actions and business strategies.

Apart from the abovementioned general architecture of IoT, many other architectures are built-in literature by various researchers to fulfill different requirements of the application. The first NDN architecture was proposed by Jacobson et al. [19, 20]. NDN manages many functionalities of IoT at the network layer, e.g., data aggregation, security, etc. IoT is the collection of heterogeneous applications. There are many requirements of IoT applications that can be fulfilled by NDN, e.g., due to low power operation, the nodes of NDN make data available to a different consumer. NDN helps in improving the energy efficiency of the network. There are many features of NDN that help to fulfill the main requirements of IoT. Energy efficiency in-network caching is also available. Similarly, for reliability, in-network caching and multipath routing feature are used. Data integrity is also a feature of NDN for security purposes in IoT.

In another work [21], the authors have discussed a general architecture of IoT in which the requirement and importance of Quality of Service (QoS) in IoT are focused. This paper discusses the various tasks in IoT, i.e., inquiry task, control task, and monitoring tasks. The monitoring tasks have different service requirements. The main requirements of QoS are service awareness. The architecture of QoS is divided into three layers: Application layer, Network layer, and Perception layer. One factor, which needs to be focused on, is Interoperability. Interoperability is the interconnection between devices. This concept covers the major applications of IoT, and this concept of interconnectivity is required at each of these layers: data model, messages, and network [22]. This is the modified version of architecture because, in existing architecture, there is a concept of end-to-end message delivery, but this architecture achieves the intelligent solution by integrating the web technologies with the existing architecture. The next architecture in the list is Software-Defined Networking Architecture, which is used for a more secure network. SDN-based architecture for IoT is Scalable with multiple SDN domains [23]. It also does the work of interoperability that was also focused on in the previous architecture.

4.2. Communication Technologies in IoT. Aggregation of heterogeneous networks and devices is done in IoT. To make centralization decisions concerning IoT, reliable communication between the gateway and things is essential [24]. The IoT gateway works as a communication between the sensing domain and the network domain. Zigbee, Bluetooth, WiFi are the technologies that are used to connect Smart Things to IoT gateway [25].

IoT gateways are required in two situations: when the connection occurs between different sensing domains like Zigbee, Bluetooth, and the connection between sensing and network domain, e.g., Zigbee and 3G. The commonly used communication standards and technologies used in IoT Communication are given below:

4.2.1. NFC. It is short-distance wireless communication technology. When two NFC-enabled devices are very close to each other, roughly around 4 cm, they can communicate using radio waves. NFC modes of operation are card emulation mode, peer-to-peer mode, and reader/writer mode. Some useful applications of NFC are file sharing, mobile payment, information sharing using smart posters, and business cards. Apart from that, it can be used for home automation, library systems, and healthcare [26]. At home, automatic switching off of lights, closing of doors, and turning off of air-conditioners can be performed using NFC.

4.2.2. RFID. Radiofrequency identification is a technology that works on radio frequency or radio waves. This technology is used to identify objects automatically. Here, the objects can be anything. Objects can be books in the library or any item you are purchasing from the shopping mall, or it can be your car, etc. They can be used not only to track objects but also to track humans, birds, and animals. It is very similar to the technology that is used in a barcode. The difference is that the barcode is a line of sight technology but RFID is not a line of sight technology. RFID system contains two components, namely, RFID reader and RFID tag. There are two RFID tags, namely, Active and Passive tags. Use cases of RFID are people tracking, school bus tracking, parking selection, healthcare, supply chain management, and manufacturing.

4.2.3. V2V. V2V is a wireless protocol similar to WIFI called dedicated short-range communications. When DSRC is combined with GPS, low-cost technology is formed. The V2V communication system provides a 360-degree view of similarly equipped vehicles within the communication range. Transmitted messages common to all vehicles include current GPS position, vehicle speed acceleration, headings, and vehicle control information such as the transmission state brake status and steering wheel angle, and the vehicle's path history and the path prediction. V2V does not include current technologies such as navigation, Internet access, assistant services, rearview cameras, and other advanced technologies. V2V provides crucial information when the driver needs it. V2V provides the driver with 360-degree awareness. This secure system keeps personal information anonymous and does not track your vehicle. The driver sees warning to prevent potential hazards through the display. It gives warnings like stop crash alert, intersection movement assist, do not pass application, blind-spot warning.

4.2.4. Zigbee Technology. Zigbee is a small packet device with low data rates and low power consumption [27]. It comes under the category of Home network. Zigbee is the technological standard created for control and sensor network. It is based on IEEE 802.15.4 created by the Zigbee alliance. The layers architecture of Zigbee is the application layer, stack, and silicon. The stack part consists of three layers, namely, API, security, and network. And in silicon, there are two layers, namely, MAC and a physical layer. The application layer is for the customer, the stack is under the Zigbee alliance, and silicon comes under IEEE 802.15.4.

4.2.5. WiFi. Wifi gives a facility to the computer and other devices to communicate over wireless signals. Wifi stands for Wireless Fidelity. IEEE gives the standard of Wifi, but it is a trademark of Wifi Alliance. It is commonly used for wireless local area networks. Mobile phone, cities, homes, everything is communicating through the wireless signal.

4.2.6. Bluetooth. Bluetooth was a very good communication medium in the early days. It was the open standard for the development of the personal area network. This technology has features such as low power consumption, low cost, and a short-range. A Bluetooth-enabled device can exchange information with other Bluetooth-enabled devices over a radio. Bluetooth helps in creating a small network of devices that is close to one another.

A comparison of Zigbee, Bluetooth, RFID, and NFC concerning a different domain is done in Table 5.

4.3. Benefits/Applications of IoT. IoT devices have the responsibility to ensure that the messages and data sent by the devices have reached their destination. IoT applications enable interactions between the device and device or human and device [28]. Domain description of the key application areas of IoT summaries are provided in Table 6.

IoT equips a multitude of domains and millions of devices with connectivity every day. IoT technology is used in day-to-day life in which various everyday things are connected to the Internet like online shopping, wearable technology, smartphones, vehicles, home lighting home, appliances, etc.

IoT in healthcare: Healthcare sector faces various issues and challenges that can be handled using the IoT [29]. Also, the healthcare capabilities can be enhanced multifold using the IoT. In the Healthcare sector, there is a lack of real-time data, a lack of smart card devices, inaccurate standard analytics, and other enhancements like remote monitoring of patients that can be made possible using IoT. IoT could be the answer to all these problems.

Smart cities, agriculture, industrial automation, and disaster management are a few domains where IoT can be used. Some applications and domains where IoT can be brought into use are shown in Figure 5.

4.4. Challenges in IoT. While going through many papers, it was found that IoT has some prominent challenges that require consideration. The main issues in IoT are security issues, privacy concerns, interoperability issues, IoT standards issues, legal issues, regulatory rights issues, emerging economy issues, developmental issues [5].

4.4.1. Security and Privacy. The security problem for things is created by vulnerabilities produced by a careless program design. Vulnerabilities mean inherent weakness in designing, configuring, implementing, and managing a network or system that renders it susceptible to a threat [30]. There are many security-related challenges in IoT: design practices and no security laws for developing IoT devices, i.e., set of similar appliance that has the same characteristics. Also, not much sufficient information is given to maintain or upgrade the IoT system. Since many devices are in the loop, one device is being attacked by the rest of the devices. As discussed earlier, security design requires three things, namely Confidentiality, Integrity, and Availability, known as CIA [31].

In the case of the Privacy Concern issue, there are no fixed rules against data users, and the data collected by IoT devices are not protected. User data could be vulnerable to theft. You could be tracked/monitored by anyone, as you are connected 24*7 on the Internet. To take advantage of IoT, the less developed regions have to implement the policy requirement and technical skill requirements.

4.4.2. Architecture. One more main challenge is to choose the architecture of IoT. The selection of architecture is very difficult, as different architectures are needed according to the need [32]. Therefore, there is a chance of developing new architecture or modifying the existing one.

4.4.3. Legal and Regulatory Rights Issues. Just like privacy, there are many legal and regulatory questions surrounding the IoT. QoS is achieved through the wireless network, but it needs attention in cloud computing.

4.4.4. Data Extraction and Management. Data extraction from the complex environment cannot be extracted continuously. For example, if there is a hilly area where there is no Internet, then how to extract data. For example, drugs are to be maintained at a particular temperature. There is no surety that drugs are maintained at the same temperature. If the 1-degree temperature is missed, the drugs could be spoiled. There is no surety of getting the exact data.

4.4.5. Power Requirements. A maximum of 90% of IoT devices is powered by a battery. How long is the battery going to live? Does it have recharging ability? Are there are some green methods of charging from sources like the solar wind? Therefore, power requirements are also the main challenge of IoT.

4.4.6. Complexity Involved. In IoT, a study of many techniques is important. It is not easy; many experts and teamwork among them are necessary. Many technologies need to come together, so one cannot say I have built the IoT product. For IoT products, a team is needed and experts are required to work on particular technologies.

4.4.7. Storage Cloud and Heterogeneous Devices. Storing is also the main challenge. Where to store data, either on the local server or on the cloud? Do we use the cloud for particular storage? If yes, then purchase or store the data in free cloud service. All these decisions are very important. A massive amount of data is generated through IoT sensors and devices; how to manage these data and how to deal with the heterogeneous nature of data are the main challenges [28]. In IoT, there exist many different applications, and it is very difficult to handle the heterogeneous applications in one architecture.

Table 5: Comparison of different communications.

Parameters/technology	Zigbee	Bluetooth	RFID	NFC
IEEE standards	IEEE 802.15.4	IEEE 802.15.1	IEEE 802.15	ISO/IEC 14443 A&B, JIS X63194
Frequency band	2.4 GHz	2.4GHZ	125khz, 13.56 Mhz, 902–968 MHZ	125khz, 13.56 Mhz, 860 MHZ
Network	WPAN	WPAN	Proximity	P2P network
Topology	Star Mesh cluster	Star Mesh cluster	P2P network	P2P network
Data rate	250 Kbps	1 Mbps	4 Mbps	106212 or 424 kbps

Table 6: Application areas of IoT.

Security	Security system, surveillance system, device security, data preserving
Payment method	Payment gateways, POS (point of sale)
Health	Remote diagnosis, remote monitoring
Metering service	Water, electricity, cab, energy
Remote access	Various sensors
Manufacturing services	M2M, automation, etc.

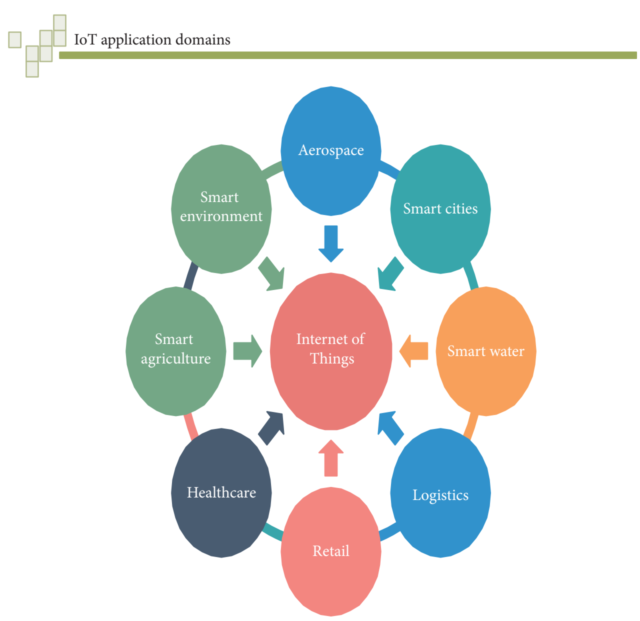

Figure 5: IoT applications.

4.5. Challenges in the Use of Blockchain with IoT. The integration of Blockchain with IoT is very beneficial as the capabilities and application domain of IoT can be increased considerably. However, the integration of different technologies can introduce some challenges in the network considering the different limitations of each network technology [33, 34]. Blockchain is an emerging technology and has various constraints, like massive storage requirements. IoT has its own constraints, like a massive amount of data are involved in this network; all of these constraints can impact technology integration.

Some of the challenges in the use of Blockchain technology along with IoT networks are scalability, storage, lack of skills, legal issues, and smart contracts [35].

Scalability and storage are already a challenge in Blockchain but in the context of IoT, they become a much greater challenge [36]. IoT network contains a large number of nodes and Blockchain scales poorly when there numerous nodes in the network.

IoT devices have low storage capacity but the distributed ledger contains memory as time passes, and with the increased number of nodes, it increases the memory.

Lack of skills is also a main challenge when Blockchain is integrated with IoT, as IoT is used almost in every field. Blockchain technology is new, and very few people know about this technology [9]. Many people think that Blockchain is only used in Bitcoin.

Blockchain is a new territory and connects with different countries without any legal or compliance precedents to follow, which is a serious issue for manufacturers and service providers. This challenge is also a major issue for integrating Blockchain with IoT.

5. Integration of Blockchain and IoT Technologies in Healthcare

The number of patients across the country is increasing day by day and with the increase in the number of patients, it has become difficult to provide full medical care. In the last few years, the quality of medical care has improved with the help of IoT and wearable devices [37]. Remote patient monitoring is the main modality to address healthcare issues. Wearable devices used for collecting and transferring data to hospitals, and IoT devices play an important role in remote patient monitoring [38]. The main aims of these devices are to provide important information such as breathing patterns of a person, blood glucose level, and blood pressure to health providers [39].

Healthcare devices that are used for data collection data can be categorized into four parts: (a) Stationary Medical Devices: these devices are used for specific physical locations, (b) Medical Embedded Devices: these devices are placed inside the human body, (c) Medical Wearable Devices: these devices prescribed by doctors, and (d) Wearable Health Monitoring Devices: these devices are worn on the body. The main motive of RPM is to secure the data that are targeted by hackers. To secure the data, Blockchain technology is used. Blockchain helps to secure the data from many cyberattacks by using the concept of decentralization. Blockchain also authenticates the data with smart contracts.

Healthcare is an IoT system application that requires unique additional requirements like interoperability and data transfer for securing the patient's information. The term interoperability means the process of sharing data with other sources. The concept of centralization includes the limitation to achieve interoperability. IoT is based on centralization, where the data gets stored in the cloud where the data is not secured. Blockchain integrated with IoT can overcome the security issues faced by healthcare applications [40]. Many experiments are already done in Blockchain regarding healthcare [41].

6. Various Applications of Blockchain and IoT in Healthcare

Blockchain helps to maintain and share the patient's medical record with hospitals and health providers. There are many applications of healthcare:

6.1. Drug Traceability. Drug traceability is usually done in a centralized manner in which some conditions like privacy, authentication of data, and flexibility of the system are not achieved [42]. To overcome issues of drug traceability, many decentralized models have been implemented. For authenticity and privacy of traceability data, a Blockchain-based system is proposed [43] called Drugledger. Drugledger integrates Blockchain with the drug supply chain for drug traceability. Drugledger maintains two flows of drugs: The physical flow of drugs in combination with the supply chain and the information that flow goes to the drug ledger network in the form of a drug chain network. This system changes the previous traditional architecture by separating service providers into three different parts: CSP, certificate service provider; QSP, query service provider; ASP, anti-attack service provider. **Limitations**: the drug traceability scenario, which is shown in this paper, is very simple, but the real-life scenario is more complex. **Future work:** to compare the proposed framework of drug traceability with some existing frameworks and find out which framework is more secure in case of DoS attacks.

IoT when integrated with blockchain makes the system more secure and reliable. In the field of healthcare, many frameworks were proposed regarding the traceability of drugs or patient monitoring systems. Authors in [44] introduce a framework to avoid drug fraud by tracking each drug in the supply chain. The main aim is to reduce counterfeit drugs using Blockchain. The main two technologies that are used to improve the visibility and traceability of drugs are Blockchain and RFID. **Limitations:** Implementation is not done.

For the transparent flow of drugs, the Gcoin Blockchain model (G stands for global governance) is proposed in [45], and this model also changed the drug supply chain system from regulating to surveillance and inspection of drugs, which means the government model combines with DAO (Decentralized autonomous organization). Blockchain is used to build an atmosphere where two parties can trust each other. There are many ways to implement Blockchain but, in this paper, Consortium proof of work is used to implement Gcoin Blockchain. Gcoin Blockchain tracks every drug in the same way as the Blockchain tracks in bitcoin. It builds trust between buyers and sellers. The main aim of Gcoin is to improve the efficiency of data, which is exchanged. **Future work:** analysis of regulatory impact and system simulation test is to be done in the future.

In India every year, many lives are at risk due to the consumption of fake medicines. A framework is proposed [46] to detect fake medicines in the system of the supply chain. This proposed framework is based on Hyperledger fabric architecture, where one PC is serving as the client, and five computers are used for ordering service. This system is purely based on Blockchain technology. The supply chain of medicines from drug manufacturing to wholesale local drug distributors and distributors to hospitals/clinics and retail shops is managed using Blockchain, which helps to track the fake medicines. This system was tested in various scenarios like stolen drugs, audits of drugs in-retailer or distributor, fake drug distribution. The proposed system compares their performance with another existing system in many parameters like resistance against single point of failure, counterfeit medicine detection, diverted medicine detection, medicine shortage detection, ease of operations, involvement of stakeholders, transparency, privacy, security, and immutability. Limitations: the proposed system does not have the ability to find and eliminate out the consumption of unauthorized medicines. Future work: this particular framework can be implemented in many domains like courier consignment tracking and election management.

In the case of drugs, a very common threat is that the drug which is manufactured is not received by the pharmacy and is replaced by a counterfeit in the supply chain method. The supply chain method does not have the ability to trace the culprit who is responsible for the drug replacement because information is deleted in each step. India manufactured most of the counterfeits in 2006, and it is estimated that around 35% of fake drugs were sold all over the world. To overcome these problems, authors [47] introduced a framework using the Blockchain. Blockchain is more transparent because even if a single-user makes a change or does any transaction, it will reflect to all the users. Blockchain is the concept of decentralization and there is no need for the central authority to verify the transaction. Implementation: the authors analyses the result on two platforms: Ethereum and Hyperledger. Blockchain using Ethereum: in Ethereum Blockchain, every operation requires fees. Miner is given money to execute the transaction and to maintain the Ethereum network. There is no need of Know your Customer (KYC) in this process, which results in a blind spot which tells us about the person who is operating the account. It takes a long time. Ethereum can handle 100 transactions per second (TPS), which is not feasible. Blockchain using Hyperledger: this process does not require fees, which makes it feasible for the manufacturer to make the transaction, and is available for KYC. Certificate authority in this process manages the identity. Hyperledger is the private Blockchain and takes care of throughout and transaction per second.

6.2. Patient Monitoring/Electronic Health Record (ERH). According to the International Organisation of Standardization, electronic health records store the patient data in a digital format, and the data are exchanged securely and only accessible by authorized authority [48, 49]. It contains private information regarding a person's health issues, and its main objective is to maintain and provide efficient service to the patient. There are many Blockchain-based EHR systems:

(a) Medrec**:** it is a decentralized record management model. It is a Blockchain model used for authentication, confidentiality, and data sharing [50, 51]. This model uses all the features of Blockchain-like smart contracts and the concept of decentralized data.

(b) Data sharing through Gem health network: Sharing of data is a big problem in the traditional systems, so to overcome such issues and to provide a secure environment while transferring user's data, Gem health network is used [51, 52]. This network is used to remove the concept of centralization of data and include the concept of decentralization. Gem health network framework is fully based on the concept of decentralization, and the main feature of Gem network is that all the record under this network is transparent, and any alteration with the record will be reflected to all the users of this network.

(c) Healthbank: it is a platform that stores and securely manages health information. This is a new start-up that also provides some incentives to patients for their contribution [52].

(d) OmniPHR: public health record (PHR) provides a facility for patients to access their data. This model is developed to update the records and to differentiate between Electronic health records and PHR [40].

A real-time Blockchain-based patient monitoring system is proposed in [53] using smart contracts. This system secures the data and uses the patient's data in a more relevant form. Smart contracts are used for security purposes and to evaluate the information collected by patient's IoT healthcare devices. Private Blockchain is used for fast transactions. Limitations: time is the main aspect, but there is some delay while verifying each block in the Blockchain. Maintaining the security of each node is also a main challenge. Future work: implementation of the proposed system is done on Ethereum Blockchain. In the future, Hyperledger and other Blockchain platforms will be used on this proposed framework.

Blockchain, when integrated with IoT, always gives a more secure network. There are some Blockchain features due to which IoT network becomes more secure, such as the concept of distributed ledger, public-key cryptography, and the consensus algorithms. Transparency of data is achieved by the decentralization concept of the Blockchain. For a remote patient monitoring system, a framework is proposed in [54] using Blockchain technology. Before proposing the framework, this paper discussed the positive and security benefits of the Blockchain when integrated with IoT and also discussed the practical obstacles that are generated when the Blockchain integrates with IoT. The framework works to try to remove the obstacles and gives a more secure network. Future work: to implement this model for testing the performance.

To provide health services, there are many facilities such as hospitals, pharmacies. Dangerous diseases usually claim human lives. To provide the resources to the patient on time, it is compulsory to continuously monitor the patient`s health. For continuously monitoring patient health, there are many frameworks in which patients are required to wear IoT-based monitoring devices. These devices collect their medical data and store it in the cloud. Healthcare now has become very popular, but the main issue is to provide security to the patient's data. There are many cases registered against healthcare data leakage when storing the data in the cloud [55]. Many countries are very particular about the privacy and security of patient's data. In Europe, Health Insurance Portability and Accountability Act (HIPAA) is used to protect the patient data and guarantee transferring of medical data in a secure manner [56]. To monitor the vital signs of the patient, a framework is proposed in [51] to secure the medical data. The purpose of the framework is based on the healthcare devices that read the vital signs of patients and share that information to the authorized doctors and hospitals in a secure Blockchain network. Hyper Caliper, developed by the Linux Foundation, is used to evaluate the performance in terms of transaction per second, transaction latency, and resources that are used. Future work: interoperability is also an important aspect of the healthcare system. Future work will involve checking the performance of the interoperability of the system with different IoT frameworks.

There are many applications where IoT is used. Healthcare monitoring is also an application of IoT where devices are interconnected to each other, and the data sharing and collection should be done in a secure environment. Fabric Hyperledger, a Blockchain framework, is proposed in [57] to secure the healthcare application. Using the Blockchain technology, the proposed framework provides distributed and secured access to all the data collected by the devices. Limitations: it does not cover all the security aspects of IoT. It does not consider the attacks in IoT. Future work: to create a more secure health monitoring framework, the proposed framework has to implement more functionality based on attacks.

IoT helps to monitor the patient's health using different sensors. The information collected from the human body via sensors are then processed and analyzed. The data that are transferred from the sensor to the cloud have threats of privacy, tempering of data, and data manipulation. To solve these issues, the author in [58] has proposed an architecture to combat all these threats by combining Blockchain and IoT. Each block in the Blockchain consists of the patient's private data. This paper simply applies the Blockchain for secure and transparent data transfer between the hospital and patient. Limitation: this paper describes the basic work of how Blockchain makes the system more efficient but does not provide the exact example for securing the health records.

