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Research Article

An Artificial Neural Network-Based Pest Identification and Control in Smart Agriculture Using Wireless Sensor Networks

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Despite living in a rural country, farmers in India face several challenges. Every year, they suffer significant losses due to agricultural insect infestation. These losses are primarily the result of inadequate field surveillance, crop diseases, and ineffective pesticide management. We need cutting-edge technology that is constantly evolving to maintain control over such major concerns responsible for output reductions year after year. Wireless sensor networks address all of these issues; in fact, wireless sensor network technology is quickly becoming the backbone of modern precision agriculture. We propose a strategy for pest monitoring using wireless sensor networks in this study by simply recognizing insect behaviour using various sensors. We proposed a rapid and accurate insect detection and categorization approach based on five important crops and associated insect pests. This method examines insect behaviour by collecting data from sensors placed in the field. The results show that the proposed work improves the accuracy of the existing work by 3.9 percent.

1. Introduction

India is the world's second-largest agricultural producer. It employs a wide range of households. Because this is such a large industry, increasing overall output is critical. Agriculture employs approximately 67 percent of the workforce, implying that nearly two-thirds of the total population are entirely dependent on agricultural employment for a living. Agriculture methods are not economically beneficial and harmful to the environment due to a lack of adequate irrigation infrastructure and services. Farmers face several challenges, including decreased rainfall, crop loss due to a lack of water and flooding, and low seed quality, resulting in crop failure and the waste of time, money, labour, and other resources [1, 2]. Furthermore, crop loss is caused by a lack of cold storage because crops are typically kept out in the open, making them vulnerable to insects, humidity, and wetness, among other things.

1.1. Agriculture through WSN. As an agricultural country, India requires agricultural modernization [3]. This is made possible by modern technologies that allow computation, communication, and control within devices. The most effective solution is to use wireless sensor networks. Indeed, wireless sensor network technology is quickly becoming the foundation of modern precision agriculture. Agriculture benefits from WSN support in dispersed information collection, monitoring harsh environments, accurate irrigation, and fertilizer delivery, and farmers benefit from real-time data collection. Precision farming with WSN aims to increase the overall efficiency of the development system. The result of a distributed sensor network sensing and sequentially monitoring different related parameters over a large area and collecting or displaying this data and assisting farmers in taking appropriate action to manage their farm based on sensed data is an increase in the agriculture sector's efficiency. Precision agriculture, made possible by WSN, enables farmers to focus their efforts on crop pattern selection and the locations that require water, nutrients, and other care, such as pesticide spraying. If such sensor devices are invented and developed, they have the potential to boost the agriculture sector, which is the engine of our economy.

1.2. Wireless Sensor Network. A wireless sensor network is a self-configuring network of tiny sensor nodes that communicate with one another via radio waves and are widely distributed to perceive, monitor, and comprehend the physical environment. Wireless sensor network (WSN) has recently piqued agriculturists' interest [4, 5]. Wireless sensor networks are ad hoc networks that allow us to run a wide range of applications, such as tracking a specific task or monitoring a specific region. These networks, in a nutshell, are used for acquiring, storing, and exchanging sensed data.

Wireless sensor networks (WSN), also known as wireless sensor and actuator networks (WSAN), are networks of partially distributed autonomous sensors that monitor environmental or physical conditions such as sound, temperature, moisture, and pressure. MEMS (microelectromechanical system) technology's rapid advancement has enabled the development of smart sensors [6]. These new smart sensors outperform previous sensors in several ways, including being smaller, less expensive, and more intelligent. The network is made up of many interconnected nodes, the number of which can range from hundreds to thousands. A radio transceiver with an internal antenna or a connecting space for an external antenna, a microcontroller, an electrical circuit connecting many sensors, and a power supply is part of a sensor network.

1.3. Precision Agriculture. It is the art and science of increasing crop productivity through modern technologies. Wireless sensor networks are an important technology that is propelling precision agriculture forward. Changes in soil and crop factors within a field are monitored and accurately mapped in this style of agriculture, and critical actions are taken as needed. This concept was developed to increase agricultural yield while decreasing pollution and environmental deterioration [7].