6.3. Managing Medical Records and Other Data. The traditional method of monitoring medical records needs to be changed. Now, the use of the Internet in the healthcare system makes it more efficient. Internet smart objects make it easy to store and process the data in any format like audio, images, or text. To efficiently use the medical resources and to enhance the patient's health quality, IoT is used in healthcare. Using the healthcare application with IoT addresses many drawbacks like security, privacy issues, and other issues like doctors recommending unnecessary medicines and tests to patients with a profit motive. To prevent these healthcare issues, a framework of IoT for healthcare using the Blockchain is proposed in [59]. In this framework, a hash of each data is generated to prevent the data from alteration. This framework assures the patient that any malpractices regarding the medical records cannot be done. It focuses on the transparency of records and the security of data. Limitation: transaction time is a very important aspect of healthcare applications. This framework does not focus on transaction time. Future work: this framework ensures that no illegal practices or malpractices are done but does not experiment with the cost required during the communication. So, in the future, an experiment on the cost required in communication will be performed.

To secure data that is transferred from IoT devices in the healthcare system is proposed in [60] using Blockchain technology. Blockchain technology helps to identify users who are associated with the transaction. Blockchain technology is used in healthcare for the privacy and security of data and to provide accurate and proper data of patients to doctors. **Limitations:** implementation is not done in this paper. **Future work**: To implement the framework and to check whether the framework is secure or not.

IoT is important in every field where the applications require fast results, collection of data, storage of data, and efficient usage of that data. Now, IoT is also updated by healthcare applications. Various IoT-based wearable devices are used in healthcare applications. But, these devices are not secure, as there is a chance of data leakage or data misuse. To reduce this risk, IoT technology is connected with Blockchain technology to provide a more secure network. To reduce the various attacks, such as DOS, modification of data, mining attacks, and storage attacks in healthcare, a system is proposed [61]. A hybrid structure was implemented to ensure the security and privacy of data. This system is called hybrid because Blockchain is combined with the private key, public key, and advanced cryptographic functions. This system consists of five parts: (1) overlap network: all the nodes in the network should be verified and certified; (2) cloud storage: data of the users are grouped in the form of blocks, and the system does not need any third party for storage; (3) healthcare providers: these companies provide service when they receive an alert of health issues; (4) smart contract: these are the conditions that are set for the particular framework; and (5) healthcare wearable IoT devices: these are the devices that continuously monitor the patient and collect all its information. Limitations: Blockchain technology is resource-constrained so it is not suitable for many IoT devices. There are some more issues in Blockchain-technology-related costs; it requires high bandwidth and more computational power. Future work: To explore more security issues and to provide the implementation of this conceptual framework.

All the nodes in healthcare when integrated results in the healthcare IoT system. It ensures an efficient delivery process of patient data. But, it does not give security to a trustworthy network. A trustworthy framework of IoT healthcare is proposed in [62] where smart contracts authenticate and validate the other nodes. The framework is named as decentralized interoperability trust model for healthcare IoT. This framework is divided into layers: In the first layer, all the data are collected and changes are made in the data sensor, and actuators are used in this layer. The second layer is used to transmit the data through the gateway and network. The third layer is the health edge layer, and this layer is in between the technology and application levels. The last layer is the application layer. Future work: artificial intelligence and deep learning technology are used in training states to authenticate and identify the pattern to enhance the framework.

Table 7 lists out various proposed frameworks in the literature using Blockchain and IoT technologies for strengthening the capabilities of the Healthcare sector.

7. Challenges of Using Blockchain in Healthcare-Derived Industrial IoT

The main challenges in the use of Blockchain Technology, along with IoT in the Healthcare and Medical Sector, are as follows:

7.1. Interoperability. Healthcare interoperability means exchanging information with each other in the Blockchain network. It is the main challenge due to the large and varied providers and due to its large open nature [63]. There can be different players like hospitals, insurance companies, physicians, private doctors, etc. In the Healthcare sector, ensuring proper interoperability among them can be a challenge.

7.2. Security. As the concept of decentralization is more secure, there are also some disadvantages associated with it. As in decentralized Blockchain, the data are distributed in a public ledger, which can cause privacy leakage. Blockchain provides an atmosphere where people know or trust each other and can securely share data. However, in some scenarios, it can fail—for example, if 51% of the consensus nodes become malicious. Many patients can be uncomfortable in sharing their personal medical information due to security reasons [63].

Table 7: Various proposed frameworks for healthcare based on Blockchain and IoT

Reference	Application of Blockchain	Type of Blockchain used	Advantages	Limitations	Simulation parameters used	Future work
[61]	Managing medical records and other data	Private and public Blockchain	To reduce the various attacks, such as DOS, modification of data, mining attack and storage attack, in the healthcare system	Blockchain technology is resource-constrained, so it is not suitable for many IoT devices. There are some more issues in Blockchain technology-related costs; it requires high bandwidth and more computational power	—	To explore more security issues, and implementation is done to provide some real work
[40]	Patient Monitoring/ Electronic Health Record (ERH)		Blockchain integrated with IoT overcomes the security issues that are faced by healthcare applications	Many issues are not considered yet such as mining incentives, and there are some specific Blockchain attacks, which halt the entire system	—	
[43]	Drug traceability		To overcome the issue of privacy and authentication of data, increase the flexibility of the system	The drug traceability scenario, which is shown in this paper, is complex	Traceability data authenticity and privacy	To make the system more prone to DoS attacks while comparing with the traditional system
[44]	Drug traceability	Public Blockchain	The integration of IoT with Blockchain makes the drug supply chain system more secure and reliable and avoids any drug fraud by tracking each drug in the supply chain	Implementation is not done	Privacy, limiting theft and diversion	
[45]	Drug traceability	—	Improves the efficiency of data exchange	—	Information infrastructure breakdown, information delays, and transparency of drug supply chain	Analysis of the regulatory impact and system simulation test is done in the future
[46]	Drug traceability	—	Detects fake medicines in of supply chain	The consumption of unauthorized and Ingenium medicines not to be eliminated in this system	Resistance against single point of failure, counterfeit medicine detection, diverted medicine detection, medicine shortage detection, ease of operations, involvement of stakeholders, transparency, privacy, security, immutability	This particular framework can be implemented in many domains like courier consignment tracking, election management

Table 7: Continued.

Reference	Application of Blockchain	Type of Blockchain used	Advantages	Limitations	Simulation parameters used	Future work
[53]	Patient Monitoring/ Electronic Health Record (ERH)	Private Blockchain	The system secures the data and uses the patient's data in a more relevant form	Time is the main aspect, but there is some delay while verifying each block in the Blockchain. Maintaining the security of each node is also the main challenge	Speed, privacy, transparency, traceability, availability, confidentiality	Implementation is done using the Ethereum Blockchain; to explore more implementation parts use hyperledger
[59]	Managing medical records and other data	Public	It ensures the patient that any illegal activity cannot be done. It focuses on the transparency of records and the security of data	Transaction time is a very important aspect of healthcare applications. This framework does not focus on transaction time	Number of nodes in a CRN, grid facet, transmission range data size or users request, simulation time	This framework experiments with the illegal activities done on IoT devices but does not experiment with the cost required during the communication. So, in the future experiment on the cost required in communication is to be done
[62]	Managing medical records and other data	Public	The interoperability trust model for healthcare IoT	Identification of patterns of symptoms, which are obtained from wearable devices cannot be done	Scalability, data integrity, mutual authentication, trustworthiness, privacy	Artificial intelligence and deep learning technology are used in training states to authenticate and identify the pattern to enhance the framework
[60]	Managing medical records and other data	Variation of the Blockchain is used in personal health care and external Blockchain for record management	An uplifting of society with accurate and efficient healthcare	Implementation is not done	—	To implement the framework and to check whether the framework is secure or not
[54]	Patient Monitoring/ Electronic Health Record (ERH)	Cannot prefer any particular Blockchain	Try to remove the obstacles and give a more secure network	Implementation is not done	—	To test the performance of the framework, implementation is necessary in the future
[57]	Managing medical records and other data	Medical devices Blockchain consultation Blockchain	Paper works on the security issues	It cannot cover all the security aspects of IoT. It cannot consider the attacks in IoT	—	To make a more secure framework of health monitoring, this proposed framework has to implement more functionality based on attacks
[51]	Patient Monitoring/ Electronic Health Record (ERH)	Public Blockchain	Healthcare devices that read the vital signs of patients and share that information with the authorized doctors and hospitals in a secure Blockchain network	Lack of communication between the server and devices	Energy consumption and efficiency	Interoperability is also an essential aspect of the healthcare system to check the interoperability performance of the system with different IoT frameworks

7.3. Scalability and Storage Requirement Handling. It is not practically possible to maintain the data of every individual. The medical record is usually in the form of documents, images, and lab reports. Digital storage of the medical records of numerous patients will require colossal storage capacity. The medical transactions of every individual stored in a distributed manner with the same record stored in more than one location will require huge storage capacity and could affect the healthcare system [64].

7.4. Lack of Standardization. Blockchain is a trending technology and is adopted in many countries. In domains and networks where the concept of security, trust, and trackability is involved, the Blockchain is used. Proper standardization of protocols, technologies, etc., is very important. Aspects like what data, size, and format can be sent to the Blockchain, and what data can be stored in the Blockchain should be clearly defined [65, 66].

7.5. Hesitation among Hospitals and Related Entities in Sharing Information. Many hospitals can be reluctant to share their patient-related and other medical records, such as in for-profit situations, as they will want to charge different fees from different customers. Similarly, hospitals and insurance companies can be reluctant to share their data, as it can be competitively advantageous for the hospitals to keep the fees-related data with themselves. It is essential to build trust between the parties and convince them to share their data for a better healthcare system [67].

7.6. Hesitation and Lack of Trust among the Patients to Share Their Medical History. Trust building among one of the key stakeholders, the patients, is very important for the success of this technology-driven medical and healthcare system. Many patients can be reluctant and hesitant to share and disclose their medical records in the public domain with third-party entities. So, it is very much required to build trust and confidence among the patients regarding the security and privacy aspects of this whole Blockchain and IoT-driven healthcare system.

7.7. Lack of Skills among Doctors and Medical Practitioners. Asking doctors and other medical practitioners to shift from paper to technology can be a big challenge. The use of electronic records and prescriptions instead of paper-based prescriptions can be a challenge for many. For instance, doctors usually do not fill the unnecessary fields in their day-to-day practice while filling some form. However, in the case of electronic records, doctors cannot omit the fields marked as mandatory. Similarly, relying on technologies like Blockchain and IoT for remote monitoring can raise question marks among many doctors regarding their accuracy and efficiency. This technology-driven healthcare's accuracy, efficiency, and performance will depend on doctors' skills and training. So, before bringing these technologies into practice, proper training and required skills need to be imparted to the doctors to build confidence in using these technologies.

Table 8: Summarizes the list of abbreviations used in this survey.

List of abbreviations	
Abbreviations	Full-form
IoT	Internet of things
CIA	Confidentiality, Integrity, and Availability
RFID	Radiofrequency identification
DOS	Denial of Service
ERP	Enterprise Resource Planning
SWAMP	The smart water management platform
EMR	Electronic medical records
POS	Proof of stake
POW	Proof of work
PSN	Pervasive social network
FHIR	Fast health interoperability resources
POA	Proof-of-activity
POB	Proof-of-burn
POV	Proof-of-validation
WSN	Wireless sensor network
IDPS	Intrusion Detection/Prevention System
DDoS	Distributed denial of service
LAN	Local area network
GPS	Global positioning system
NFC	Near Field Communication
WiFi	Wireless fidelity
SDN	Software-Defined Networking
QoS	Quality of Service
PoS	Point of Sale
M2M	Machine to Machine
V2V	Vehicle to Vehicle
NDN	Named data networking

7.8. Data Ownership and Accountability. Data ownership and accountability are other challenges in deploying Blockchain and IoT technologies in the Healthcare sector. Who will hold the data, who will grant permission to share people's private health-related data, and who will have the ownership are the main questions?

8. Conclusion

In Today's world, IoT technology is implemented in every field like agriculture, healthcare, smart cities, etc. In the field of healthcare, IoT is brought into use for applications like monitoring of the patient's health regularly, drug traceability, etc. However, there exist various security issues in IoT, which can be solved by integrating IoT with the Blockchain. The Blockchain is a decentralized technology that can be used to enhance the security of the system. Blockchain technology along with healthcare ensures that patients' sensitive health-related records remain safe from any type of tampering and leakage.

In this article, an attempt was made to enumerate different possible ways with which the IoT technology along with the Blockchain can be integrated into the Healthcare sector to improve the overall performance and to strengthen the current Healthcare sector. Three major application areas of healthcare, viz. (a) remote monitoring of patient`s health, (b) drug`s traceability, and (c) medical records management, where IoT and Blockchain technologies have their applicability were explored in detail. Also, various possible challenges and issues in the deployment of these two revolutionary technologies, i.e., IoT and Blockchain, in the Healthcare sector were explored and discussed.

Based on this study, it can be clearly said that these two technologies have a huge potential in the Healthcare sector, and once integrated will revolutionize the whole Healthcare sector. Table 8 provides the list of abbreviations used throughout this survey article.

Data Availability

No data were used to support this study.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

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Research Article

Short-Term Forecasting of Agriculture Commodities in Context of Indian Market for Sustainable Agriculture by Using the Artificial Neural Network

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Prediction of well-grounded market information, particularly short-term forecast of prices of agricultural commodities, is the essential requirement for the sustainable development of the farming community. Such predictions are mostly performed with the help of time series models. In this study, the soft computing method is used for short-term forecasting of agriculture commodity price based on time series data using the artificial neural network (ANN). The time series data for sunflower seed and soybean seed are considered as the agriculture commodities. The soybean seed time series data were collected for the period of five years (Jan 2014–Dec 2018), for Akola district market, Maharashtra, India. The sunflower time series data were collected for the period of six years (Jan 2011–Dec 2016), for Kadari district market, Andhra Pradesh, India. The dataset is available at the Indian government website taken from the website www.data.gov.in. For forecasting, the ANN model is used on the abovementioned datasets. The performance of the model is compared with the result of the traditional ARIMA model. The mean absolute percentage error (MAPE) and root mean square percentage error (RMSPE) are considered as the performance parameters for the forecasting model. It is observed that the ANN is a better forecasting model than the ARIMA model by considering the two forecasting performance parameters MAPE and RMSPE.

1. Introduction

In India, the 2/3rd parts of total population directly or indirectly depend on the agriculture [1, 2]. As per the survey conducted by "Agriculture Census of India" in 2011, approximately 62% of Indian population living in rural area is dependent upon agriculture directly or indirectly. To this sector of population, agriculture is the main source of income. India is second ranked in terms of production of agriculture commodity. Agriculture sector contributes almost 18% to the Indian GDP [3]. Agriculture commodities are the important source from the earning point of view. Hence, the influence of commodity price [4] is crucial in Indian economy. The agriculture commodity price forecast will play the important role for the farmers, the policymakers, and various administrative offices. For example, if a farmer knows in advance the price of crop in near future (short term), then he can decide about the farming area of that particular crop to be undertaken. Other than farmers, government agencies also need to know the probable price of commodity in advance for implementing the government schemes (subsidy schemes and import/export activity) smoothly.

Agriculture commodity forecasting is very important for sustainability of future generation. With ever increasing demand of agricultural products and reduction in agricultural land, this forecasting methodology is very important for sustainability of farmers. Indian economy is majorly an agriculture-based economy. This forecasting methodology can help the farmers and other stakeholders to make it sustain for a larger duration. The advantage of this forecasting methodology includes healthy and economical food products to the consumers leading to improved health parameters. This can lead to sustainability of the agricultural land and products.

Forecasting of agricultural commodity is very essential for our day-to-day life. The agricultural price fluctuations are rising nowadays, hence, resulting in mismanagement of people's food expenditure. Agriculturalists need to resolve this problem for the better future of agricultural commodity.

Fluctuating and rising agricultural prices are one of the major factors resulting in global fight against poverty. Many models are used for the forecasting of which statistical method is used the most. But still no proper model is made to resolve the problem efficiently.

The forecasting of agriculture commodity price is mainly divided into two parts: structural and nonstructural. The structural methods [5] mainly consider the supply demand ratio. Computationally, it is very difficult to estimate the consumers' needs and the production of that particular crop for developing countries. The nonstructural methods [6] may be categorized as statistical technique [7, 8] and machine learning technique. For nonstructural methods, historical data are collected as time series data. The time series data can be of linear or nonlinear in nature. There are various methods [9] for forecasting based on time series data. The ANN is a better alternative than the statistical model for nonlinear time series data [10, 11].

Some research studies have been performed in forecasting of agriculture commodities price in developing countries such as India. According to [12, 13], there are some special features of the ANN such as nonlinearity, adaptability, and mapping procedures providing strong support for using the ANN as a good forecasting model.

In [14], the ARIMA model and time delay neural network (TDNN) are for time series forecasting of agriculture commodity price. They concluded that the neural network model performed better due to nonlinear nature of time series data. Finally, they presented a hybrid model for forecasting. Surprisingly, the hybrid model was less efficient than the ANN for soybean data and more efficient for mustard.

According to the work reported in [15], the neural network is presented which is a very good alternative for "short term" forecasting, while the Box–Jenkins method performs better for very short-term forecasting. They also discussed that the neural network without a hidden layer can work similar to the Box–Jenkins method.

Work presented in [16] used the support vector machine for forecasting of financial time series data to perform better in terms of efficiency in comparison with the back propagation neural network.

In [17], the authors presented the ANN approach for multivariate time series data. They used the dataset of flour price of three cities, and based on training and testing results, they concluded that the ANN model can well be used for forecasting.

In [18] too, the ANN model is used for electrical load forecasting. They used the characteristics of the ANN to learn from the relationship among the past data, current, and future temperature. Based on the testing data, the result was very satisfactory.

In [19], the Jordan neural network is used in forecasting the inflation based on time series data. They used macroeconomic variables such as financial variable, lagged inflation, and labor market variable. In the work [20], the ANN is used for sales forecasting of the apparel retail chain stores. The MAPE for the model they observed was 8.79%. Some of the applications of the ANN model for forecasting based on time series data are as follows:

(1) Electricity load forecasting [21, 22]

(2) Financial forecasting [10, 23]

(3) Monthly average rainfall prediction [24]

This study is summarized in five sections. The first and current section contains the brief introduction of problem statement and various solutions given by the scholars. The second section elaborates the computational models ARIMA and ANN. The third section explains the implementation and result analysis for the sake of efficiency measurement of computational models discussed in second section. The fourth section explains the conclusion of work presented in this study.

2. Materials and Methods

Sunflower time series data and soybean time series data are taken in this research work. Statistical description of the data is given in Table 1. Description of soybean time series datais as follows:

(1) Taken from "data.gov.in" an Indian government website

(2) For the period of five years (January 2014–December 2018)

(3) Data related to the Akola district market, Maharashtra, India

Description of sunflower time series data is as follows:

(1) Taken from "data.gov.in" an Indian government website.

(2) For the period of five years (January 2011–December 2016).

(3) Data related to the Kadari district market, Andhra Pradesh, India.

2.1. Forecasting Techniques. Forecasting is defined as the prediction made on the basis of some scientific calculation based on historical data and demand-supply data. Classification of forecasting techniques [25] is shown in Figure 1. Forecasting technique is mainly divided into two types: "Quantitative technique" and "Qualitative Technique." In the qualitative method, we use the facts that cannot be measured in terms of the numeric value. It is also known as judgmental forecasting [26] where the prediction is made on the basis of survey, events, and many more noncomputational parameters. The quantitative technique [27] works on numerical data or computational data. It is also known as statistical technique or time series technique. The time series forecasting can be divided into two parts: the (a) classical Box–Jenkins Models [15, 28, 29] and (b) machine learning

Table 1: Description of time series data.

Time series data	Sample size	Train data	Test data	Min. price	Max. price	Standard deviation
Sunflower time series data	Jan 2014–Dec 2018	Jan 2014–Dec 2017	Jan 2018–Dec 2018	2534	4340	431
Soybean time series data	Jan 2011–Dec 2016	Jan 2011–Dec 2015	Jan 2016–Dec 2016	2466	4315	487

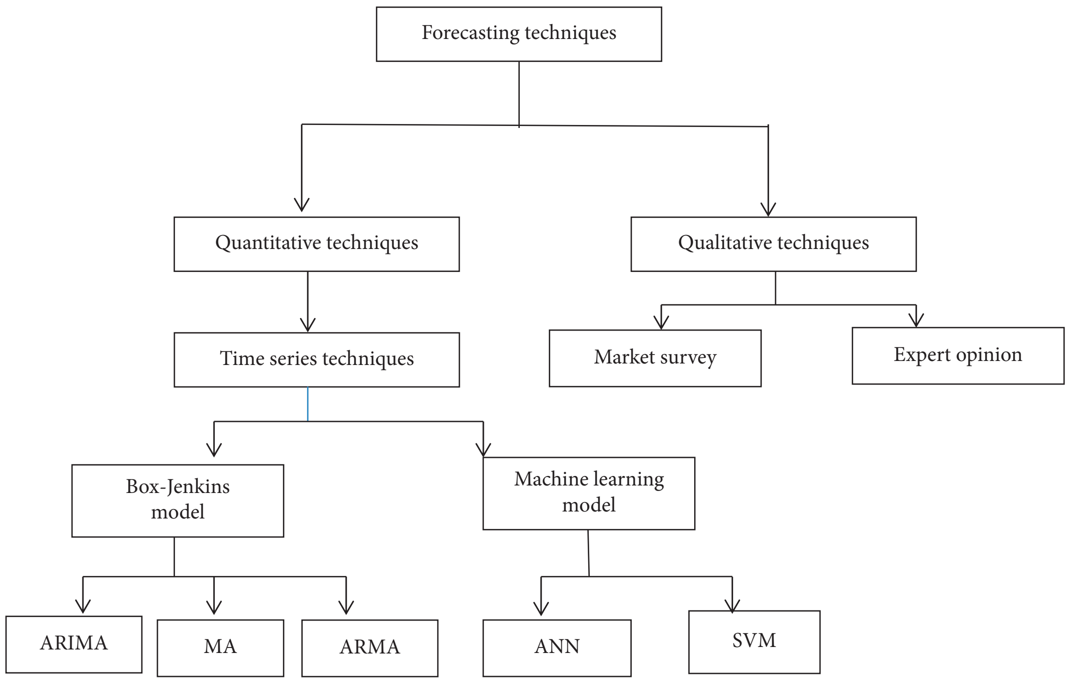

Figure 1: Forecasting techniques.

models [30, 31]. The classical models work well on linear data, while the machine learning models work well on a wide range of data. The ARIMA model and ANN model are further discussed later in this section.

Selection of forecasting technique depends upon the various parameters. Some of them are level of accuracy required, purpose of forecasting, type of data available, tenure of the forecasting, and many more. Qualitative models for agriculture commodity forecasting are very expensive and not suitable for developing countries. As India is a developing country, time series forecasting models are suitable to forecast the agriculture commodity price. The agriculture time series data are nonlinear in nature; hence, naturally, the "Artificial Neural Network Model" is a best suitable model [32–35] for forecasting of agriculture commodity price.

2.2. Forecasting Using ARIMA. ARIMA stands for autoregressive (AR) integrated (I) moving average (MA). It works on the principle of Box–Jenkins [5, 29, 36, 37]. ARIMA [38] is associated with three important parameters, namely, p, d, and q as shown in Figure 2.

The working model of ARIMA is shown in Figure 3. Visualization of time series data is fundamental and most basic for ARIMA. After visualization, we can do the preprocessing of the data such as removing the outliers and dealing with missing data. By visualization, we can also conclude whether the data are stationary or not. If the series is nonstationary, then first of all, we should make time series stationary. After the stationary time series, we should find the optimal parameters for the ARIMA model with the help of ACF plot and PACF plot [39].

2.3. Forecasting Using the Artificial Neural Network. The feed forward neural network with a single hidden layer is used as shown in Figure 4. Back propagation concept is used for learning purpose. Let "m" be the input size (neurons at the input layer) of the neural network and "n" is the number of nodes at the hidden layer. The input $y_{t-m}, y_{t-i+1}, \ldots, y_{t-1}$ is scaled into the interval [0, 1]. The activation function rectified linear unit (ReLU) [1] is used for finding the activation value for the input layer neuron to hidden layer neuron. Sigmoid is used for calculating the activation for the intermediate layer to output layer. The ReLU function, mathematically, is defined as

$$y = \max(0, x). \quad (1)$$

The final output of the network will be given by the following equation:

$$Y_t = f_2\left(\sum_{i=0}^{m} w_i f_1\left(\sum_{i=0}^{n} w_{ij} Y_{t-i}\right)\right), \quad (2)$$

where f_1 and f_2 are the activation functions at the hidden layer and output layer, respectively.

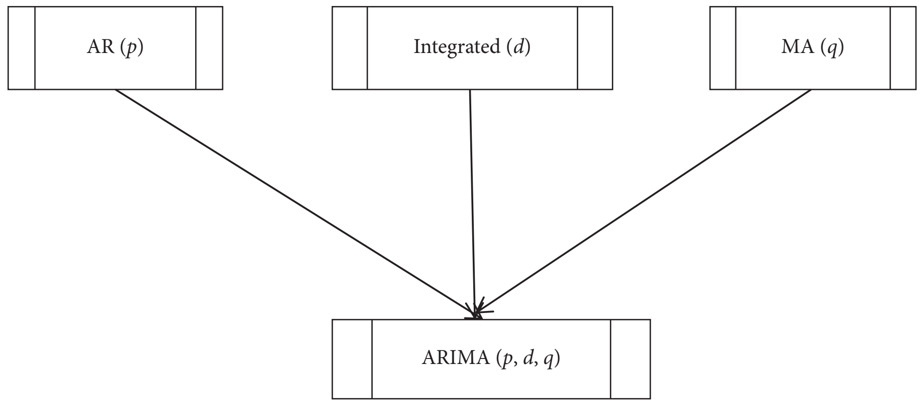

Figure 2: Components of ARIMA.

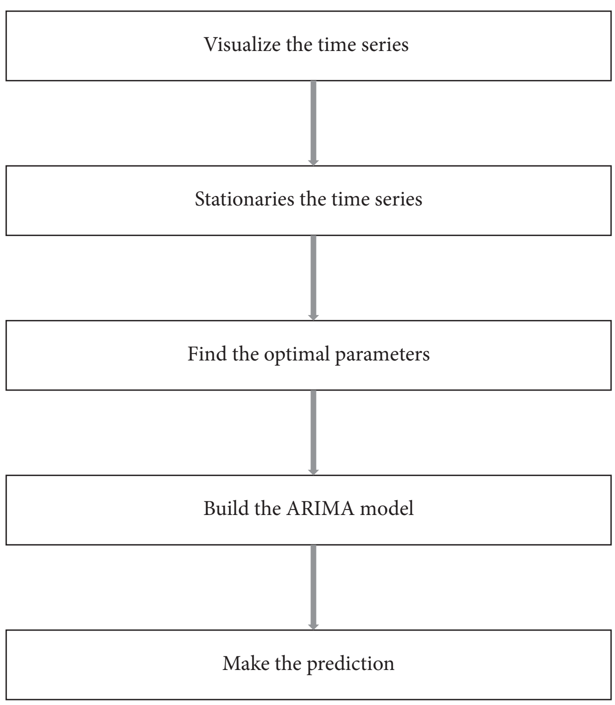

Figure 3: Framework for the ARIMA model.

2.4. Learning Method. The training session of the network categories consists of two parts. In the first part of the training, the network will produce the output based on the selected input window. In second part, the error is calculated based on the actual value and the predicted value. Now, this error is propagated back via the output layer for updating the weight of the neurons in the hidden layer for next round as shown in Figure 5.

For training purpose, the error is calculated by comparing the actual value y_t with the predicted value. The error is back propagated to the neural network for updating the weight of connection between the hidden layer and output layer.

The output of a neuron is calculated by the following equation:

$$O_i^{(L)} = \sum w_{ij}^{(L)} z_j^{(L-1)} - (\text{Bias})_i \text{ in } L^{\text{th}} \text{ layer}, \quad (3)$$

where $O_i^{(L)}$ is the output of neuron i in the L^{th} layer, $(\text{Bias})_i$ is the bias in L^{th} layer, $w_{ij}^{(L)}$ is the weight from i^{th} neuron of the layer $(L-1)$ to j^{th} neuron of layer L, and $Z_i^{(L)}$ is the output of i^{th} neuron in layer L.

The updated weight at time T will be given by the following equation:

$$\Delta w(T) = \eta \delta^L Z_j^{(L-1)} + \alpha \Delta w_{ij}^{(L)} (T-1), \quad (4)$$

where η is the learning rate, α is the momentum, and δ [40] can be calculated with the help of gradient of the output function of neuron.

3. Results and Discussion

3.1. Results by Using ARIMA

3.1.1. Analyzing the Time Series Data. The implementation part is performed in *R*. Figures 6 and 7 show the plot of monthly average price of soybean for the period of 2014–2018 and monthly average price of sunflower seed for the period of 2011–2016, respectively.

By seeing the boxplot of soybean time series data in Figure 8, it seems that the price is with higher mean and variance in the months of February, March, and April. Similarly, in the boxplot of sunflower time series data, the price is with higher mean and variance in the months of March and April as shown in Figure 9.

3.1.2. Components of Time Series Data. After analyzing the time series data from Figures 8 and 9, we can clearly say that there are components such as seasonality, trend, and cycle which are shown in Figures 10 and 11.

3.1.3. Finding Parameters of the ARIMA Model. Stationarity of the time series data is checked with the help of the "Augmented Dickey–Fuller Test" as shown in Figure 12. The ADF test for the soybean time series data is as follows:

Data: Soyabean

"Dickey–Fuller" = −2.2649, "Lag order" = 3, "p value = 0.4683"

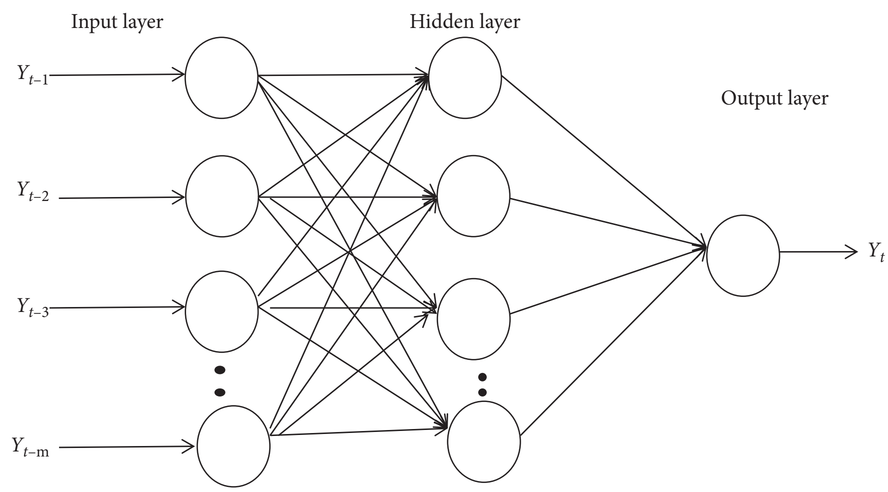

FIGURE 4: Architecture of the feed forward neural network with the single hidden layer.

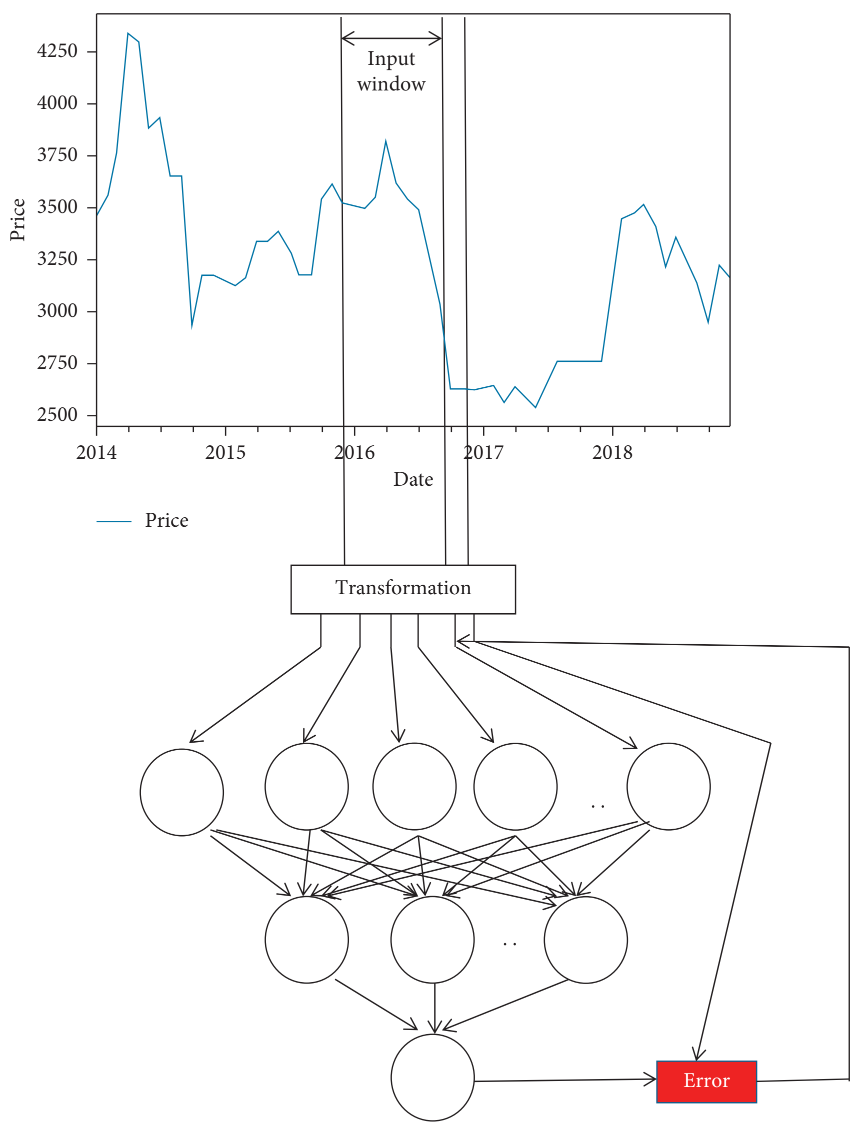

FIGURE 5: Learning by using the ANN.

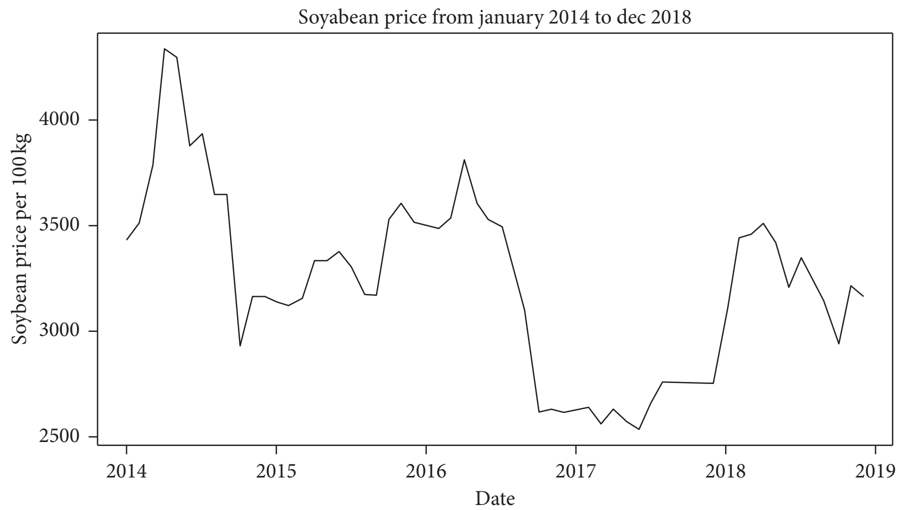

Figure 6: Monthly average price of soybean seed price.

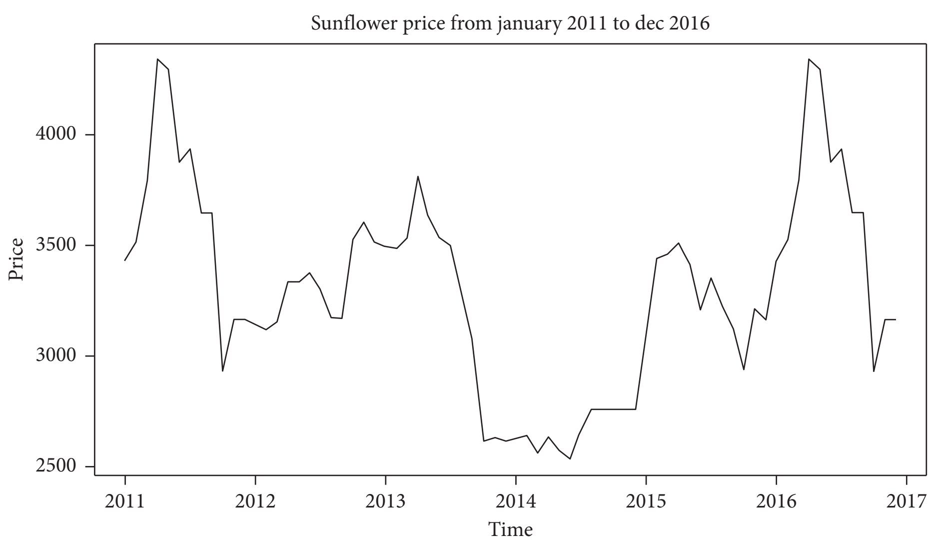

Figure 7: Monthly average price of sunflower seed price.

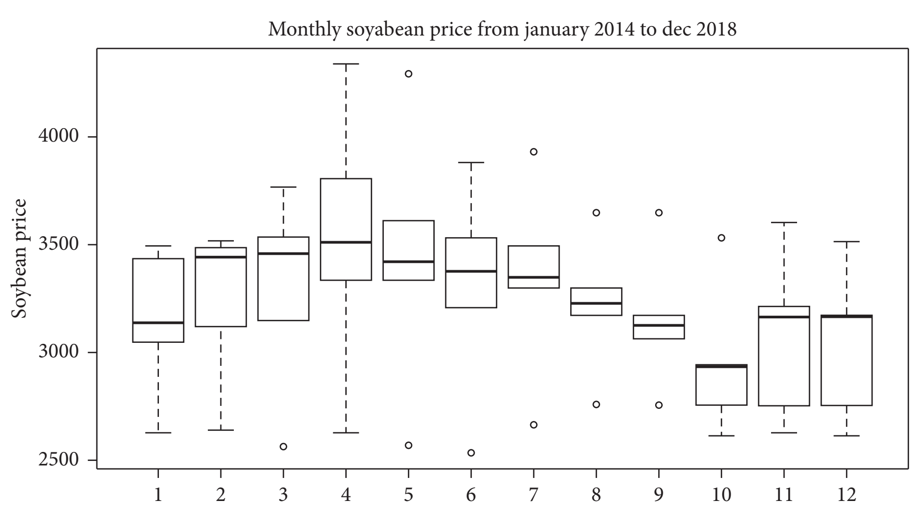

Figure 8: Boxplot of monthly average price of soybean seed price.

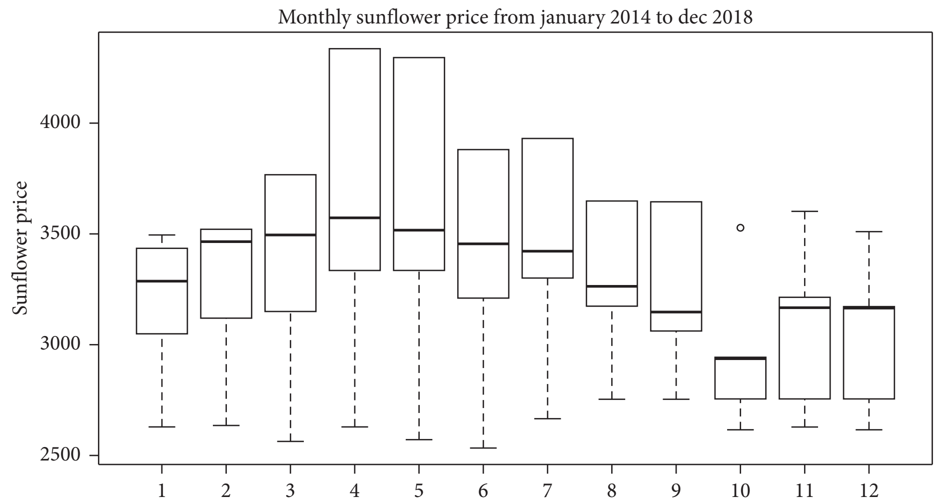

Figure 9: Monthly average price of sunflower price.

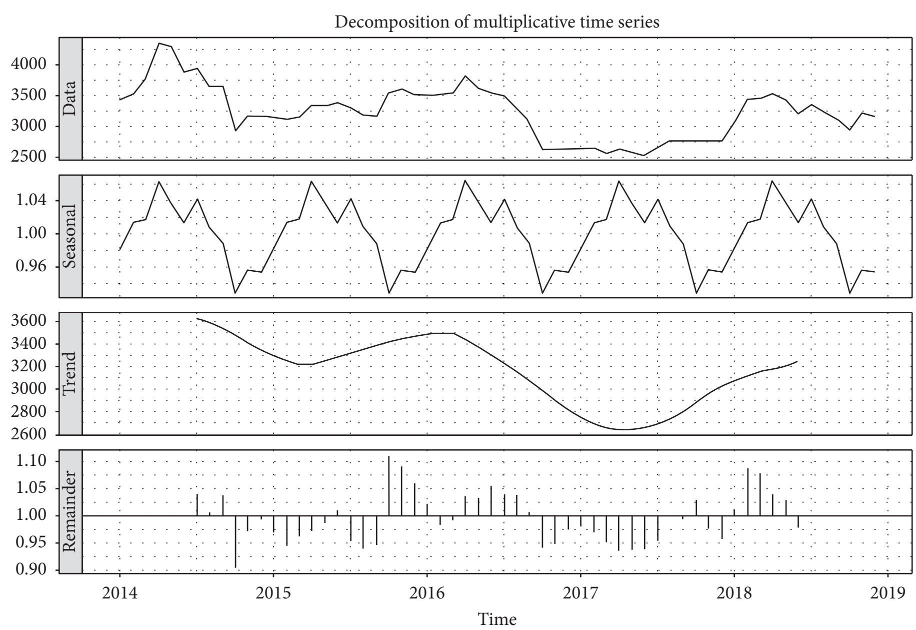

Figure 10: Components in soybean time series data.

As p value >0.05, hence, the series is not stationary. To get the stationary data, difference operation is applied on the data, and again, the ADF test was performed. Now, the result of ADF test is as follows:

Data: diffSoyabean

Dickey–Fuller = −3.4255, Lag order = 3, p value = 0.04386

Alternative hypothesis: stationary

Similarly, the result of ADF test on sunflower time series data is as follows:

Data: diffSunflower

Dickey–Fuller = −3.829, Lag order = 3, p value = 0.02325

3.1.4. Forecasting the Price. The "auto.arima( )" function is used to automatically fit the model based on the input time series data and to find the optimal parameters for the ARIMA model. ARIMA (0, 1, 0) is chosen as an optimal model for forecasting for both sunflower time series data and soybean time series data as shown in Figures 13 and 14. Figures 15 and 16 show the plot of linear models for the soybean time series data and sunflower time series data, respectively.

3.2. Results by Using the ANN. Implementation of the ANN is performed in Python. Two time series data, namely, soybean price and sunflower price are considered as the experimental dataset. The soybean time series data are

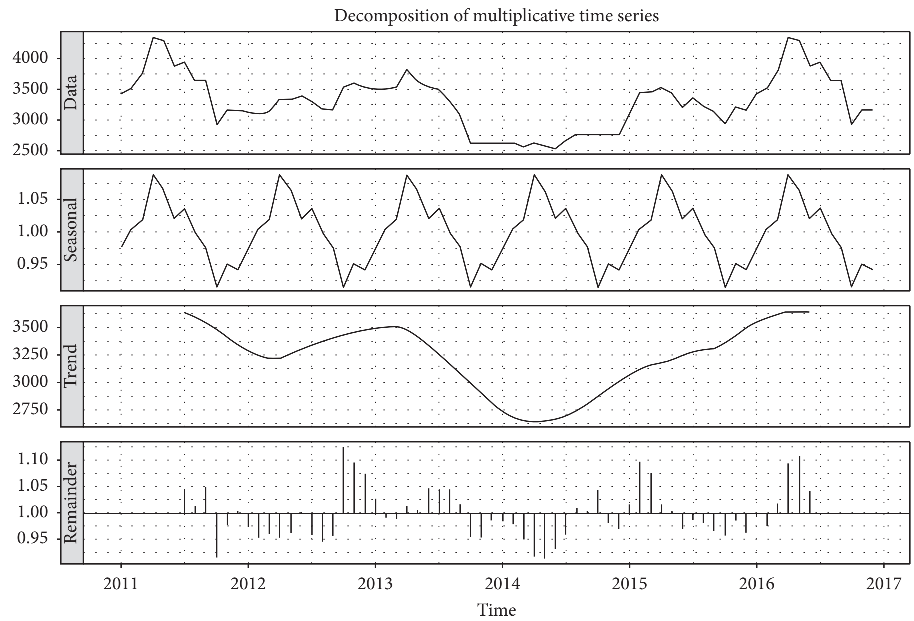

Figure 11: Components in sunflower time series data.