1.4. Green House Technology. Precision agriculture technologies can be used to grow high-quality crops shortly. This section will concentrate on WSN applications for precision agricultural management and greenhouse variable monitoring. Crop production can take place only in an ideal climate, which must be controlled and monitored for success. Crop growth stages, dynamic changes in the target area, soil type, climate, and plant type influence sensor configuration. Several types of plant structures are used in greenhouse technology at various stages of crop development [8, 9]. With this app, you can control everything from the water pump to the carton slider to your fans based on what is going on in your greenhouse at the time.

1.5. Number of Sensor Nodes and Input Variables. Depending on the size of the greenhouse, sensor nodes and actuators are required. A $35\,\text{m} \times 200\,\text{m}$ grid requires approximately 200 nodes (the basic size of the focused area). The three types of nodes are *A*, *B*, and *C*. Two sensor nodes are used in the greenhouse: one for the outside and one for the inside [10, 11]. Type "*B*" sensors are used to monitor climate conditions at 20 to 30 meters. *C* type sensors are soil sensors that must be used in a specific way in agricultural plantation architecture. Greenhouses are used to regulate the flow of irrigation water. They are frequently used every two meters. The table below shows the variable ranges for various crop management methods for a general crop. These data shown in Table 1 are compiled using the crop's datasheet [7].

1.6. Parameters and Their Use. The primary goal of a WSN system for precision farming is to regulate the surrounding circumstances following the crop datasheet [12]. Sensors installed outside capture data on the greenhouse's external environment, such as temperature, light, moisture, pressure, CO_2, wind speed, and wind direction. This system enables determining the behaviour of controls such as in-out airflow control, protection from direct sunlight, and moisture and temperature management [13].

A general view of a greenhouse is shown in Figure 1.

1.6.1. Climatic Control Problem in a Greenhouse. Crop development is typically influenced by the climatic conditions of the surrounding habitat and the amount of water and fertilizer delivered by irrigation [14]. A greenhouse is ideal for optimum agricultural development, since it manages fertilizer and climatic conditions, allowing for good crop growth and harvests.

1.7. Motivation. The primary goal of precision agriculture is to optimize efficiency to flourish properly. Remote sensing can guide farmers' efforts to regions that lack or require water, fertilizers, or other care. This data may enhance farming efficiency by allowing farmers to get it at the right moment and act on it. The mass production of such gadgets would be extremely beneficial to the agricultural industry. Modern agriculture necessitates tools and processes to improve production efficiency, product quality, and post-harvest activities while minimizing their environmental impact. Precision agriculture, often known as precision farming, is a significant contribution made by computerization in agriculture. Precision farming may be defined as using the proper quantity of input such as water, fertilizer,

Table 1: Input variables for the system.

Crop	Temp. (°C)	pH values	Light [k Lux]	CO_2	Moisture	
					Soil	Air
Carnation	16–22	5.5–7.0	45–50	1000	16	65
Gerberas	27–30	5.5–6.5	35–40	1000	17	65
Anthodium	24–26	5.5–6.5	18–35	1000	20	75
Tomato	16–35	5.5–7.0	30–40	1500	16	65
Roses	15–30	4.0–5.5	30–40	1000	17	70

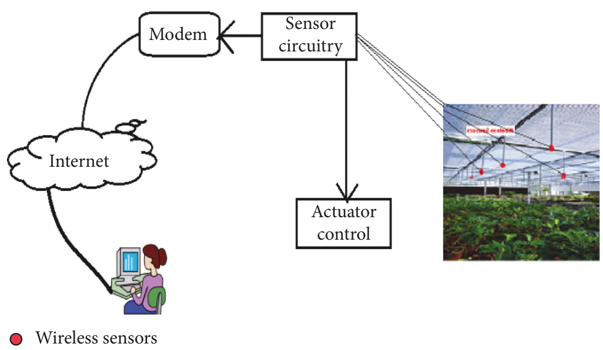

Figure 1: General view of a greenhouse technology with sensors employed in it.

and pesticides at the right location and time to maximize crop yield and quality while also not hurting the environment, making it environmentally friendly. Wireless sensor networks aid in monitoring farms, vineyards, and orchards, allowing farmers to safeguard their crops from harm and increase crop yield [15].