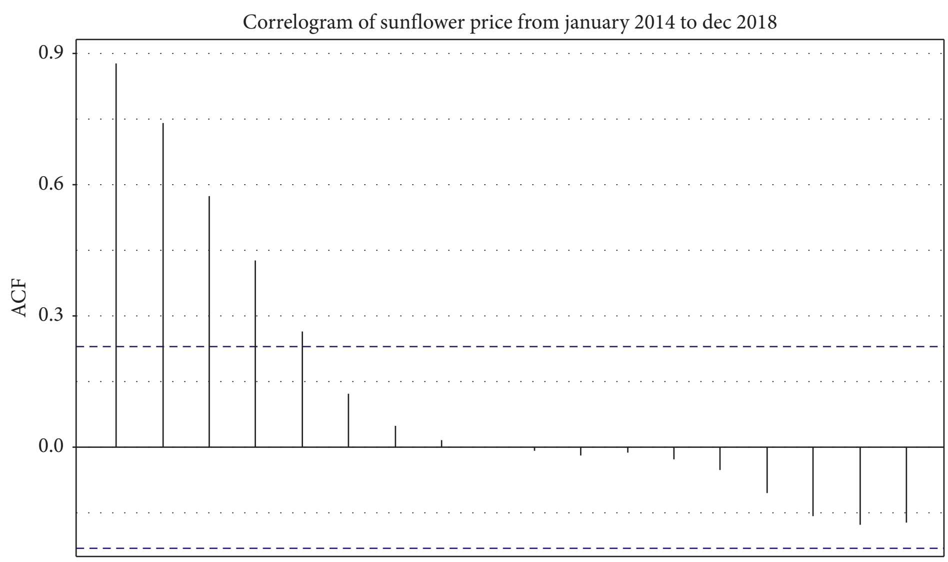

Figure 12: ACF plot of sunflower time series.

collected for the period of sixty months (Jan 2014–Dec 2018), for Akola district market, Maharashtra, India [41]. The sunflower time series data are collected for the period of sixty months (Jan 2011–Dec 2016), for Kadari district market, Andhra Pradesh, India.

3.2.1. Data Preprocessing. In data preprocessing, we mainly focus on to analyze the data, remove the noise, deal with the missing values, and transform the input value to the desired scale for the model to be implemented. The first step for data preprocessing is to plot the series. Figure 17 shows the plot of monthly average price of soybean for the period January 2014–December 2018. Similarly, Figure 18 shows the time series data for sunflower.

3.2.2. Training Dataset and Test Dataset. We used the supervised learning concept. The former 80 percent of the preprocessed data is used to train the model and last 20 percent of the data is used to test the model as per the standard accepted by the various scholars [42]. Figure 19 shows the division of the soybean dataset into train data and test data. Similarly, Figure 20 shows the division of the sunflower dataset into train and test data.

3.2.3. Forecasting the Price. For actual forecasting, the trained model is applied on the test data. Figures 21 and 22 represent the comparison of actual price and forecasted price for the agriculture commodities soybean and sunflower, respectively. The forecasted results of the ANN model are

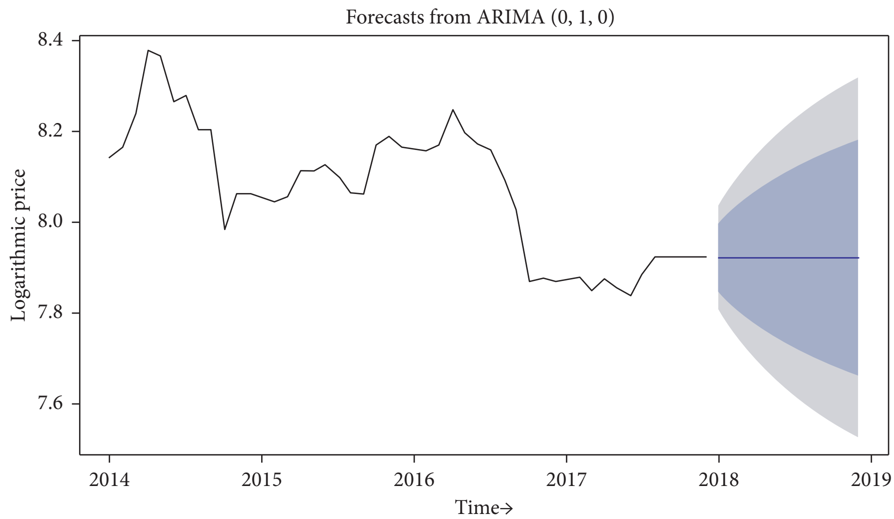

Figure 13: Forecasting of soybean time series data by using ARIMA.

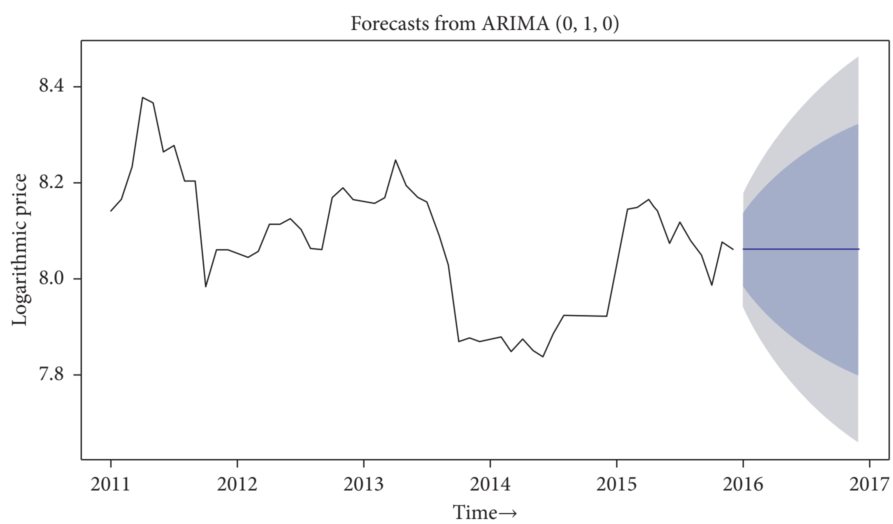

Figure 14: Forecasting of sunflower time series data by using ARIMA.

given in Tables 2 and 3 for the commodities soybean and sunflower, respectively.

3.3. Evaluating Forecasting Accuracy. We have used two parameters "Mean Absolute Percentage Error (MAPE)" and "Root Mean Square Percentage error (RMSPE)" for the forecasting accuracy.

3.3.1. MAPE. MAPE [43, 44] is one of the important parameters to measure the quality of the forecasting system. It is defined in the following equation:

$$\text{MAPE} = \frac{1}{n}\sum\left|\frac{A_t - \text{F}_t}{A_t}\right| * 100, \quad (5)$$

where A_t is the actual price at time t, F_t is the forecasted price at time t, and n is the number of the forecasted value.The MAPE by using the ANN for the forecasted sunflower time series data is 2.4 and for soybean time series data is 7.7% as given in Table 4.

3.3.2. RMSPE. RMSPE can be calculated by following the given steps:

Step 1: Calculate the percentage residuals by using the following formula:

$$\text{Residual} = \left|\frac{(A_t - F_t)}{A_t}\right| * 100, \quad (6)$$

where A_t is the "actual price", and F_t is the "forecasted price."

Step 2: Calculate the residuals square

Step 3: Calculate the mean of residuals squares by adding the residuals squares and divide it by n

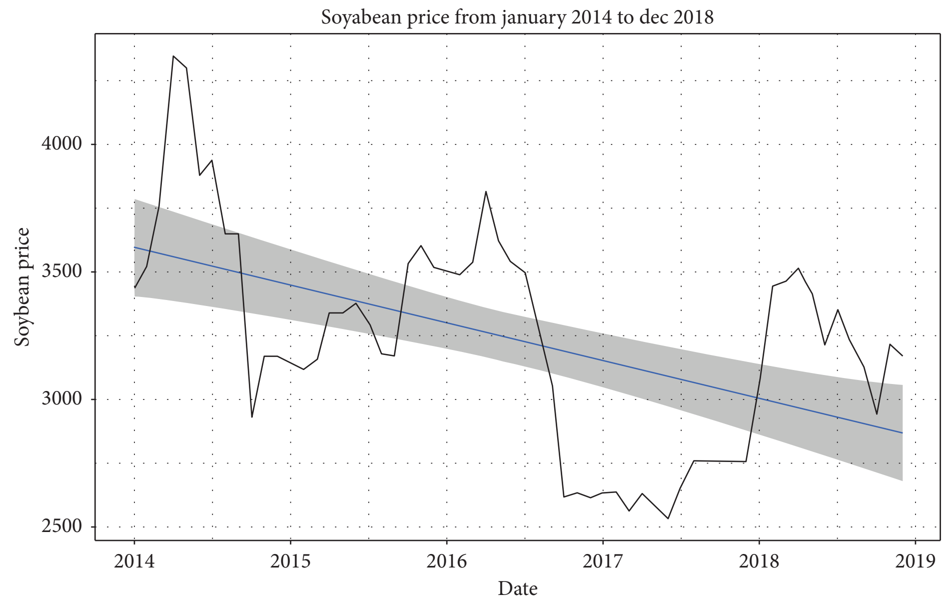

Figure 15: Forecasting of soybean time series data using the linear model.

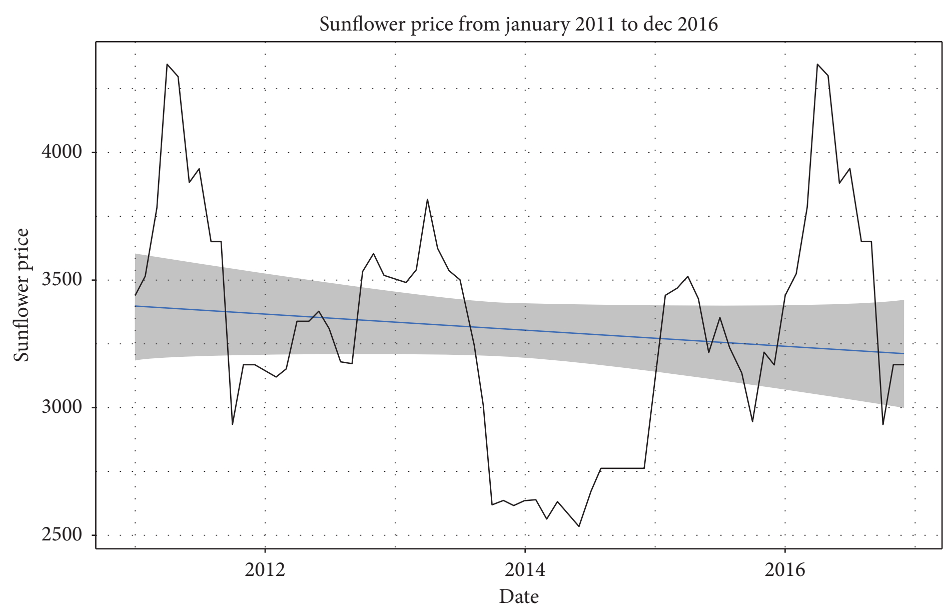

Figure 16: Forecasting of sunflower time series data using the linear model.

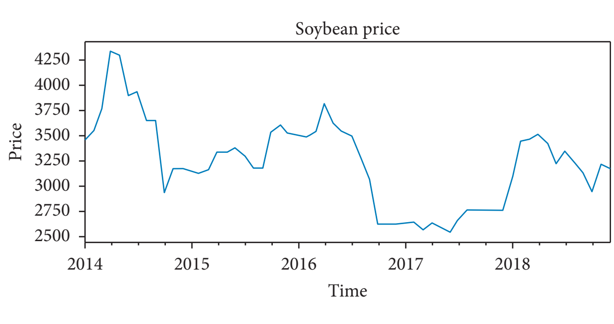

Figure 17: Soybean monthly average price.

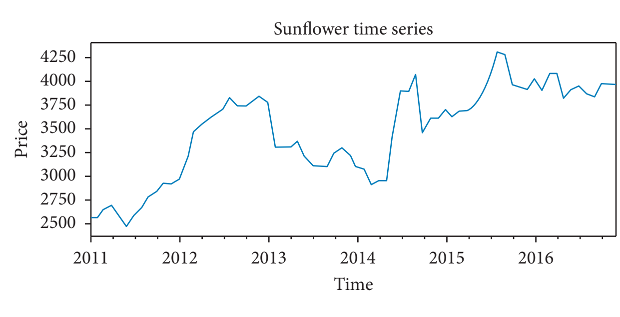

Figure 18: Sunflower monthly average price.

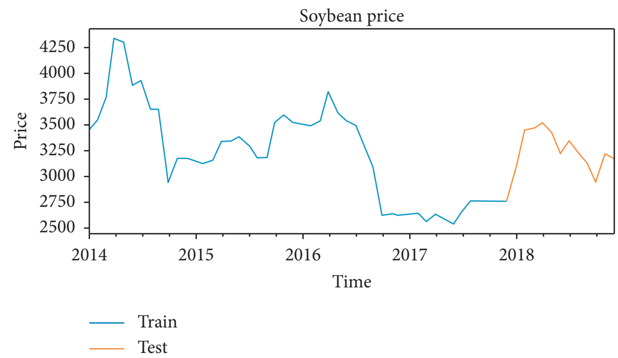

Figure 19: Train data and test data for soybean time series.

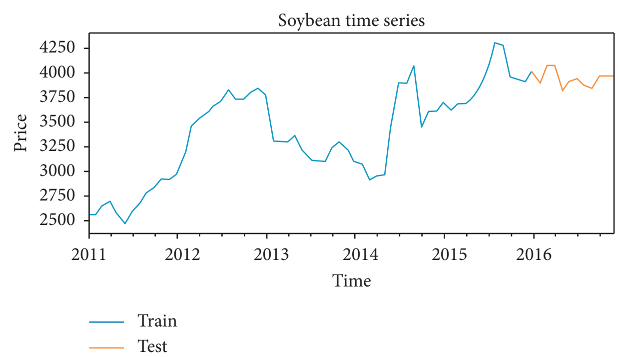

Figure 20: Train data and test data for sunflower time series.

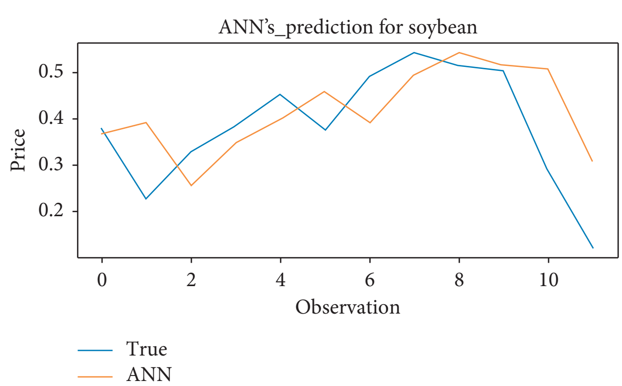

Figure 21: Forecasting of soybean price by using the ANN.

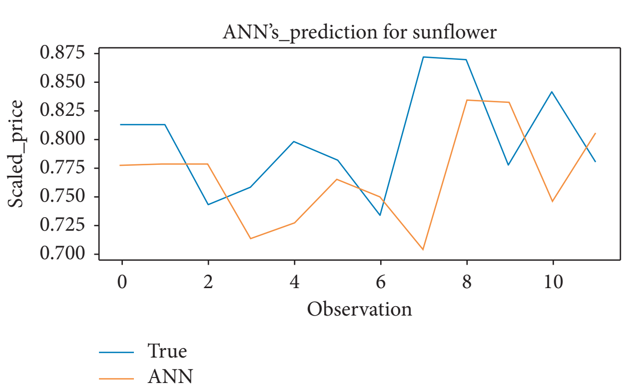

Figure 22: Forecasting of sunflower price by using the ANN.

Table 2: Forecasting of soybean price.

Date	Actual price of soybean	Forecasted price using the ANN
Jan 2018	3049.79	3197.08
Feb 2018	3443.33	3242.21
Mar 2018	3461.76	2995.83
April 2018	3512.56	3162.45
May 2018	3420.45	3252.34
June 2018	3213.13	3362.75
July 2018	3348.68	3239.79
Aug 2018	3226.96	3427.85
Sept 2018	3127.86	3511.40
Oct 2018	2944.17	3465.32
Nov 2018	3215.79	3448.60
Dec 2018	3166.04	3091.63

Table 3: Forecasting of sunflower price.

Date	Actual price of sunflower	Forecasted price using the ANN
Jan 2016	4021.88	3904.16
Feb 2016	3905.00	3907.30
March 2016	4074.19	3906.33
April 2016	4077.78	3785.58
May 2016	3822.22	3811.92
June 2016	3913.04	3881.68
July 2016	3942.86	3853.53
Aug 2016	3868.97	3767.79
Sept 2016	3841.07	4009.06
Oct 2016	3968.97	4005.67
Nov 2016	3970.00	3845.94
Dec 2016	3966.67	3955.94

Table 4: Comparison of forecasting accuracy.

Performance parameter	Forecasting models	
	ANN	ARIMA
MAPE for sunflower	2.4	19.76
MAPE for soybean	7.7	15.21
RMSPE for sunflower	3.15	19.84
RMSPE for soybean	8.92	15.90

Step 4: Calculate the square root of mean obtained in Step 3

4. Conclusion and Future Work

Currently, India is ranked second in the world for production of agricultural commodities and contributes almost 18% in the Indian GDP. Although, the market prices of these commodities fluctuates geographically. To give a better understanding of these fluctuations to stakeholders, in this study, we have presented a short-term price forecasting model which will eventually lead to more sustainability to different stakeholders. For this, we have compared the ANN and ARIMA model for forecasting the prices. We considered sunflower time series data and soybean time series data collected from Indian government portal for training and testing purpose of the proposed forecasting model. The parameters MAPE and RMSPE are used for the accuracy measurement of the presented model. For soybean and sunflower time series data for prices, the mean absolute percentage error (MAPE) by using the ANN is 2.4% and 7.7%, respectively. Whereas by using ARIMA, MAPE for soybean and sunflower time series data is 19.76% and 15.2%, respectively. Similarly, the root mean square percentage error (RMSPE) by using the ANN for soybean and sunflower time series data is 3.15% and 8.92%, respectively, whereas, by using ARIMA for the same time series data, RMSPE is 19.84% and 15.9%, respectively. These results concluded that the ANN is a better model for forecasting of agriculture commodity price than the ARIMA model. As per the literature review, the ANN model is suitable for nonlinear time series data and the ARIMA model is suitable for linear time series data. Hence, future work will be focused on developing the hybrid model for forecasting of agriculture commodity price to overcome the limitation of the ANN model.

Data Availability

The data used to support the findings of this study are taken from the website "http://www.data.gov.in" managed by Government of India.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

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Research Article

Models for Predicting Quality of Solar-Dried Shrimp (*Penaeus vannamei*) during Storage Based on Protein Oxidation

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The purpose of this study was to explore the correlation between protein oxidation and quality and to study the changes in various indexes of solar-dried shrimp (*Penaeus vannamei*) stored at 37°C and 20°C through vacuum packing and vacuum packaging with antipressure sterilization. The results showed that ΔE as well as TVB-N and carbonyl contents increased, whereas moisture and free thiol (SH) contents decreased with time. Furthermore, SDS-PAGE and scanning electron microscopy revealed protein degradation and damage of shrimp muscle microstructure during storage. A quality prediction model based on protein oxidation was established according to Arrhenius equation. Verification of shrimp quality prediction models revealed that the relative errors of the models based on SH and carbonyl contents were below 10%, indicating that these protein oxidation parameters can be used for reliable estimation of quality changes in dried shrimp during storage.

1. Introduction

Penaeus vannamei shrimp is one of the most popular seafood because of its attractive flavor and high nutritional value [1]. Fresh shrimps deteriorate easily and, therefore, must be preserved or processed soon after harvest to increase their shelf life [2]. Freshly processed dried *Penaeus vannamei* is delicious, and its flavor gradually becomes weaker with the prolonging of storage time. Drying predominates over other preservation and processing methods because it allows storage of dried shrimp at room temperature for a long time [3]. China is rich in solar energy resources, which not only prevent the invasion of mosquitoes and microorganisms but also provide effective solar energy utilization and high temperatures to perform solar drying, which, compared with natural drying, can significantly shorten the drying time and improve the quality of the final product [4].

During storage, many chemical reactions occur in seafood, the most important of which is protein oxidation leading to nutrient degradation and changes in food sensory properties [5]. In their study, M. Malgorzata et al. [6] found that high concentration of oxygen promoted the increase in disulfide bond cross-linking after myosin oxidation, which reduced the degradation of intermyosin and the tenderness of meat. In their study, on the influence of high oxygen packaging on pork quality, R. M. Delles et al. [7] found that the high oxygen system causes protein oxidation, and myosin aggregates through disulfide cross-linking, which weakens the ability of protein to bind to water, leading to a decrease in water holding capacity. Many factors such as moisture, the packaging method, and storage temperature can influence the rate of protein oxidation [8]. Packaging and storage are important steps in the distribution and marketing of processed food, which critically affect the quality of the final product [9]. In particular, packaging methods and materials significantly influence the oxidation stability of dried seafood products; for example, vacuum packaging, including packing with antipressure sterilization, can delay protein oxidation and improve the overall quality of muscle foods through oxygen exclusion [10].

Constructing a quality prediction model of solar-dried shrimp based on protein oxidation can help to better understand the relationship between protein oxidation and quality formation. Artificial intelligence has a good application prospect in many fields. An image fusion based on multimodal medical images renders a considerable enhancement in the quality of fused images [11]. N. Zhu et al.

Table 1: Experimental design of the change rule of main physicochemical indexes of dried *Penaeus vannamei* during storage.

Treatment group (°C)	Processing method
VP 20	Vacuum-packed and placed in an incubator at 20°C
VP 37	Vacuum-packed and placed in an incubator at 37°C
AP 20	Vacuum packaging combined with antipressure sterilization (110°C/20 min) was placed in an incubator at 20°C
AP 37	Vacuum packaging combined with antipressure sterilization (110°C/20 min) was placed in an incubator at 37°C

[12] used the artificial neural network to establish a multiple mass prediction model based on protein degradation. In order to study the relationship between quality change and protein oxidation of turbot during storage, changes in protein oxidation parameters and quality indicators during refrigeration (4°C) and ice (0°C) storage were determined, and the correlation among them was analyzed [13]. The classic Arrhenius model, which is commonly used to describe the relationship between chemical reaction rates and temperature, can potentially reduce experimental burden and provide a practical method for predicting and preventing quality deterioration of processed food during storage [14]. However, there are few reports on the relationship between protein and quality based on the Arrhenius model. Compared with previous studies, Arrhenius equation is often used to predict the shelf life of food. However, in this study, it was applied to analyze the correlation between protein oxidation and quality indicators, which is helpful to better regulate the storage quality of *Penaeus vannamei*.

In this study, solar-dried shrimp (*Penaeus vannamei*) was used as the research object to explore the change rule of protein and quality of shrimp in different packaging methods and storage temperatures. Using Arrhenius equation, a quality prediction model based on protein oxidation was established. Our results provide a theoretical basis and technical support for the quality assessment of dried products during storage.

2. Materials and Methods

2.1. Raw Material, Processing, Packaging, and Sampling. Fresh *P. vannamei* shrimp (average wet weight 19.52 ± 2.2 g, average body length 12.3 ± 0.5 cm) was obtained from Tangshan City, Hebei Province Caofeidian aquaculture area in October 2020. Ten kilograms of shrimp were frozen at −80°C and 80 kg was dried.

Fresh shrimp were graded, washed, and boiled at the following conditions: salt solution concentration, 3% (w/v); shrimp/salt solution ratio, 1 : 2 (w/w); and boiling time, 6 min. Weighed samples were placed in a single layer on plastic meshed trays and dried using solar drying equipment (Tangshan Luanfeng Breeding Co., Ltd.) for approximately 7 h. Dried shrimp were cooled, shelled, and subjected to vacuum packaging (VP) or vacuum packaging with antipressure sterilization (AP) at 110°C for 20 min.

For the storage experiment, the samples were divided into two groups stored at 37°C and 20°C, respectively. A total of 4 experimental treatments (the experimental design method is given in Table 1) were set; each treatment was a mutual control and stored for 30 days. Every 3 days, the samples were analyzed for color and moisture, TVB-N, SH, and carbonyl contents and every 6 days for protein composition by SDS-PAGE. At days 0 and 30, the samples were evaluated for the microstructure of muscle fibers under a scanning electron microscope (SEM).

2.2. Color Analysis. The color of the shrimp surface was measured using a chroma meter (Konica Minolta Laboratory USA, Inc.) calibrated using a white board, and the CIE parameters L^* (lightness from 0 to 100%), a^* (color from green to red), and b^* (color from yellow to blue) were obtained [15, 16]. The color results were expressed as the mean value of at least 10 samples, excluding the maximum and minimum values [17]. The total color difference ΔE was calculated as follows:

$$\Delta E = \sqrt{\left(L^* - L_0^*\right)^2 + \left(a^* - a_0^*\right)^2 + \left(b^* - b_0^*\right)^2}, \tag{1}$$

where L_0^*, a_0^*, and b_0^* are the shrimp color parameters before storage, and L^*, a^*, and b^* are the color parameters during storage. The difference between two colors was assessed according to a previously developed color scale: $6 < \Delta E < 12$ indicated strong difference and $\Delta E > 12$ indicated distinct colors [18].

2.3. Moisture Content Analysis. The moisture content was determined by drying the sample in an oven at 105°C until a constant weight was obtained [19]. Triplicate measurements were performed for each batch.

2.4. TVB-N Measurement. The TVB-N content in shrimp samples was measured in a K1100 automatic Kjeldahl nitrogen analyzer according to GB 5009.228-2016 "National Food Safety Standard for the Determination of TVB-N in Foods." Accurately weighed (3.0 ± 0.1 g) minced shrimp meat was placed into an Erlenmeyer flask with 50 mL of 20 g/L trichloroacetic acid (TCA), stirred every 5 min for 30 min, and filtered. Then, 10 mL of the filtrate was placed into a digestive tube, mixed with 5 mL of 10 g/L magnesium oxide solution, distilled for 5 min, and absorbed with 20 g/L boric acid; the absorption solution was titrated with 0.1 mol/L HCl. Blank control contained 10 mL of 20 g/L TCA and 5 mL of 10 g/L magnesium oxide without the shrimp sample. The TVB-N content was calculated as follows:

$$X = \frac{\left(V_1 - V_2\right) \times C \times 14}{m \times (10/50)} \times 100, \tag{2}$$

where X is the TVB-N content in the sample (mg/100 g), V_1 and V_2 are the volumes (mL) of the HCl titration solution used for the test sample and blank control, respectively, C is the HCl concentration (mol/L), and m is the sample mass (g).

2.5. Determination of SH Content. The SH content was determined according to the modified Ellman method [20]. Dried shrimp (2.0 g) was homogenized in 10 mL of 50 mM phosphoric acid buffer (pH 8.0) and centrifuged to obtain the upper protein-containing fraction, which was diluted 10-fold and mixed with 0.02 ml reagent containing 2 mM/L 5, 5′-dithio (2-nitrobenzoic acid) (DTNB); the absorbance was measured at 412 nm after 1 h incubation at 25°C eddy dimming reaction. Protein content of the sample was determined using a BCA kit (Beijing Leagene Biotechnology Co., Ltd.), and the SH content was calculated as follows:

$$-\mathrm{SH}\,(\mathrm{SS})\left(\frac{\mathrm{mol}}{10^{5}\,\mathrm{g\ protein}}\right) = \frac{a \times d}{(c \times b)}, \quad (3)$$

where a is the absorbance, b is the protein concentration (mg/mL), c is the molecular absorbance coefficient (13,600 $\mathrm{mol}^{-1}\,\mathrm{cm}^{-1}\,\mathrm{L}$), and d is the replacement coefficient of 10.

2.6. Determination of Carbonyl Content. The carbonyl content was estimated using the method of M. Morzel et al. [20] with slight modifications. The method is based on the formation of protein hydrazones with 2, 4-dinitrophenylhydrazine (DNPH). Dried shrimp (2 g) was homogenized in 10 mL of 0.6 M NaCl (pH 6.5) in a blender, centrifuged at 5,000 rpm for 10 min, and the supernatant (400 μL) was mixed in a 1.5 mL Eppendorf tube with 200 μL of 2 M HCl containing 10 mM DNPH. The samples were incubated for 1 h in the dark at 37°C in a waterbath under agitation, and proteins were precipitated with 1 mL of 40% TCA. After 20 min, the samples were centrifuged at 13,000 rpm for 15 min, and the resultant pellets were washed with 1 mL of ethanol:ethyl acetate (1 : 1) and centrifuged at 13,000 rpm for 10 min to remove free DNPH; washing was repeated until the supernatant became colorless. The pellets were dissolved in 3 mL of 6 M guanidine-HCl and left overnight; then, 200 μL was placed in triplicate into a 96-well plate, and the absorbance was measured at 370 nm in a microplate reader (1510, Jinqiao Export Processing Zone, Pudong New Area, Shanghai). Protein concentration was determined using the BCA method, and the results were expressed as nmol carbonyl/mg protein.

2.7. SDS-PAGE. Salt-soluble proteins were extracted from shrimp samples (0.1 g) using 10 mL of PIPA lysis buffer (strong) (50 mM Tris, pH 7.4, 150 mM NaCl, 1% Triton X-100, 1% sodium deoxycholate, and 0.1% SDS) supplemented with protease inhibitors [21]. After sufficient homogenization in a high-throughput tissue grinder (Ningbo Xinzhi Biotechnology Co., Ltd.), the samples were incubated for 20 min on ice to achieve complete cell lysis, centrifuged at 14,000 × g for 10 min, and the supernatant was transferred to a new tube and used for further analysis as the total sample protein. Protein concentration was determined using the BCA method, adjusted to 1,500 μg/mL for all samples, and 40 μL of each lysate was mixed with 5× reducing SDS-PAGE loading buffer for 40 s and heated in a waterbath at 100°C for 3–5 min. If the sample was not used immediately, it was stored at −20°C. Samples were loaded into SDS-polyacrylamide gels (5% stacking and 10% separating) and subjected to electrophoresis in a JY600C Electrophoresis Cell (Beijing Junyi Dongfang Electrophoresis Equipment Co., Ltd.) at 130 V constant voltage for approximately 100 min. The gels were stained for 15 min in SDS-PAGE staining buffer, followed by decolorization in distilled water, and the molecular weights of individual proteins were determined by comparison with standard protein markers (10–250 kD) (Shanghai Saiao Biotechnology Co., Ltd) [22].

2.8. Muscle Microstructure Analysis. Shrimp muscle microstructure was analyzed by SEM as previously described with slight modifications [23, 24]. The second shrimp segment was cut into 5 × 5 × 3 mm pieces, fixed in 2.5% (w/v) glutaraldehyde solution at 4 °C overnight, washed three times with distilled water for 20 min, and dehydrated in gradient ethanol solutions (25%, 50%, 75%, and 95%, w/v) for 20 min, then in 100% (w/v) ethanol for 20 min three times, and finally in isoamyl acetate for 20 min three times. Afterward, the sample was gold-coated at 20 mA and 10 Pa vacuum for 5 min in a vacuum ion sputtering instrument (Beijing Zhongke Instrument Co., Ltd,) and observed at 1000× magnification under a 4863-P SEM (Ametech Trading (Shanghai) Co., Ltd.).

2.9. Establishment of a Kinetic Model. Changes in the quality characteristics of dried shrimp during storage at different temperatures could be expressed based on the rate constant (k) and its dependence on temperature. The rate of changes in the selected quality indices can be represented by the following kinetic equation:

$$\frac{\mathrm{d}B}{\mathrm{d}t} = kB^{n}, \quad (4)$$

where B is the value of quality index after storage for time t (days), k is the rate constant, and n is the kinetic order of reaction [25]. Rate constant k is temperature dependent and often described by the following Arrhenius equation [26]:

$$k = k_0 \exp\left(\frac{-E_A}{R}\right), \quad (5)$$

where k_0 is the preexponential constant, E_A is the activation energy in kJ/mol, R is the universal gas constant (8.3144 J/K·mol), and T is the absolute temperature. Fitting equation (5) into equation (4) yields

$$\frac{\mathrm{d}B}{\mathrm{d}t} = k_0 \exp\left(\frac{-E_A}{RT}\right)B^{n}. \quad (6)$$

Intergrating equation (6) results in

$$\int_{B_0}^{B_{(t)}} \frac{\mathrm{d}B}{B^{n}} = \int_0^{t} k_0 \exp\left(\frac{-E_A}{RT}\right)\mathrm{d}t. \quad (7)$$

At $n = 0$, a zero-order kinetic equation is obtained:

$$B_{(t)} = B_0 + k_0 t \ \exp\left(\frac{-E_A}{RT}\right). \quad (8)$$

At $n = 1$, a first-order kinetic equation is obtained:

$$B_{(t)} = B_0 \exp\left(k_0 t \ \exp\left(\frac{-E_A}{RT}\right)\right). \quad (9)$$

At $n = 2$, a second-order kinetic equation is obtained:

$$\frac{1}{B_{(t)}} = \frac{1}{B_0} + k_0 t \ \exp\left(\frac{-E_A}{RT}\right), \quad (10)$$

where B_0 is the initial value of the selected quality indices.

2.10. Validation of Predictive Models. Protein oxidation indices (SH and carbonyl content) of samples stored at 20°C were used to validate models predicting shrimp quality changes, and the calculated predicted values were compared with the observed values.

2.11. Statistical Analysis. All experiments were repeated three times, and the results are shown as the mean ± standard deviation. Statistical analysis and correlation analysis were performed using SPSS 23 (SPSS Inc., Chicago, IL, USA). Differential significance analysis was performed using the Duncan method, and $p < 0.05$ indicated statistically significant differences. A data chart was created using Origin 2018 software.

3. Results and Discussion

3.1. Changes of Indexes during Storage. The appearance of the product is one of the most important parameters in consumer acceptance, and the color is a characteristic indicator of dried shrimp quality. ΔE is used to quantitatively assess the total difference between two colors; the larger the ΔE, the greater the difference. Changes in ΔE of VP and AP shrimp samples during storage at 37°C and 20°C are shown in Figure 1(a). All samples showed a significant increase in ΔE with the time of storage; however, at the same temperature, ΔE was higher for AP than for VP shrimp, which is consistent with previous reports [27]. In average, the ΔE value of all samples increased by 19.74% at the end (day 30) compared with the start (day 0) of the storage period, which could be due to water loss and subsequent browning of dried shrimp. In order to avoid great changes in total color difference of dried shrimp during storage, VP20°C treatment should be selected to maintain the stability of color and luster for up to 21 days.

Moisture content of dried shrimp decreased during 30 days of storage at different temperatures (Figure 1(b)). Under the same packing method, the moisture content was significantly lower in samples stored at 37°C than in those stored at 20°C, indicating that higher temperature accelerated the loss of moisture, which is consistent with the results of a previous study [28]. At the same time, the packaging method also affected the rate of moisture loss, which was higher in AP than in VP shrimp. In order to reduce the water loss of dried shrimp during storage, the storage condition of VP20°C should be adopted, and the best storage time is 6 days to ensure that the water content does not change greatly.

TVB-N value, as the main hygienic index, indicates the freshness of meat products and reflects the spoilage degree of meat products. Protein degradation due to enzymes and microorganisms generates alkaline ammonia, amines, and nitrogen-containing substances, such as volatile basic nitrogen compounds, which are small molecular substances and toxic nonprotein nitrogen-containing compounds, such as metabolism products of amino acids and nucleotides [29]. Figure 1(c) shows that the TVB-N content in all samples increased with storage time ($p < 0.05$); however, the increase was slower for AP shrimp than for VP shrimp, indicating that vacuum packaging after antipressure sterilization could delay the spoilage of dried shrimp. Therefore, in order to maximize the freshness of dried shrimp, the AP20°C treatment group should be selected for storage.

SH groups in cysteine residues are particularly vulnerable to attacks by reactive oxygen species and other radicals, resulting in a wide array of oxidative changes [30]. Figure 1(d) shows a significant storage time-dependent decrease of SH content in all samples ($p < 0.05$), which was more pronounced in VP than in AP shrimp, indicating that the antipressure sterilization packaging was better in inhibiting protein oxidation. Similar results were reported in previous studies [31, 32]. In order to delay the process of protein oxidation, the best treatment group was AP20°C, and the original quality could be best maintained after 6 days of storage.

Carbonyl content is one of the most reliable indices of the extent of protein oxidation [33]. Amino acids with NH or NH_2 groups on their side chains are highly sensitive to hydroxyl radicals and are transformed into carbonyl groups during protein oxidation [34, 35]. The carbonyl content of dried shrimp showed an increasing trend over the storage period (Figure 1(e)). Under the same packaging method, the level of carbonyls was higher at 37°C than at 20°C; at the same time, it was lower in AP shrimp than in VP shrimp. Similar results were reported by [36]. In order to ensure that a large degree of protein oxidation does not occur in the storage process of dried shrimp, AP20°C should be used, and the storage time can reach 18 days.

Electrophoresis analysis of shrimp proteins showed that the main protein components of dried shrimp were myosin heavy chain (MHC, 220 kDa), actin (43 kDa), and troponins T (37 kDa), I (23 kDa), and C (18 kDa) Figure 2. After storage, the MHC band disappeared in all treatment groups, which is in agreement with previous findings [37, 38]. MHC degradation was probably due to oxidation, which may also lead to degradation, cross-linking, and aggregation of actin as indicated in an earlier report [39]. Indeed, the actin band in VP and AP shrimp samples decreased but did not completely disappear during storage. Similarly, the troponin T band gradually decreased with storage at 37°C; however, it did not significantly change during storage at 20°C. The same trend was observed for troponin I, which showed a less significant decrease at 20°C than at 37°C; still, the corresponding band was reduced or even disappeared in all

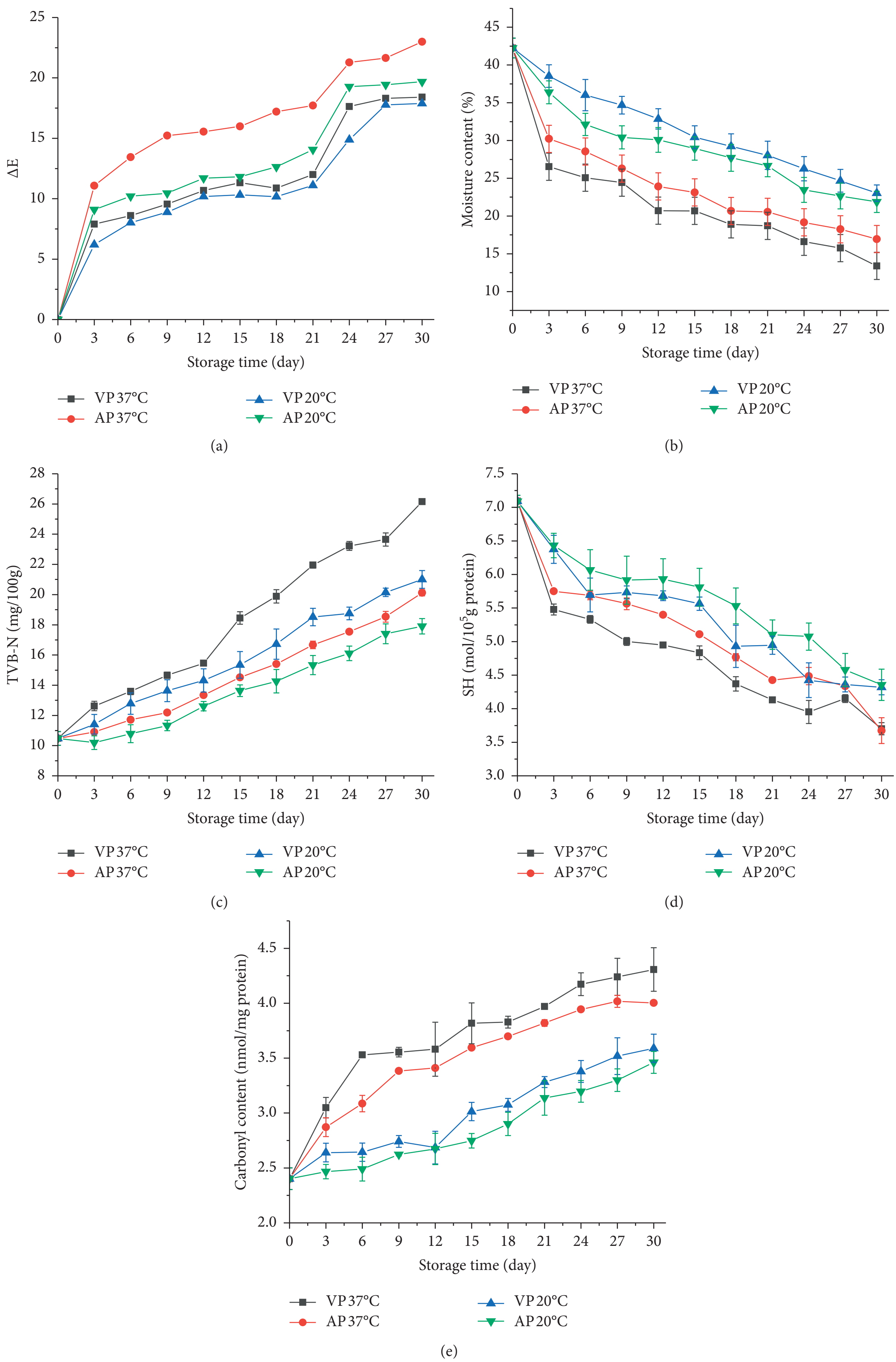

Figure 1: Variation in ΔE (a), moisture content (b), TVB-N (c), SH (d), and carbonyl content (e) of dried shrimps during storage.

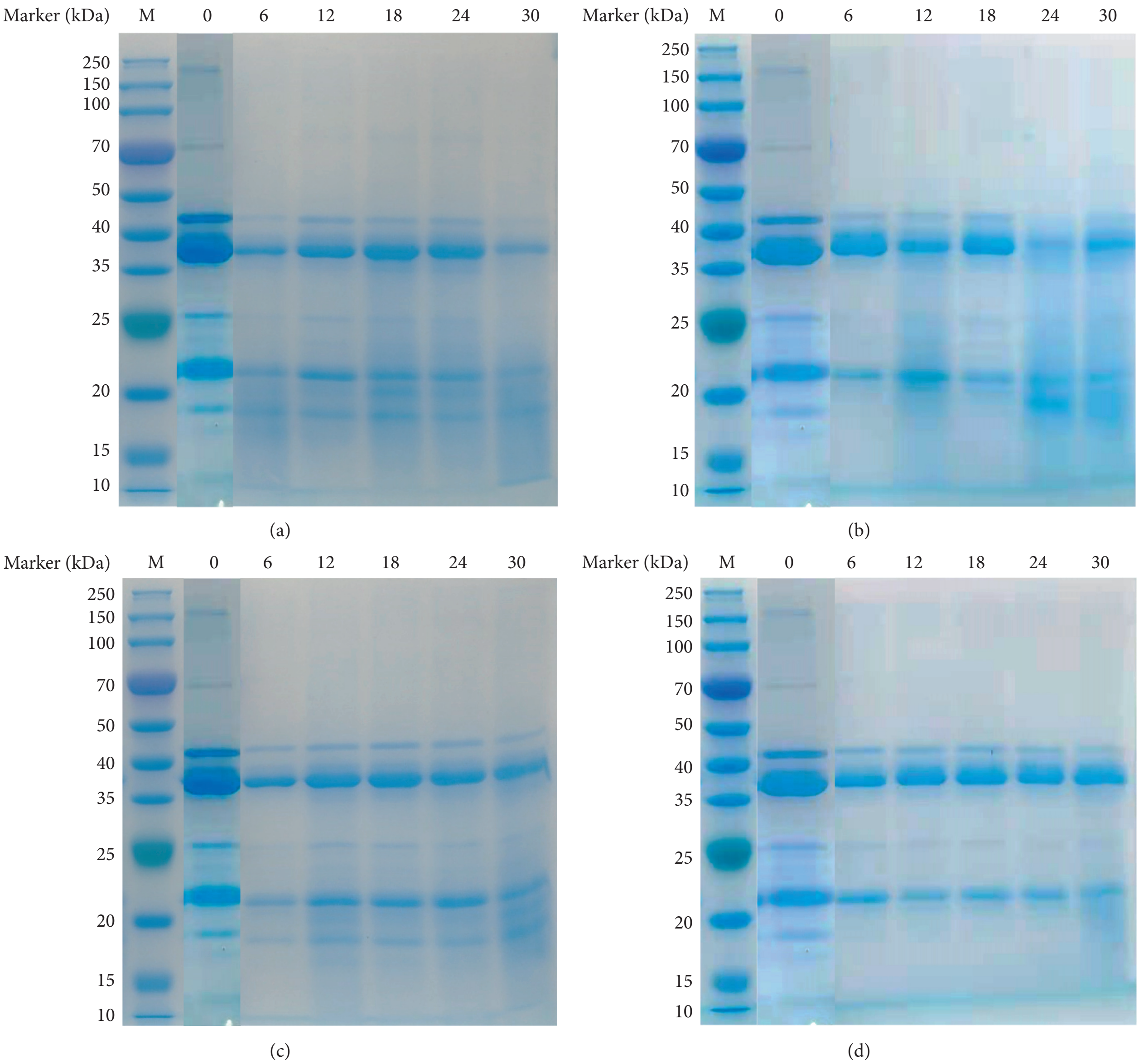

Figure 2: The SDS-PAGE pattern of dried shrimp myofibril protein during storage. (a) VP37°C; (b) AP37°C; (c) VP20°C; (d) AP20°C.

samples. The troponin C band also decreased or almost disappeared in AP shrimp at the end of the storage period, but did not significantly change in VP shrimp. Therefore, in order to delay the occurrence of protein degradation in the storage process of dried shrimp, the optimal treatment group should choose VP20°C.