1.8. Paper Organization. Section 1 describes the basic knowledge of pest control and precision agriculture; Section 2 contains the state of the art of exiting work; Section 3 contains the proposed work and parameters used for analysis; and Sections 4 and 5 contain result analysis and conclusions.

2. Literature Review

The author of [16] mentions the use of WSN for improved water management and control of other factors. Wireless sensor networks in agricultural water management and rural development are demonstrated therein. This method, aimed at impoverished farmers in rural areas, makes extensive use of information technology. This technique may aid them in storing and utilizing rainwater to increase productivity and reduce farming costs, among other things. Crop waste occurs when crops are exposed and vulnerable to insects, wetness, and moisture due to a lack of cold storage. The document depicts the rice crop cultivation procedure and the various stages of crop growth of a paddy crop. A variety of sensors were used to track soil moisture, water monitoring, insect monitoring, and the effect of weather change, and each sensor operates on its frequency. This method will help farmers produce higher-quality crops.

The publication in [16] provides a comprehensive survey of the current wireless sensor network literature, focusing on recent research areas in this field. The author also discussed sensor node architecture, which is used for communication between multiple nodes and is classified into two types: flat architecture and hierarchical architecture. WSN is used in various industries, including agriculture, military, industry, health care, smart homes, and environmental monitoring. It is now widely used in precision agricultural applications, which estimate the amount of fertilizer needed, the amount of pesticide needed, and crop protection from insect pests. Security in a WSN was also discussed and classified into two types: operational security and information security. The quality of service provided by a WSN is also prioritized because it ensures the network's overall continuity of operations. WSN provides several options in a wide range of applications, and the technology is rapidly expanding. Several issues arise during processing these materials, necessitating improvement, and they are a current area of research in this sector.

Reference [17] specifies the deployment of wireless sensor networks in agriculture and the dissemination of WSN for precision farming. A WSN comprises intricately dispersed sensor nodes that help with monitoring (sensing), signal processing, embedded operations, and connection. The authors proposed system architecture for use in the agricultural sector. This will help farmers obtain meteorological information, choose the best crop, and communicate with agriculture experts. India's agriculture industry uses antiquated practices, and the entire system needs to be modernized. Precision agriculture helps farmers grow the perfect crop by monitoring various factors such as weather, moisture, and temperature, resulting in higher yields and lower losses.

Another paper [18] focuses on very small but conspicuous insects commonly thought to be crop enemies. That paper contains some hidden facts about many insects and descriptions of both beneficial and harmful insects. It includes nine major insect orders, which are listed in a table. Many insects benefit humans and play a positive role in nature by providing us with various products such as silk, honey bee guts, dyes, beeswax, and royal jelly. Many insects are very important for pollination, and they also help with weed control and many other benefits that are mentioned in this paper. That paper also discusses the harmful effects of insects, such as their role in disease transmission. It also includes a description of some household pests and the fact that these insects are harmful to domestic animals. That paper examined insects' harmful and beneficial effects and concluded that insects are more friendly than their harmful effects.

The authors of [19] presented the results of a survey conducted in rib areas on diseases, insect pests, and parasitic weeds. It was also suggested that the recorded major pests require research and development and some monitoring strategy needs to be designed to control them. During the survey periods, 11 crops were assessed, including onion, potato, tomato, cabbage, pepper, and others, and it was discovered that these were affected by dozens of diseases and pests. That paper also includes a table of major diseases in various crops and their major pests that must be addressed to be controlled on time. It also states that timely monitoring is required because a minor insect can become a major pest after a certain period.

The authors of [20] assessed current insect and pest knowledge in Sri Lanka and management strategies used in recent years. Potential future methods for increasing rice yield and insect management to protect the environment were also discussed. Regarding host plant resilience, natural predators of rice crop pests are also investigated. The focus is on pest control strategies used by Sri Lankan farmers. Some of the most serious issues that crops face due to the onslaught of numerous harmful crop-feeding insect pests are also highlighted. The study also makes recommendations for using new pesticides that are less toxic, require lower doses, and have insect selectivity. The authors suggest that efforts be made in Sri Lanka to establish a rice pest surveillance and forecasting system.