Alterations in muscle microstructure are an important indicator of the quality of dried shrimp. Analysis of shrimp muscle structure by SEM indicated that before storage (day 0), muscle fibers were well maintained; they were relatively thin and evenly spaced, and there was no aggregation (Figure 3). However, at the end of the storage period (day 30), muscle fibers became coarser and appeared to aggregate, the gap between fiber bundles increased, and the uniform and delicate muscle microstructure was destroyed. AP shrimp showed larger crevices in muscle fibers and coarser muscle tissue than VP shrimp both at 37°C and 20°C. Similar results were obtained by Yingying et al. [40] who studied the influence of long-term storage on shrimp muscle microstructure. In order to better maintain the muscle microstructure of dried shrimp, VP packaging should be used during storage, and it should be placed in a room temperature environment of 20°C.

3.2. Establishment of the Kinetic Model. Next, we developed kinetic models for predicting quality of VP shrimp during storage. The results of the kinetics order of reactions determined by a graphical method are given in Table 2. Moisture, TVB-N, SH, and carbonyl contents were important indicators of quality changes in dried shrimp during storage at different temperatures as evidenced by regression coefficients (R^2), which were all above 0.89. Changes of moisture and SH contents were well-fitted into the second-

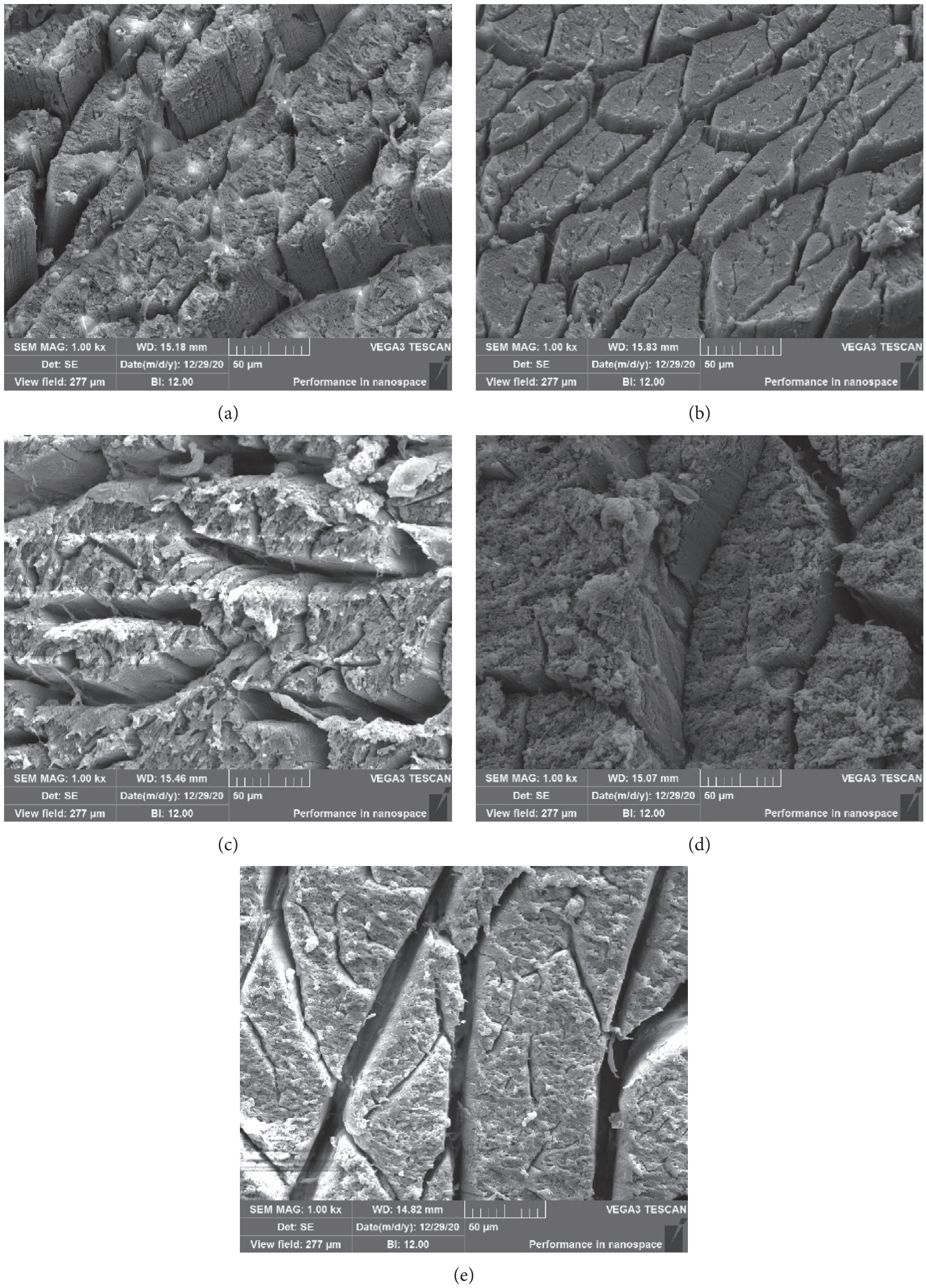

Figure 3: Influence of different packing methods and storage temperatures on the microstructure of dried shrimp muscle (magnification: 1000). (a) 0 day. (b) 30-day VP37°C. (c) 30-day AP37°C. (d) 30-day VP20°C. (e) 30-day AP20°C.

order kinetics model, whereas those of TVB-N and carbonyl contents obeyed the zero-order kinetics model.

The activation energy (E_A) values of moisture, TVB-N, SH, and carbonyl contents were 37.64, 16.47, 8.10, and 12.22 kJ/mol, and the corresponding preexponential constant (k_0) values were 3.08×10^3, 3.08×10^2, 0.08, and 5.99, respectively, at 37°C and 20°C. Protein degradation and quality prediction models for dried shrimp based on moisture, TVB-N, SH, and carbonyl contents were obtained by inserting the E_A and k_0 values into equation (7).

The quality prediction model for dried shrimp is based on moisture content:

$$\frac{1}{y_{1(t)}} = 0.02 + 3.08 \times 10^3 t \, \exp\left(\frac{-37640.12}{RT}\right). \quad (11)$$

Table 2: Estimation of the order of quality change of dried shrimps by examining the regression coefficient (R^2) and rate constant (k) from plots of zero-, first-, and second-order reactions.

Indices	Temperature (K)	Initial value (B_0)	0 order, B versus time		1st order, ln B versus time		2nd order, $1/B$ versus time	
			R^2	k	R^2	k	R^2	k
Moisture content (y_1)	293	42.251 ± 0.538	0.9833	−0.5991	0.9950	−0.0190	0.9951	0.0006
	310	42.251 ± 0.538	0.7592	−0.6851	0.8870	−0.0290	0.9409	0.0014
ΔE (y_2)	293	0 ± 0.000	0.8872	0.4868	—	—	—	—
	310	0 ± 0.000	0.8615	0.5026	—	—	—	—
TVB-N (y_3)	293	10.480 ± 0.187	0.9935	0.3565	0.9881	0.0232	0.9642	−0.0016
	310	10.480 ± 0.187	0.9878	0.5165	0.9789	0.0296	0.9408	−0.0018
SH (x_1)	293	7.092 ± 0.036	0.9249	−0.0850	0.9430	−0.0160	0.9487	0.0030
	310	7.092 ± 0.036	0.8298	−0.0870	0.8900	−0.0170	0.9265	0.0036
Carbonyl content (x_2)	293	2.402 ± 0.04	0.9641	0.0398	0.9641	0.0133	0.9588	−0.0045
	310	2.402 ± 0.04	0.9622	0.0524	0.7967	0.0152	0.7218	−0.0045

Data are mean ± SD ($n = 3$).

Table 3: Correlation between protein and quality.

	SH	Carbonyl content
Moisture content	0.935**	−0.979**
TVB-N	−0.928**	0.894**

**Correlation is significant at 0.01 level (two-tail).

Table 4: Predicted and observed values of moisture content for dried shrimps at 293 K.

Carbonyl content	Moisture content		Relative errors (%)
	Predicted value	Observed value	
2.402 ± 0.040	42.252	42.251 ± 0.538	0.00
2.640 ± 0.035	36.684	38.533 ± 0.607	4.80
2.644 ± 0.034	36.618	36.017 ± 0.846	−1.67
2.741 ± 0.022	34.743	34.677 ± 0.478	−0.19
2.686 ± 0.061	35.781	32.863 ± 0.549	−8.88
3.014 ± 0.034	30.407	30.433 ± 0.618	0.09
3.075 ± 0.024	29.572	29.240 ± 0.670	−1.14
3.282 ± 0.020	27.073	28.036 ± 0.762	3.43
3.379 ± 0.041	26.050	26.272 ± 0.655	0.85
3.518 ± 0.068	24.696	24.667 ± 0.618	−0.12
3.590 ± 0.052	24.056	23.032 ± 0.447	−4.45

Data are mean ± SD ($n = 3$).

The quality prediction model for dried shrimp is based on TVB-N content:

$$y_{3(t)} = 10.48 + 3.08 \times 10^2 t \exp\left(\frac{-16469.16}{RT}\right). \quad (12)$$

The protein oxidation prediction model for dried shrimp is based on SH content:

$$\frac{1}{x_{1(t)}} = 7.09 + 0.08t \exp\left(\frac{-8099.06}{RT}\right). \quad (13)$$

The protein oxidation prediction model for dried shrimp is based on carbonyl content:

$$x_{2(t)} = 2.40 + 5.99t \exp\left(\frac{-12218.01}{RT}\right), \quad (14)$$

where y_1 (t), y_3 (t), x_1 (t), and x_2 (t) are the predicted values of moisture, TVB-N, SH, and carbonyl contents, respectively, in dried shrimp stored for a certain time at 37°C and 20°C.

3.3. Correlation Analysis of Protein Oxidation and Quality and Establishment of the Prediction Model. Table 3 provides the correlation between protein oxidation indexes and the quality of dried shrimp during storage under VP conditions at 37°C and 20°C. The results indicated that protein oxidation indexes were significantly associated with moisture and TVB-N content, some showing positive and the other negative correlations. Thus, there was a significant correlation between SH and TVB-N contents with high Pearson coefficient and $p < 0.01$ in a two-tailed test. Carbonyl and moisture contents also showed a significant correlation with high Pearson coefficient and $p < 0.01$ in a two-tailed test. Therefore, the changes in moisture and TVB contents could be predicted by carbonyl and SH contents, respectively.

According to equations (11) and (14), the model predicting moisture content based on carbonyl content can be calculated as

$$\frac{1}{y_1} = 0.024 + 513.167\left(x_2 - 2.402\right)\exp\left(\frac{-25422.09}{RT}\right). \quad (15)$$

According to equations (12) and (13), the model predicting TVB-N content based on SH content can be calculated as

$$y_3 = 10.48 + 3691.185\left(\frac{1}{x_1} - 0.141\right)\exp\left(\frac{-8370.14}{RT}\right). \quad (16)$$

3.4. Validation of the Predictive Models. The validity of quality prediction models based on protein oxidation in dried shrimp during storage at 20°C was verified by comparing the predicted and observed values of each protein index. Table 4 provides the moisture content measured in real samples and predicted based on carbonyl content in dried shrimp at 293 K. Table 5 provides TVB-N content measured and predicted based on SH content in dried

Table 5: Predicted and observed values of TVB-N for dried shrimps at 293 K.

SH	TVB-N		Relative errors (%)
	Predicted value	Observed value	
7.092 ± 0.036	10.480	10.480 ± 0.187	0.00
6.374 ± 0.085	12.366	11.410 ± 0.266	−8.38
5.694 ± 0.103	14.592	12.783 ± 0.288	−14.15
5.733 ± 0.040	14.452	13.637 ± 0.298	−5.98
5.683 ± 0.030	14.635	14.315 ± 0.312	−2.23
5.564 ± 0.041	15.080	15.347 ± 0.361	1.74
4.929 ± 0.129	17.831	16.721 ± 0.409	−6.64
4.946 ± 0.055	17.753	18.512 ± 0.237	4.10
4.425 ± 0.106	20.582	18.755 ± 0.170	−9.74
4.360 ± 0.045	20.977	20.149 ± 0.114	−4.11
4.319 ± 0.046	21.239	21.005 ± 0.240	−1.12

Data are mean ± SD ($n = 3$).

shrimp at 293 K. The relative differences between the predicted and observed values of each selected quality index were used to assess the performance of quality prediction models based on protein oxidation [41]; if the relative errors were below 10%, the model was considered to be acceptable [42]. In the present study, the relative errors for moisture and TVB-N contents were within 10%, indicating that the two models were sufficiently reliable.

4. Conclusions

In this study, we analyzed the changes in the quality and protein oxidation of solar-dried *P. vannamei* shrimp during storage. According to the variations in ΔE, protein composition, muscle microstructure, and moisture content, VP shrimp was preserved better than AP shrimp. The Arrhenius equation used to analyze the kinetics of various indexes in VP shrimp during storage indicated that moisture and SH contents fitted well into the second-order kinetics model, whereas TVB-N and carbonyl contents obeyed the zero-order kinetics model. There was a significant correlation between moisture and carbonyl contents and between TVB-N and SH contents. The models of predicting moisture content based on carbonyl content and TVB-N content based on SH content were established and their reliability verified.

Data Availability

The data used to support the findings of this study are included within the article. Raw data are available from the corresponding author upon request.

Conflicts of Interest

The authors declare that there are no conflicts of interest.

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Review Article

Artificial Intelligence to Improve the Food and Agriculture Sector

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The world population is expected to reach over 9 billion by 2050, which will require an increase in agricultural and food production by 70% to fit the need, a serious challenge for the agri-food industry. Such requirement, in a context of resources scarcity, climate change, COVID-19 pandemic, and very harsh socioeconomic conjecture, is difficult to fulfill without the intervention of computational tools and forecasting strategy. Hereby, we report the importance of artificial intelligence and machine learning as a predictive multidisciplinary approach integration to improve the food and agriculture sector, yet with some limitations that should be considered by stakeholders.

1. Introduction

The estimation of the global food production must be increased by 60–110% to feed 9-10 billion of the population by 2050 [1, 2]. Thus, the sustainability of agriculture field is the key to guarantee food security and hunger eradication for the ever-growing population. In addition, due to the appearance of several food safety scandals and incidents in the food sector such as bovine spongiform encephalopathy and dioxin in poultry [3], a well-documented traceability system has become a requirement for quality control in the food chain. Moreover, weather and climate change conditions, together with the sustainable water management due to water scarcity, are crucial challenges in the next years. For these reasons, urgently, the establishment of a strategic shift from the current paradigm of enhanced agricultural productivity to agricultural sustainability is needed. To anticipate efficient solutions, helping farmers and stakeholders to enhance their decision by adopting sustainable agriculture practices is a crucial choice, especially the use of digital technologies including Internet of things (Iot), Artificial Intelligence (AI), and cloud computing. Additionally, the subsets of AI (machine and deep learning algorithms) combined with location intelligence technologies are extensively used. The goal of our review is to present the main applications of artificial intelligence and machine learning techniques in the agri-food sector.

2. Artificial Intelligence and Machine Learning Approach

The artificial intelligence (AI) is a creative tool that simulates the human intelligence and ability processes by machines, principally computer systems, robotics, and digital equipment [4]. Several applications of the AI include natural language processing (NLP) to comprehend human verbal communication as it is spoken, computer vision to see an analog-to-digital conversion such as video, and speech recognition and expert systems to simulate the judgment. The AI encoding is based on learning (acquire data and then create algorithms to turn them into actionable information), reasoning (choose the right algorithm to reach a preferred result), and self-correction (continually adjust designed algorithms and ensure that they provide the most accurate results) as three cognitive skills [5]. The AI technique is being used in several sectors which are seeing the fastest growth in the recent years such as finance, healthcare, retail, pharmaceutical research, intelligent process automation, and marketing. Machine learning (ML) is one of the central themes of AI and helps people to work more creatively and efficiently. In ML, statistical and mathematical methods are used to learn from datasets to make data-driven predictions/decisions. Several different methods exist for this. General distinction can be made by two systems; the first one is the symbolic approaches (the induced rules and the examples are explicitly represented) and the second one is the subsymbolic approaches (artificial neuronal networks: ANN). The ML approach is classified into three major tasks: supervised, unsupervised, and reinforcement learning. According to the supervised learning, the aim of this approach is to map the variables to the preferred output variable [6]. The predictive model is created using the labeled data with the prior knowledge of the input and the desired output variables. Algorithms used under supervised learning techniques are numerous, particularly, decision trees, Bayesian networks, and regression analysis. Concerning the unsupervised learning, it includes algorithms such as Artificial Neural Networks (ANNs), clustering, genetic algorithm, and deep learning and uses unlabeled datasets without prior knowledge of the input and output variables. In fact and as mentioned by Jordan and Mitchell [7], this case of unsupervised machine learning method establishes the hidden patterns by using the unlabeled dataset and is primarily used for dimensionality reduction and exploratory data analysis. According to the third category of ML task named the reinforcement learning, numerous algorithms are used for machine skill acquisition, robot navigation, and real-time decision making such as Q-learning and deep Q-learning. In this case of ML task, the learner interacts with the environment to collect information and the two steps of training and testing datasets are combined. The learner gets awarded for his actions with the environment leading to an exploration versus exploitation dilemma. The learner must explore new unknown actions to gain more information as compared to exploiting the information already collected [8]. Recently, AI technology has opened the doors of its implementation in the agri-food sector. In fact, AI approaches offer significant contributions and assistances to understanding a model's identification, service creation, and the decision-making processes as support to the different agri-food's applications and supply chain stages. The principal goal of AI in agriculture is to provide precision and forecasting decision in order to improve the productivity with resource preservation [4]; through this, AI tools propose algorithms to evaluate performance, classify patterns, and to predict unexpected problems or phenomena in order to solve comprehension problems in the agricultural field and for the identification of pests and its suitable method of treatment, as well as the management of the irrigation process and water consumption by setting up smart irrigation systems. Abiotic and biotic factors are being assessed through remote sensing and sensors in order to optimize crop and livestock management [4, 9]. In addition, the AI implementation and applications have enormous advantages which could revolutionize the agri-food sector and its related business. Firstly, AI provides more efficient ways to produce, harvest, and sell crops products as well as emphasis on checking defective crops and improving the potential for healthy crop production and also AI is being used in applications such as automated machine adjustments for weather forecasting and disease or pest identification with 98% accuracy. In fact, recently, Sujatha et al. [10] compared the performance of machine learning (ML) and deep learning (DL) methods to detect and identify the citrus plant leaf disease. They showed that the VGG-16 deep learning method gave the best result in terms of disease classification accuracy. Secondly, the progression in the AI technique has reinforced agro-based businesses to run more proficiently by improving crop management practices, thus helping many tech businesses invest in algorithms that are becoming useful in agriculture as well as by solving the contrasts farmers face such as climate variation and an infestation of pests and weeds that decreases yields. Indeed, Crane-Droesch [11] developed a novel modeling approach for augmenting parametric statistical models with deep neural networks, which we term semiparametric neural networks (SNNs), and by using data on corn yield from the US Midwest, they showed the outperformance of this approach in predicting yields of years withheld during model training compared to classical statistical methods and fully nonparametric neural networks. Thirdly, by using AI tools, farmers could be able to remain updated with the data related to weather forecasting and, therefore, predicted weather data help farmers to increase yields and profits without risking the crop, and as a result, after analyzing the generated data, AI allows the farmers to better understand and learn and then to take the precaution by implementing practices in order to make a punctual smart decision. In fact, Fente and Singh [12] collected different weather parameters (temperature, precipitation, wind speed, pressure, dew point visibility, and humidity) from the Indian climate data center and implemented a weather forecasting model by using a recurrent neural network (RNN) with the long-short-term memory (LSTM) technique. They concluded that the used technique gave high-accuracy results compared to other weather forecasting approaches. Fourthly, AI approaches are capable of monitoring soil health and management by conducting and identifying the possible defects and nutrient deficiencies in the soil either by image captured with the camera recognition tool or by deep learning based tool to analyse flora patterns in farms and to simultaneously understand soil defects, plant pests, and diseases. In fact, Suchithra and Pai [13] classified and predicted the soil fertility indices and pH levels of Kerala north central laterite Indian region soil by using the Extreme Learning Machine (ELM) technique with different activation functions such as hard limit, sine-squared, triangular basis, hyperbolic tangent, and gaussian radial basis. They revealed that the maximum performance (80% of the accuracy rate calculations in every problem) for four out of five problems was obtained with the Gaussian radical basis function followed by hyperbolic tangent. However, the best performance (90%) of the pH classification problem was given by the hyperbolic tangent, whereas the moderate values were given by the gaussian radial basis. Fifthly, an important functional benefit of the AI technology employment is the environmental protection by decreasing pesticide usage. For example and in order to manage weeds faster and with greater accuracy, AI techniques by implementing robotics, computer vision, and machine learning could help farmers to spray chemicals only where the weeds are; thus, this directly reduced the use of the chemical substance spraying on the whole field. Consequently, AI tools are helping farmers find more efficient actions to protect their crops from weeds. Finally, the practice of the advanced AI-based technologies has other advantages on the agri-food supply chain such as reducing employee training costs, reducing the time needed to solve problems, reducing the amount of human errors, reducing human intervention, and offering an automated good, accurate, and robust decision-making on the right time with low cost [14].

3. Artificial Intelligence Technology and Application to Improve Agriculture and Food Industries

Currently, the use of ML algorithms in the main four clusters (preproduction, production, processing, and distribution) of the agriculture supply chain is becoming more and more important [15]. In fact, in the preproduction step, the ML technologies are used, especially for the prediction of crop yield, soil properties, and irrigation requirements. In the next stage of the production phase, the ML could be used for disease detection and weather prediction. Concerning the third cluster of the processing phase, utilization of ML approaches is applied, especially to estimate of the production planning to reach a high and safe quality of the product. ML algorithms could be used also to the distribution cluster, especially in storage, transportation, and consumer analysis. The preproduction cluster is the initial step in the agriculture supply chain. It mainly concerns the prediction of crop yield, soil properties, and irrigation requirement. Many researchers report the importance of the crop yield production in order to better support plant management. In fact, by using as an input data (equipment requirements, nutrients, and fertilizers) in predicting efficient models based on ML algorithms, these precision agriculture tools aim to make stakeholders and farmers support ideal decision in crop yield forecasting and improve the smart farming practices. Recently, different ML algorithms are used for crop yield prediction such as the Bayesian network, regression, decision tree, clustering, deep learning, and ANN [16–18]. According to the prediction of soil management properties, several ML algorithms are used in learning soil properties. Among them, the LS-SVM (least-squares support vector machine) method was used by Morellos et al. [19] to study 140 soil samples. Nahvi et al. [20] used the SaE (self-adpative evolutionary) ML algorithm to boost the performance of the extreme learning machine (ELM) architecture to estimate daily soil temperature. Additionally, Kumar et al. [21] proposed a novel method named the CSM (Crop Selection Method) to resolve crop selection problems and help improve net yield rate of crops over the season. In addition, Ben Ayed et al. [16] analyzed 18 worldwide table olive cultivars by using morphological, biological, and physicochemical parameters and the Bayesian network to study the influence of these parameters in tolerance, productivity, and oil content. They revealed that oil content was highly influenced by the tolerance of the crop. Another important parameter in the preproduction cluster is the irrigation management that plays a crucial role in affecting the quality and quantity of the crops. In fact, to achieve an effective irrigation system (better decision in when, where, and how much to irrigate), researchers used soil moisture data, precipitation data, evaporation data, and weather forecasts as input data for simulation and optimization of predicted models based on ML adequate algorithms [22]. In fact, Arvind et al. [23] demonstrated that using ML algorithm associated with other technologies such as sensors, Zigbee, and Arduino microcontroller was efficient for prediction and tackles drought situations. In addition, Cruz et al. [24] exploited the ANN feed-forward and back-propagation technologies to optimize the water resources in a smart farm. More recently, Choudhary et al. [25] used PLSR and other regression algorithms as an artificial intelligence tool combined with sensors for data collection and Internet of things hardware implementation to increase efficiency and economic feasibility.

The production cluster is the second phase in the agriculture supply chain. There are numerous parameters that affect and play a key role in the crop production step. Among them are the weather forecasts (sunlight, rainfall, humidity, etc.), crop protection against biotic stress factors (weeds and pathogens) and abiotic stress factors (nutrient and water deficiency), crop quality management, and harvesting. Many different ML algorithms are used to simulate effective models for weather prediction (ANN, deep learning, decision tree, ensemble learning, and instance-based learning) [26], for crop protection (clustering and regression) [27], ANN, deep learning [14], weed detection (ANN, decision tree, deep learning, and instance-based learning) [28], crop quality management (clustering and regression) [29], and harvesting (deep neural networks, data mining techniques such as k mean clustering, k nearest neighbor, ANN, and SVM) [30]. During the harvest stage which is the final horticultural stage after the ripening of the crops, ML algorithms are also used to predict the transformation of the fruit or crop color. In fact, many research teams used ML algorithms to predict the fruit ripening stages and fruit maturity such as Gao et al. [31] who achieved 98.6% classification accuracy when they used hyperspectral datasets and the AlexNet CNN deep learning model to classify the strawberry fruits into early-ripe and ripe stages. The processing cluster is the third stage in the agriculture supply chain. There are many types of processing techniques of agriculture products such as heating, cooling, milling, smoking, cooking, and drying. The choice of effective combined parameters in the processing stage results in a high quality and quantity of food product and, at the same time, avoiding overutilization of resources. To achieve this goal, several food industries use modern food processing technologies by installing software algorithms based on ML. Among the used ML algorithms, there are genetic algorithm, ANN, clustering, and Bayesian network [32]. In fact, Arora and Mangipudi [33] proposed support vector machine

(SVM) classifier and artificial neural network (ANN) models to detect the presence of nitrosamine in the red meat food samples, and the obtained predictive modeling results revealed that the highest testing accuracy was obtained using the deep learning model. Additionally, Farah et al. [34] used differential scanning calorimetry combined with ML tools (such as gradient boosting machine, random forest, RF, multilayer perceptron, MLP, and GBM) to determine the milk characteristics and authenticity and to detect fraud. The most efficient results were obtained with GBM and MLP machine learning tools which were able to classify 100% of adulterated samples. The distribution cluster is the final step in the agriculture supply chain. This stage is the connection between food production and processing and the final use or final consumer. ML algorithms could be used in storage, transportation, consumer analytics, and inventory management. In transportation and storage steps, the mainly used algorithms are genetic algorithm, clustering, and regression. These predictive techniques aim to better preserve the food product quality, to ensure safe food products and to minimize the product damage by tracing the product [16]. For the consumer analytics, ML techniques such as deep learning and ANN are used in the food retailing phase for predicting consumer demand, perception, and buying behavior. For the inventory management, the use of ML genetic algorithms helps in predicting daily demand and to ensure that there are no inventory-related problems [35]. Examples of AI-applied technology are numerous in the agri-food sector, *i.e.,* robotics and mechatronics [2], drones [2, 36], geographic information systems (GISs) [37], blockchain (BC) [38], and satellite guidance [2]. Miranda et al. [39] have reported and described these items as sensing, smart, and sustainable technologies, providing systematic process where connectivity, automation, precision, monitoring, and digitization are prevalent [40–43]. Smart mechanization, robotics, and mechatronics in agriculture aim to reduce drudgery and minimize inputs using highly autonomous and intelligent machines [2]. From horse to tractor, robots, and intelligent vehicles, a revolutionary era has come for agriculture and food industry, from rudimentary to high efficiency of agriculture with the introduction of mechanization, innovative technologies, computerized analysis, and decision, improving farming activities and crop productivity [2]. Revolutionizing machines, often called "agribots," are now used in agriculture for all kinds of activities, namely, soil preparation, seed sowing, weed and pest treatment, irrigation, fertilization, and ultimately, grain and fruit harvesting, minimizing effort and energy cost [2, 44–47]. As a whole crop management, agricultural drones can be used starting from soil treatment (herbicide), going to sowing step, plant treatment (pesticide), and physiological control and observation, and ending with harvest time determination [2, 36, 48–51]. Agricultural drones are now able to supply water, fertilizers, herbicides, and pesticides and even film, capture images, and generate maps in real time of plants and field in order to help farmers take management decision [2, 48, 52–56]. Today, farmers use drones for livestock surveillance for monitoring illnesses, injuries, and even pregnancies [57]. In 2019, the worldwide agriculture drone market value was about USD one million and is expected to reach USD 3.7 million by 2027 [58], whereas the robot and agriculture drone market is projected to reach USD 23 billion by 2028 [59, 60]. Based on geospatial technology that relies on satellite, GIS is applied on several fields of agriculture: crop management, irrigation control, yield estimation, disease and weed control, farming automation, livestock monitoring, vegetation mapping, erosion, and land degradation forecast [37, 61–68]. Application of GIS is, therefore, suitable in precision agriculture, real-time control, and raising awareness and significantly contributes to meet the needs of continuous rise in food demand. Blockchain is another technology that answers to consumer's awareness about food origin, quality, and mainly, safety. BC affords transparency, trust, certification, and traceability of food product supply chain from farm to fork, where every single operation and data are timely registered, saved, encrypted, and secured, not in a single central server nor under a single control, but in a common platform database where every user could access and take part in transactions [38, 69–79]. Such digital and computerized traceability of the whole food supply chain would allow detection of deficiency, contamination, and adulteration of the product, thus optimizing its quality and safety; therefore, a multitude of agencies, consortia, and platforms were born in this context [79]. In 2020, the worldwide market of BC in agri-food market size was about USD 133 million; it is estimated to grow and reach around USD 950 million by 2025 [69]. Satellite-guided technology applied to agriculture improved farm monitoring and aided mapping agricultural zones, soil management, crop husbandry, irrigation disease and weed control, yield estimation, and harvesting [2, 80–88]. Hence, in the late 1900s, one single farmer was able to produce food grains for 128, actually, and in the future, through smart agriculture, this ratio will greatly increase [2].

4. Limits and Drawbacks of AI and ML

However, despite all these advantages, the AI technology has also some drawbacks representing challenges. Firstly, the most important social challenge is the unemployment that could be a threat; in fact, smart machines and robots could replace the majority of the repetitive works and tasks; thus, human interference is becoming less, which will cause a major problem in the employment standards. Other technological challenges, for instance, machines can do only those tasks which they are programmed or developed to do, and anything out of that they tend to crash or give irrelevant outputs could be a major backdrop. In addition, the high costs of creation and maintenance of the smart machines as well as the cleaver computers could be considered as technological limits of the AI technologies, especially that AI is updating every day which is why the hardware and software need to get updated with time to meet the latest requirements. Machines need repairing and maintenance which is expensive. The creation requires huge costs as they are very complex machines. Other issues related to these applications are their high cost that could increase the price of the products. Moreover, beyond the opportunities afforded by smart and computerized technologies, some risks and apprehensions could be posed for sustainability, particularly the massive energy consumption, e-waste problem, market concentration, job displacement, and even the ethical framework [79, 89].

5. Conclusions

The agriculture and food industries are one of the most vital fields for humanity. The first products of agriculture are used as inputs in several multiactor distributed supply chains, including four clusters or stages of the agriculture supply chain (preproduction, production, processing, and distribution) in order to reach the end user or consumer. Due to several challenges in the future for the agriculture and food sector and various factors such as climate change, population growth, technological progress, and the state of natural resources (water, etc.), it is urgent to use the digital technologies at different stages of agriculture supply chain such as automation of farm machinery, use of sensors and remote satellite data, artificial intelligence, machine learning for improved monitoring of crops, and water, for agriculture food product traceability. In the present study, we demonstrate the main applications of the AI and ML algorithms in different clusters of the agriculture supply chain and the unquestionable growing tendency in the adoption of these algorithms to improve food industries.

Data Availability

The data used to support the findings of this study are available from the corresponding author upon request.

Conflicts of Interest

The authors declare no conflicts of interest.

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Research Article

Deep Learning Based on Residual Networks for Automatic Sorting of Bananas

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This study presents the design of an intelligent system based on deep learning for grading fruits. For this purpose, the recent residual learning-based network "ResNet-50" is designed to sort out fruits, particularly bananas into healthy or defective classes. The design of the system is implemented by using transfer learning that uses the stored knowledge of the deep structure. Datasets of bananas have been collected for the implementation of the deep structure. The simulation results of the designed system have shown a great generalization capability when tested on test (unseen) banana images and obtained high accuracy of 99%. The simulation results of the designed residual learning-based system are compared with the results of other systems used for grading the bananas. Comparative results indicate the efficiency of the designed system. The developed system can be used in food processing industry, in real-life applications where the accuracy, cost, and speed of the intelligent system will enhance the production rate and allow meeting the demand of consumers. The system can replace or assist human operators who can exert their energy on the selection of fruits.

1. Introduction

In the food industry, the quality of processed fruits is extremely important. Meeting the demands of the consumers and producing high-quality fruits at the production line at a very fast rate requires the implementation of high-performance technologies [1]. Moreover, the food industry is one of the few fields which have restricting conditions and constraints due to its dependency on weather conditions and the labor market [2]. For example, if the fruits were not harvested at the most suitable time due to weather conditions, the quality and quantity of the harvest may decrease due to bad weather conditions and excessive ripening of the fruits. Over the years, the most technological processes in this industry were mainly controlled by human operators. Some delicate tasks such as postharvest and grading of healthy and defective products were based on human-made decisions. Human operators are sometimes exposed to the tiredness of the eyes due to lack of sleep and fatigue caused by overworking that can affect their performances. Fruit sorting is a decision-making task which is based on some visual features of the fruit and decides whether a fruit is healthy or defective when it passes through a conveyor belt. Therefore, it is a computer vision problem which can be perfectly solved using machine learning that can prevent the errors caused by human operators [3].

Recently, different research works have been performed for controlling and grading of fruits using computer vision and machine learning techniques. The common applications are classification and sorting of fruits [4, 5], identification of the fruits defects [6], ripeness detection [7], and estimation of food security [8]. Reference [6] claimed that the products produced should have a certain weight, size, colour, and density in order to meet quality standards. Therefore, they proposed a machine vision system for controlling 1–10 conveyor belts, with a maximum performance of 15 fruits per second. The system aimed to classify the fruits into a set of classes using the weight, size, and colour of fruits. The presented system was based on the automatic visual inspection on fruits and vegetables using machine vision algorithms and sensors. The developed system using visual fruits' features implemented colour processing, weights detection, size measurements, and density detection. The authors claimed that the system performance was satisfactory as it was compared to human criteria, and no significant differences were observed. Moreover, the computation time of the system has also been decreased to 15 fruits/second, and at the same time, the system controlled 2 conveyor belts.

In recent years, research works had been carried out for determination of banana size [9], banana ripeness [10], and sorting of healthy and unhealthy bananas [11]. Reference [5] presented an automatic sorting system for bananas. The system was based on the extraction of texture features of bananas using the gray-level cooccurrence matrix (GLCM). Three algorithms backpropagation neural network (BPNN), support vector machine (SVM), and radial basis function network (RBFN) were used for classification purposes. Experimental results have shown the highest classification rate of 100% using SVM. However, RBFN and BPNN scored 96.25% and 98.8%, respectively. As a result of the implementation of these research studies, the system performances such as the production quality and quantity have been increased. Additionally, the production process has switched to the faster operating mode.

Recently, different machine learning algorithms are implemented for solving different engineering and image processing problems. Machine learning, in particular deep learning techniques, has undergone a major development that sharply improved its performance in different areas such as medicine [12, 13], agriculture [14], and food engineering [15]. Different deep learning structures have been designed in order to improve their performance in problem solutions. These are AlexNet [16] with 8 layers, VGG [17] with 18 layers, and GoogLeNet [18] with 22 layers. Chronologically, the aforementioned networks were getting deeper and deeper. However, the "in-depth" structures caused an optimization difficulty during the training of the networks, i.e., vanishing gradients. Consequently, this affected the generalization performance of the network. The accuracy of the network became saturated and degraded rapidly. To overcome this problem, residual learning was employed for training very deep networks [19]. A few research studies have been performed using residual networks for solving different engineering problems. In reference [20], the combination of a deep residual neural network (ResNet) and lower and upper bound estimation is proposed for forecasting future flow in order to construct prediction intervals. In reference [21], the deep neural network is used to identify six kinds of grain pests. The residual network is introduced in order to improve convolutional vision of the model. Reference [22] presents a local binary residual block to promote the very deep residual networks on the trainable parameters. It was shown that the used structure reduced at least 69.2% trainable parameters. The study [23] presented a deep convolutional neural network termed as the dense residual network for optical character recognition. The study [24] presents multiple improved residual networks for super resolution reconstruction of medical images. Residual learning or residual networks (ResNet) builds special constructs by skipping some connections and jumping over some layers. These ResNet models are basically designed by double or triple layer skips instead of using consecutive layer connections as it was used in other deep plain networks (AlexNet). Skipping over layers allows avoiding the vanishing gradient problem. In this study, we are using residual learning for optimization of network parameters. The study presents the design of a deep network of 50 layers, called ResNet-50, in order to sort the banana fruits into healthy or defective category. Transfer learning and residual learning are applied for the optimization of the network parameters and development of the system.

The study is structured as follows. Section 2 presents the ReseNet-50 used for grading bananas. Section 3 presents the dataset and the training process of the network. Section 4 presents the results and discussion of the study. Section 5 gives the conclusion.

2. Residual Learning

Deep networks are multilayer neural network structures with more than one hidden layer. The learning of deep networks are basically carried out hierarchically, starting from the lower level to higher, through various layers of the network [25]. Deep learning based on convolution neural networks (CNNs) have been widely used in various areas to solve different engineering problems and showed significant performance in problem solutions [26–32]. As mentioned, the "in-depth" structures caused an optimization difficulty during training of the networks, i.e., vanishing gradients problem and affected the performance of the network. In this study, we present residual learning to overcome this problem and design a deep learning structure for grading the fruits.

Figure 1 depicts a residual block of ResNet. As shown in the figure, in residual networks, stacked layers perform a residual mapping by creating shortcut connections which perform identity mapping (x). Their outputs were added to the output of the stacked layers' residual function $F(x)$.

During the training of the deep network using backpropagation, the gradient of error was calculated and propagated to the shallow layers. In deeper layers, this error becomes smaller until it finally vanishes. This is called the gradient vanishing problem of very deep networks. The problem can be solved using residual learning [19] as shown in Figures 1 and 2.

Figure 2 shows the original residual branch or unit l inside the residual network. The figure depicts weights, batch normalization (BN), and rectified linear unit (ReLU). The input and output of a residual unit were calculated as follows:

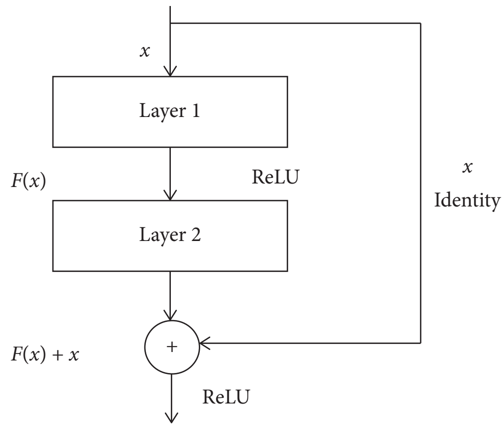


Figure 1: Identity mapping.

$$y_l = h(x_l) + F(x_l + W_l),$$
$$x_{l+1} = f(y_l), \tag{1}$$

where *h(x(l))* is the identity mapping, F is the residual function, x_l is the input, and W_l is the weight coefficient. The identity mapping can be written as *h(x(l)) = x(l)*. This defines the basis of ResNet architecture.

The residual networks were developed for the networks having a different number of layers, 34, 50, 101, and 152. In this study, ResNet-50 was used. The network consists of 50 layers. In the 34-layer of ResNet, by replacing each 2-layer block with 3-layer bottleneck block, creating a 50-layer ResNet was carried out.

3. Materials and Methods

3.1. Dataset. The proposed ResNet-50 deep learning structure was applied for classification of bananas. The model was retrained using two banana datasets that include healthy and defective banana images. Note that healthy means that bananas were eatable and can be used in the fruit industry as raw materials, while defective means they were deteriorated and not eatable. The first database used in this research was taken from [5]. The data acquisition stage was carefully considered, and the images were captured using a digital camera and then converted into the manageable entity. Collected images are of size 960×720 pixels; hence, we downsampled them in order to fit the input size of ResNet-50 which is 224×224 pixels. The dataset contains 300 images that include 150 healthy and 150 defective bananas. The second database also contains 300 images. Here, the healthy banana images were obtained from the dataset Fruit 360 [32] that includes different fruit types. Only 150 healthy banana images were collected from this dataset. However, to make equal distribution of classes, 150 images of defective bananas were collected from the web. Overall, a dataset includes 600 images that include 300 healthy and 300 defective banana images.

3.2. Data Augmentation. Data augmentation was employed in order to create a more robust sorting system and prevent the overfitting during the training of the network. Hence, shift translation and scale invariance were employed in order to have the power of detecting the condition of banana at different angles and shifts. Therefore, the 600 original images of bananas were rotated at angle 0°, 90°, and 180°. Moreover, those images were also randomly translated up to two pixels horizontally and vertically. In total, a dataset of 2400 images were formed. Note that the half of images was healthy bananas, while the other half was defective. Figure 3 shows a sample of the formed database.

3.3. Transfer Learning of ResNet-50. In this work, the "ResNet-50" model was retrained and tested using Matlab environment. The network was simulated on a Windows 64-bit desktop computer with an Intel Core i7 4770 graphical processing unit (GPU) and 8 GB random access memory.

The learning algorithm was used to train and test the pretrained model (ResNet-50). 40% of images were used for training, while the remaining 60% was used for testing and evaluating the network's performance. Note that the network was evaluated by calculating its training and testing accuracy and loss function using the following formulas:

$$\text{Loss} = -\left(\frac{1}{n}\right)\sum_{i=1}^{n} \log P(N), \tag{2}$$

$$\text{Accuracy} = \frac{N}{T}, \tag{3}$$

where the probability of the correctly classified images was denoted as *P(N)*, n was the number of images, while T represents the total number of images during the training and/or testing phases.

ResNet is a very deep network, and when it was first employed, it was used for the skip connections approach to mitigate the vanishing gradient problem. This model was first presented in ILSVRC 2015 competition with a principal breakthrough that allowed the training of more than 150 layers networks. A brief architecture of ResNet-50 is shown in Figure 4. As seen, the network consists of 4 stages excluding stage 1, each with a convolution and identity block. Each convolution and identity block was comprised of 3 convolution layers of size 1×1 and 3×3 and 1×1 convolutions. Stage 1 consists of 4 different layers such as convolution, batch normalization (BN), rectified linear regularization unit (ReLU), and maximum pooling (Max Pool). Finally, the network has an average pooling layer followed by a fully connected layer along with a softmax activation function (multinomial logistic regression). This output layer has two neurons in order to classify the bananas into healthy or defective. It is also important to mention that ResNet-50 has more than 23 million trainable parameters. Hence, it is a good structure in terms of computation time, employing transfer learning.

In this study, transfer learning was employed in order to leverage the knowledge of ResNet-50 into another classification task which is sorting out bananas. Transfer learning of ResNet-50 can be simply described in two stages, i.e., freezing and fine-tuning. In the freezing stage,

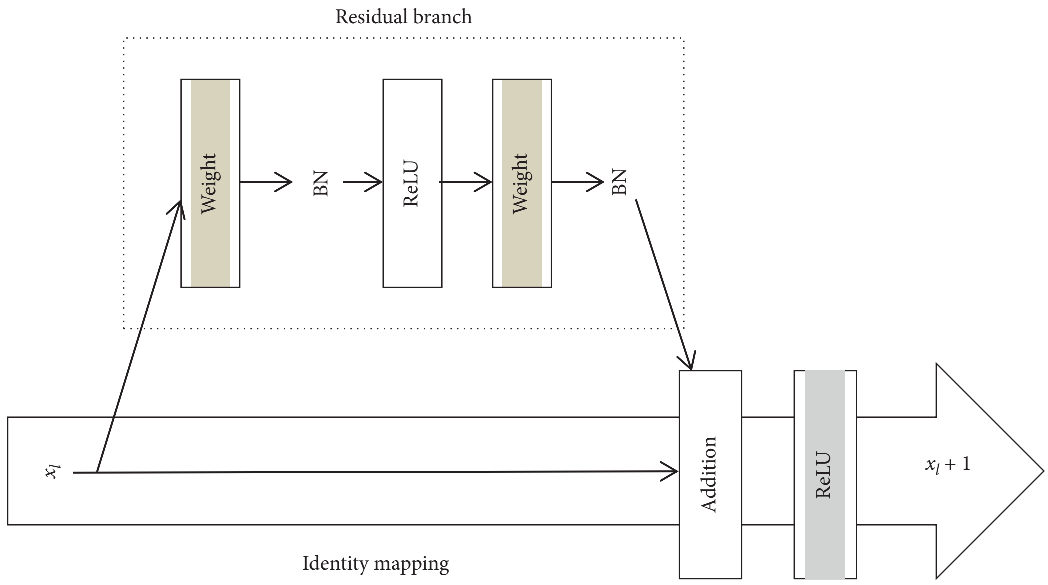


Figure 2: Original residual unit proposed by [19].