Reference [21] also presented a field investigation conducted in 2011 to calculate the variation in the population of insect pests and predators in corn. It described various dangerous crop-eating insects' corn pests and insect infestation data. Predators of these hazardous insect pests were also mentioned, as they are farmers' friends because they assist in reducing the number of these pests. According to the study's findings, trips are most common in the first five months of the year, and this is also true for a variety of other corn pests. This study also discussed the prevalence of crop predators and a variety of other bug facts. Based on this information, a farmer can manage their fields by applying the appropriate pesticides at the appropriate time to protect their crop.

Reference [22] discussed image processing approaches that continuously monitor crops using "Agri-Robo," which provides the user with a quick, accurate, and automated solution. This system can monitor crops to identify and monitor illnesses and pesticides; it can also perform automatic pesticide spraying to save the crop from disease. The paper includes the system architecture used for proper system implementation and the algorithm steps for image processing of the diseased leaf. A sprinkler motor sprays insecticides into the desired area. Several strategies for detecting plant disease areas have been described in this study. The agriculture robot diagnoses illnesses by spraying pesticides in a controlled manner onto the affected area.

3. Proposed Methodology

Pests include insects, diseases, weeds, and vertebrates, which can pose a serious threat to a farmer. They have the potential to cause crop damage, reduce agricultural yields, and harm crop quality [23].

3.1. Insects in Agriculture. Pests include insects, diseases, weeds, and vertebrates, which can pose a serious threat to a farmer. They have the potential to cause crop damage, reduce agricultural yields, and harm crop quality [23]. An insect is considered a nuisance if it harms both a valuable resource and human health. Pest control is often accomplished by eradicating the pest with a poisonous chemical, but it can also be accomplished by studying insect behaviour. Traditional farmers use synthetic pesticides to combat various pests that harm their crops; however, due to a lack of understanding the amount of pesticide required to kill the bacterium, the farmers frequently spray the pesticides in greater quantities than necessary. This excess pesticide seeps into the ground, contaminating the water we drink, and the plants suffer due to the unnecessary pesticide application. These herbicides also have some negative side effects. Insecticide resistance can develop, necessitating a modified or stronger chemical treatment. Furthermore, these heavily sprayed insecticides have the potential to harm beneficial insects and natural predators.

Natural predators are regarded as farmers' allies because they attack and destroy various hazardous pests of various crops by eating them, reducing the number of dangerous insect pests. These natural predators are imprisoned in fields using pheromones, and, when necessary, they are released from farm traps, and a pheromone switch is activated to catch them again. They are drawn to these pheromones because of their fragrance and are enticed to use them again in the future. One example is ladybird versus aphid; the ladybird is a natural predator, but aphids are devastating pests of many important crops. Ladybirds eat these aphids and kill them, protecting the crop and reducing pest populations [24].

Some beneficial insects in the fields are required for an agricultural farm because they aid in pollination, and some aid in fertilization; one of these insects is the earthworm. These insects provide a variety of essential items in our daily lives, such as honey, silk, guts, colours, and royal jelly [25]. They aid in the natural fertilization of soil and increase the system's overall productivity. This allows pests to thrive, while crops that rely on insects for pollination fail to bear fruit.

Manipulation of insect behaviour to protect crops is an entirely new concept. We can help farmers apply pesticides in the right amounts to protect crop quality while also protecting the environment if we understand how insects behave. The behaviour category includes the colour of several insects, the noise they make, the material released by several insects to communicate among their society, their speed of walking or flying, size, their respective host plants, and whether they are beneficial or harmful to crops. The amount of insecticide required to be sprayed can be easily calculated based on the behaviour of a specific insect.

An intelligent monitoring system is developed based on data obtained by analyzing the characteristics of many pests of key crops such as wheat, rice, maize, potato, tomato, and many other vegetables [26]. Based on MATLAB data processing, this method enables a farmer to preserve their crop while avoiding beneficial insects intelligently. As a result, this paper will discuss the hazardous and useful insects of key crops (as previously mentioned), which must be managed reasonably to be both safe for human health and environmentally friendly.