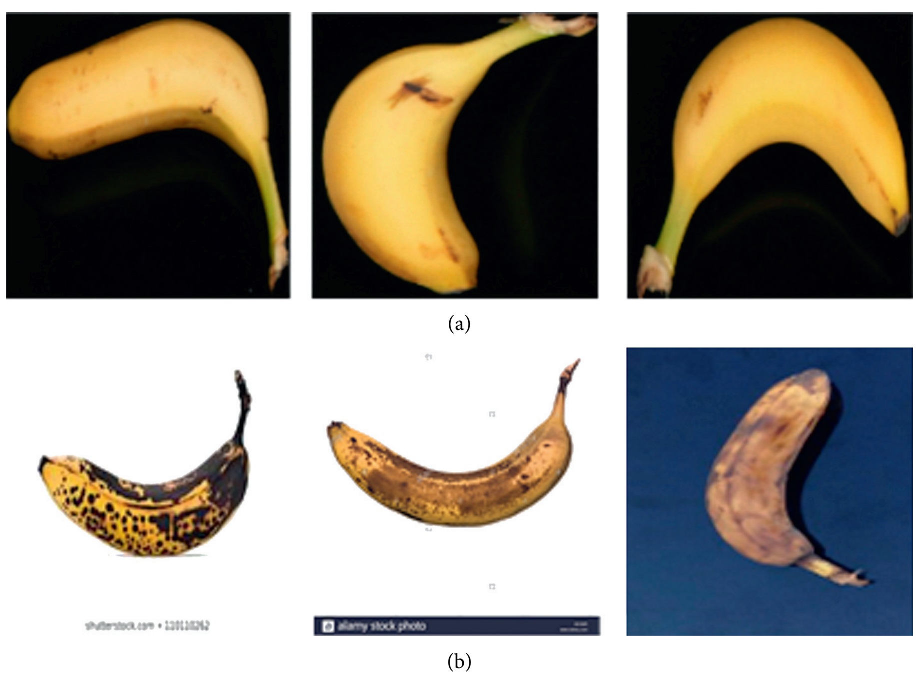


Figure 3: Sample of the databases training and testing images; (a) Healthy banana images. (b) Defective banana images.

the publicly available weights and learned parameters of the pretrained models were frozen and used. Fine-tuning begins by removing the fully connected layer (FC) of the ResNet-50 and then rearchitecting it to three fully connected layers with two output neurons at the output layer which corresponds to healthy and defective bananas. We noted that the weights of the FC layers were initiated randomly during training. On the contrary, the weights of the remaining layers were frozen in order to act as a strong feature extractor of high levels of abstractions of input images, as they have been already trained on millions of images from ImageNet dataset [33].

As mentioned, the network was trained using only 40% of the data. The stochastic gradient descent optimization method [34] was used to train the network with a batch size of 64 images for every iteration.

To minimize the cost function, an initial learning rate and a reducing factor of the fully connected layers were set to 0.0001 and 0.1, respectively, during training. Selecting the number of epochs was complex, as it was directly associated with a number of optimization during training. Hence, if the epoch's number was high, the network might overfit and performed poorly. Therefore, to avoid the overfitting problem, the error and performance rate on validation images were monitored. It

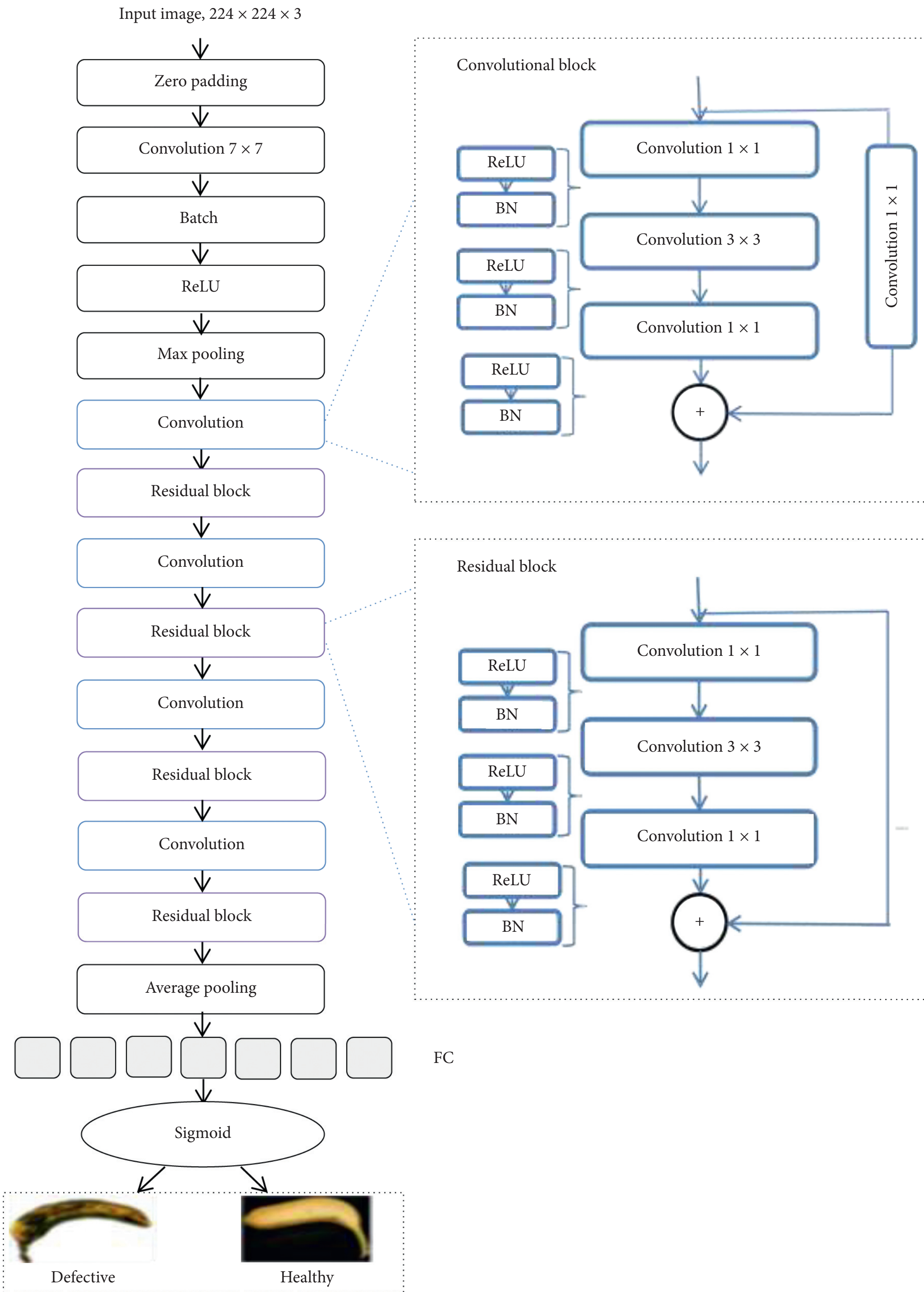


FIGURE 4: ResNet transfer learning process for the bananas sorting system. BN, batch normalization; FC, fully connected layer.

was found that the ResNet-50 achieved its highest training accuracy and best generalization capability at epoch 6. Table 1 shows that the training performance of the network was relatively good as it scored a 100% accuracy in a very short time (37 seconds) and a small number of epochs (6) despite the depth of the network and the training scheme (40 : 60).

Table 1: Models learning parameters.

ResNet-50	
Learning parameters	Values
Training ratio	40%
Learning rate	0.0001
Number of epochs	6
Training accuracy	100%
Training time	37 seconds
Achieved mean square error (MSE)	0.0001

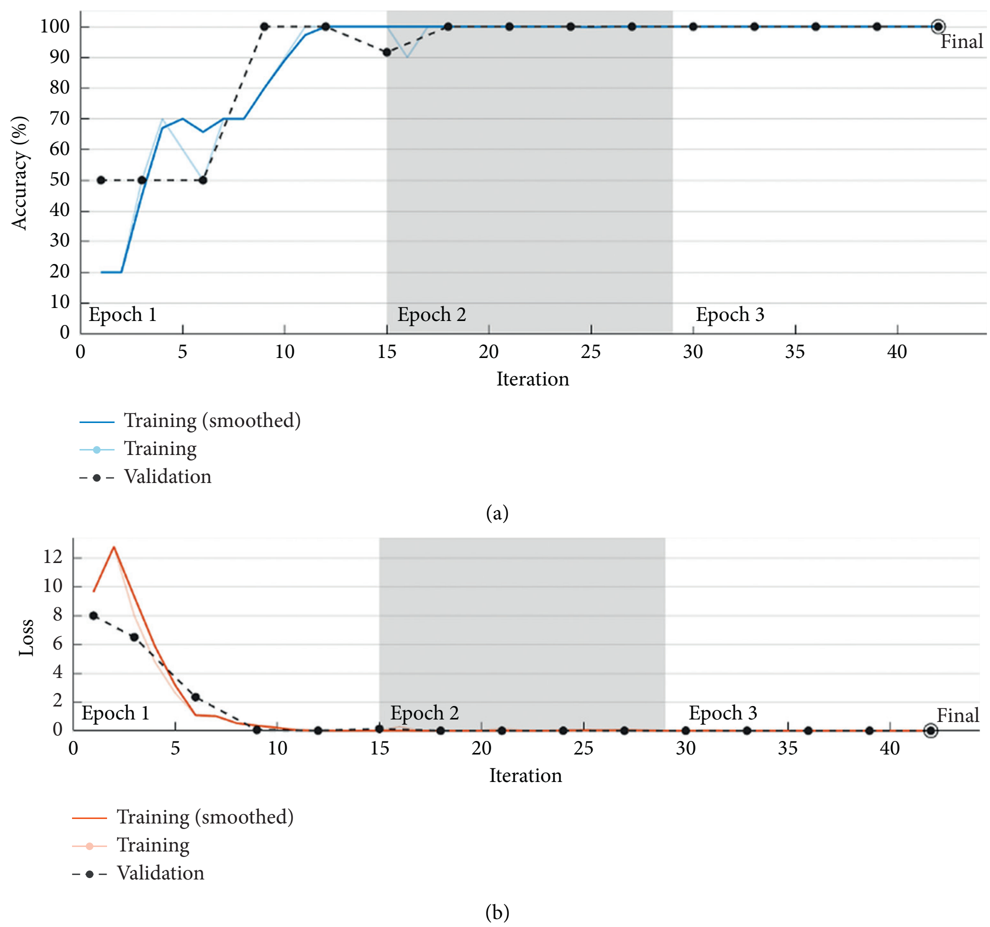


Figure 5: Learning curves and loss for ResNet-50.

Figure 5 shows the network's training progress curves and its associated loss function (error), respectively. The learning curve shows variations of the training accuracy with each epoch. From the curve, it can be seen that the network's learning was difficult only during epoch 1, but once it has passed that stage, the network's performance raised sharply until it reaches 100 at approximately epoch 2. The network reached a very small loss as shown in Figure 5.

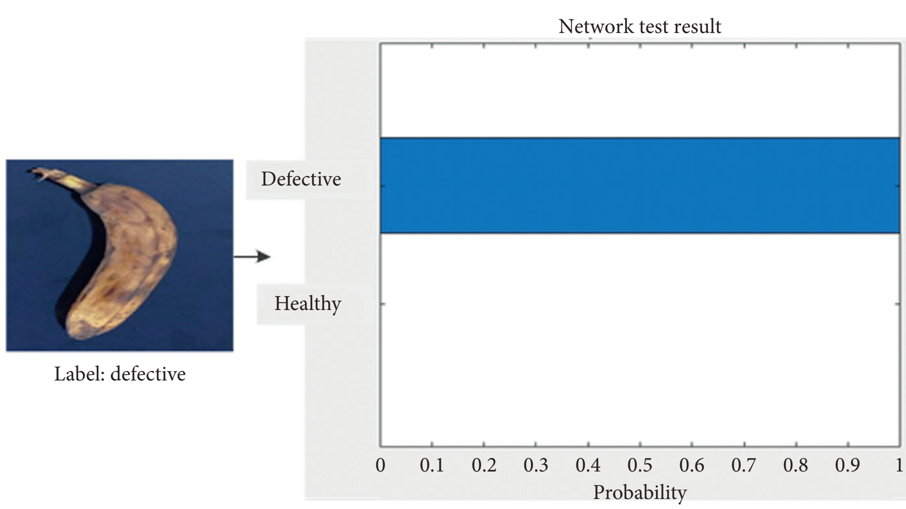
Table 2: ResNet-50 testing performance evaluation.

ResNet-50	
Total number of testing images	60% (1440)
Learning scheme	40 : 60
Number of correctly classified images	1296
Testing accuracy	99%

4. Results and Discussion

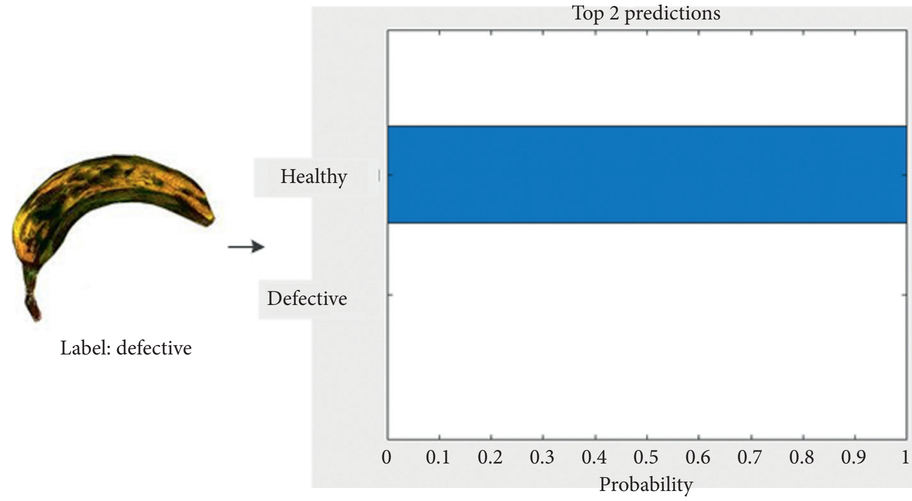
In order to verify the feasibility of the proposed transfer learning-based banana sorting system, we conduct an experimental test of 60% of the remaining images of our dataset. Those images are test images that are not seen before by the system, and the number of these test images is more than training images. As mentioned, the learning scheme was 40 : 60. As given in Table 2, the ResNet-50 has a very high recognition rate of 99% (Table 2) during testing based on the formulas (2) and (3). This means that 99% of the images of healthy and defective bananas are correctly classified during

Figure 6: Samples of testing images.



(a)

Figure 7: Continued.



(b)

FIGURE 7: Samples of misclassified images.

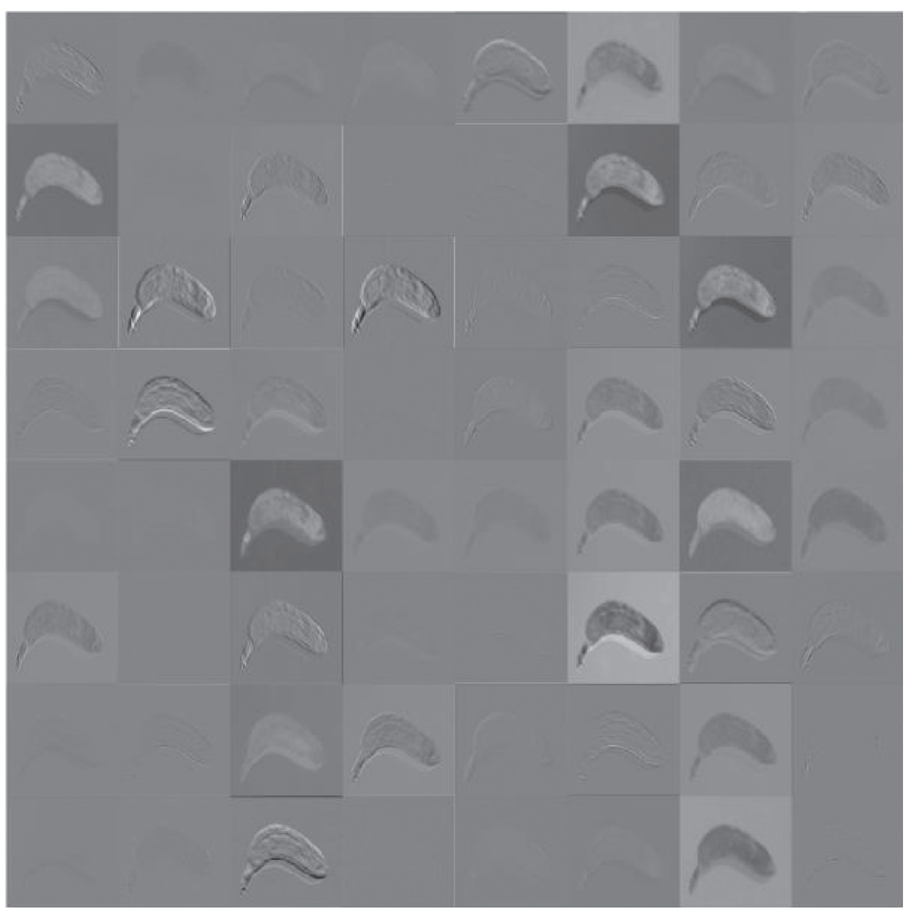


FIGURE 8: Learned features of the convolution layer 1.

testing, as the network gained a high generalization power when tested on 60% of unseen banana images.

Figure 6 shows samples of some banana images used to test the ResNet-50. Figure 7 shows samples of some misclassified and correctly classified abnormal bananas using ResNet-50. It is seen that the misclassified images are all defective bananas. All of the healthy bananas are classified correctly. This figure shows the network results that correctly classified a defective banana, while it failed to classify another defective one (Figure 7(b)).

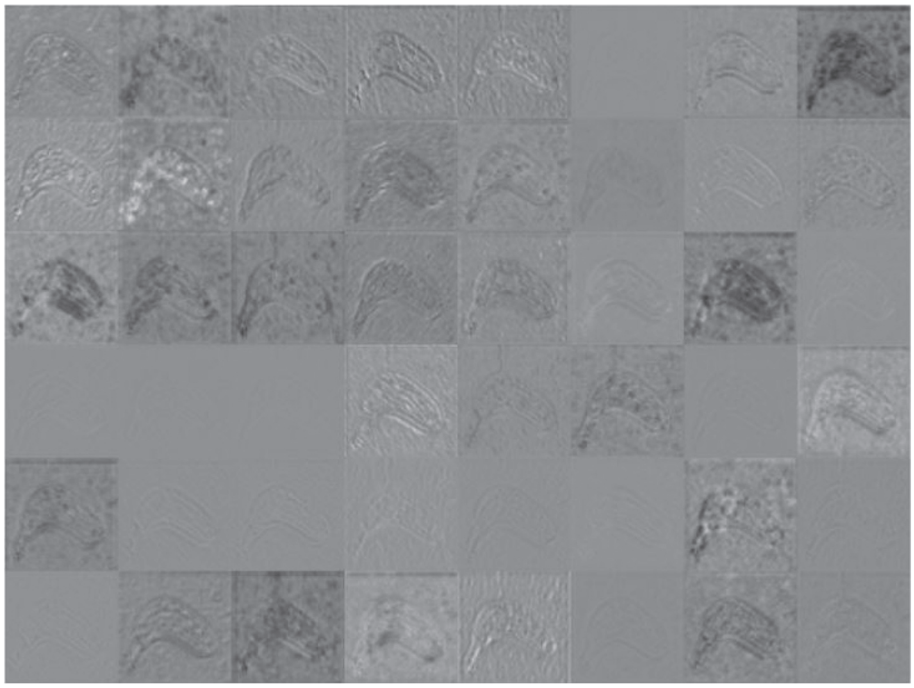


Figure 9: Learned features of a deeper convolution layer 5.

(a) (b)

Figure 10: Strongest activations of a banana image.

We visualize the learned features of different convolution and pooling layers in order to have a look at the network learning inside its deeper layers. Figure 8 shows the learned kernels of convolution layer 1. It is seen that these learned filters consist of gradients and features of different levels, orientations, and edges which are very helpful for the process of banana sorting.

The network learns to detect higher levels and more complicated features than those detected by the first convolution layers. Figure 9 shows the activations that show the learned kernels of a deeper convolution layer.

Features learned in every channel may change depending on the strength of their activations. In Figure 10, we show the strongest activation channel (Figure 10(b)) of a banana image (Figure 10(a)) from the same convolution layer in Figure 9. Note that each square of this image (Figure 10(b)) is an activation output of a channel in the convolutional layer 1 in Figure 9. Nonetheless, compared to the original image (Figure 10(a)), it is remarkable that this channel activates on edges in particular left and right edges. The channel activates positively on right edges and negatively on dark edges.

A comparison of the proposed model for banana grading is compared with other related works in Table 3. It is one of the most of the related research studies that employed image processing methods and texture analysis to distinguish colours, intensities, edge, and morphological shapes. These are all handcrafted engineering mechanisms for features extraction of images, and they are time-consuming and limited to human

Table 3: Model performance comparison with other previous works.

Method	Learning scheme	Accuracy (%)
Thresholding + neural network [4]	50 : 50	97
Texture analysis + neural network [11]	50 : 50	96
Colour recognition + backpropagation neural network [10]	50 : 50	96
Texture analysis + backpropagation neural network [5]	70 : 30	98.8
Texture analysis 1 radial basis function network [5]	70 : 30	96.25
Our proposed system	40 : 60	99

constraints. On the other hand, deep learning networks perform this task automatically within its convolution and pooling layers, making them strong and efficient feature extractors of different conceptual abstractions in a hierarchical way. Thus, it is seen that our proposed system based on residual learning, which also helps in boosting the performance of networks due to its skip connections approach, outperforms all other models presented in Table 3.

Note that the data used in training our model are the same data used in [4, 5]; however, we added more images from different datasets as deep networks require a bigger number of examples to learn than traditional networks. It is also noted that the proposed network outperformed other networks despite its learning scheme which uses less training images than testing (40 : 60). In contrast, all other related works used more training than testing examples. This demonstrates the robustness and effectiveness of residual learning (ResNet-50) in bananas grading task.

5. Conclusion

The study presents the design of a deep learning structure for grading bananas as healthy or defective. Residual learning was employed for designing of this grading system. The systems presented a new deep learning approach named skip connections, resulting in greater performance in different types of tasks such as classification and object detection. Upon training and testing, we conclude that the ResNet-50 as a very deep network has the capability of accurately generalize the grade of a banana with a very small margin of error. As compared to other models, this network shows a better accuracy when tested on unseen test data, despite its learning scheme (40 : 60) which uses more training images than testing ones. The robustness and significance of such network in grading the banana images are due to its power of learning low and high levels of features via its deep residual blocks, convolution, and pooling layers. This depth helps in extracting unimaginable features contributing to reaching higher recognition rates during training and testing. The importance of such a system is its urgent need in the food industry, due to the big demand requested at a very fast rate. Such a system should be ascertained to be the most efficient, errorless, reliable, accurate, and flexible systems for production in the food industry field.

Data Availability

The dataset used to support the findings of this study can be downloaded from the link https://figshare.com/articles/dataset/DeepBanana/14230262.

Conflicts of Interest

The authors declare that there are no conflicts of interest.

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