Most farmers do not understand how much pesticide is needed to control the insect pest in their fields, so they spray excessive pesticides on their fields. This additional spray kills the insects that are harmful to their crop, as well as the beneficial ones, and the chemicals infiltrate the earth and change the water we drink and the nutritional content of the crop. If the behaviour of insects can be easily observed, the amount of insecticide required to control them can be precisely calculated. Furthermore, farmers can increase crop productivity and quality by deploying a slew of sensors in the field.

3.1.1. Behavioural Classification. There are three major keys to a behavioural manipulation method:

(i) The behaviour of the pest
(ii) A procedure that enables manipulation of the behaviour appropriately
(iii) A method that employs behavioural manipulation to preserve a resource from pests.

Farmers can also categorize insects based on how they behave on the farm. Many insects harm crops, while others have a good impact. Other insects can also be present, but they have neutral impacts, meaning that they have neither negative nor positive benefits. As a result, knowing the type of insect feeding on the crop is critical because not all insects are pests.

(1) Insect pest-negative behaviour. An organism is deemed a pest only if it negatively impacts the crop, that is, if it begins to harm the crops and results in lower yields.
(2) Beneficial insects-positive behaviour. Some insects are extremely valuable to farmers, since they are natural adversaries of many crop-feeding insects and natural predators. These natural predators prey on crop-feeding insects, which are insect pests, and hence assist in reducing pest populations. Ladybird beetles, for example, attack and devour aphids, diminishing their number.
(3) Neutral insects—neither negative nor positive behaviour. If an insect is neither useful nor destructive to crops, it is classified as a neutral bug, since its behaviour does not damage or reduce agricultural productivity. A house fly, for example, might be considered a neutral bug, since it does not harm the crop and does not serve to defend it from other pests.

3.1.2. Classification of Insects by Mouthparts. A pest's mouthparts and the loss induced by them can also be utilized to identify it [27]. Arthropods have a diverse range of mouthparts. Some allow insects to chew plants/roots, while others are used for sucking or probing. If we can distinguish between their mouthparts and their inflict damage, we can quickly identify insects causing crop damage.

There are three categories of mouthparts:

(1) Chewing Mouthparts: They are also referred to as "mandibulate" mouthparts. A bug with these mouthparts causes holes in the plant's leaves or chewed edges. Beetles, grasshoppers, and caterpillars are examples of pests in this group.
(2) Nonchewing Mouthparts: Pests in this group often suck fluids or sap from the plant's leaf or stem.
(3) Piercing-sucking Mouthparts: Insects with mouthparts frequently have protruding segments that form a proboscis to penetrate plant tissues. A mosquito is an example of a pest of this type. Insects with piercing organs insert their piercing organ into the leaf's surface and suck out the sap from within, destroying the plant's chlorophyll component. The leaf turns brown or develops a tumour-like protrusion as a result. Examples include aphids, flea beetles, leafhoppers, and stink bugs. Mouthparts for Rasping-Sucking Pests in this class frequently scrape the leaf's surface and suck fluid from the plant's topmost layer of cells. This type of pest includes thrips and spider mites. As a result, the leaf takes on a silvery or bronze hue.

3.1.3. Harmful Insect Pests of Some Major Crops. In India, agriculture sector faces huge loss due to several insects that feed on the crops and damage them. So, it is necessary to know the major pest of these insects so that, by knowing the behaviour of these pests, we can easily monitor them and hence take necessary actions. In our research, we are taking five major crops and will discuss their major harmful pests and diseases caused by them. Five major crops are discussed here: potato, corn, tomato, rice, and wheat.

3.1.4. Insect Pest of the Potato Crop. According to the United Nations, potatoes are the most significant food crop in the world. India has the third-highest quantity of potatoes produced in the world. For nearly 300 years, the potato has been grown in the country. It has become one of the most popular crops for vegetables. Potatoes are a low-cost dietary source of energy for humans. The problem is that this essential crop is infested by an army of insects that eat its leaves and roots, causing the plant to die and its productivity to decline. Consequently, farmers suffer enormous losses each year due to these pests, which are shown in Table 2.

3.1.5. Insect Pests of Wheat. Wheat is an imperative grain crop with more than 600 MT yearly worldwide. It is a regular food crop that fulfils the daily requirements of many populations. It is also responsible for supporting the economy of India through the agriculture sector. Wheat creating zones are experienced by either sucking or piercing pests or plant tissue sustaining bugs. These pests damage the wheat crop badly, resulting in reduced yield and a huge loss. So, here, we

Table 2: Major pests of potatoes.

Pest	Damage done	Damage
Potato tuberworm	Plant disease infection increases the risk of crop failure and reduces yield quality.	Plant leaves in early state
Potato leafhopper	To extract the fluids, they insert their mouthparts, resulting in yellow triangles on the leaves ("hopper burn") and stunted plants.	Plant leaves
Cutworms	"Hopper burns" and stunted plants are caused by their mouthparts piercing through plant leaves to obtain fluids. In feeding on stems just above or below the soil's surface, they decimate young plants.	Mouthparts piercing through plant leaves to obtain fluids
Armyworms	Feed voraciously, producing large irregular holes. High infestation causes severe defoliation.	Plant root
Aphids	They can cause great harm when they suck juices from the underside of the potato plant leaves.	Plant leaves
Colorado potato beetle	It infected the potatoes and, if left untreated, can completely defoliate plants.	
Cucumber beetle	They are responsible for the transmission of bacterial wilt; once a plant is infected, the Erwinia bacterium spreads rapidly.	Root of plant
Wireworms	They feed on grassroots and attack when potatoes are to be grown immediately following the sod.	Root of plant
White grubs	They feed on grassroots and attack when potatoes are to be grown immediately following the sod.	

will discuss some major pests of the wheat crop. If proper use of pesticides is done with a limited amount as required, then these harmful bugs can be controlled, and also it will not affect the environment. These insects' behaviour will help develop an intelligent monitoring system that enables the user to inform the farmer about suitable action that can be taken to control these insect pests of major crops shown in Table 3.

3.1.6. Insect Pest of Rice. Rice is an imperative crop that fulfils people's daily food requirements, and rice cultivation plays a crucial role in enhancing the economic growth of the country. It is a basic food crop for a huge part of the world's population, and it is gaining much attention in the current practices to improvise the world's food condition. It is heavily cultivated in the north-eastern areas of Madhya Pradesh, including Rewa district. In current agriculture, high yielding rice varieties are generally cultivated using manures and fertilizers. But there are many severe enemies of this crop which damage the crop and reduce the yield. Hence, these pests' behaviour and feeding must be understood so that preventive measures can be taken against them to protect the plant from the damage demonstrated in Table 4.

3.1.7. Insect Pest of Corn. Corn is one of the important cereal crops cultivated for food and its feed values, and it is imperative cash crop that grants calories to the consumers and the income for the traders. It is an imperative cereal crop of Pakistan which is continuously gaining a good position in crop farming; the reason behind this is its larger yield potential and less development duration, as well as being a rich resource of food and fodder. But this crop is highly vulnerable to the pest's intrusion both on the farm and in the storage area. So, farmers have to bear a huge loss each year because of these insects, so proper knowledge of these pests is necessary for the farmers to save their crops and increase their yield; the insects' damage is shown in Table 5.

3.1.8. Insect Pest of Tomato. Tomato, one of the most imperative vegetable crops globally, is used as a food source and as research material. It ranks second after potato in the vegetable crops and plays a crucial role in the country's economy. It has been cultivated to upgrade fruit quality, productivity, and resistance to biotic and abiotic stresses. It has been extensively used as a food and as research material. Production of tomatoes has increased a lot in recent years with the introduction of new hybrid varieties. A wide range of insect pests shown in Table 6 and Figure 2 attack this crop resulting in a huge loss and reduction in the yield.

Still, this technology is not sufficient for controlling all kinds of insects as we have a limited number of pheromones available on the market. Hence this field needs more research to have full command of control of insect pests in all crops that are cultivated in India. In our paper, we propose an intelligent monitoring system which is based on the behaviour of insects and reads the behaviour of feeding insects according to the collected data, and the exact amount of pesticide required is calculated and informed to the farmers; this will help in reducing the pesticide amount, and it will focus on a specific area making it safe for the land and environment shown in Figure 3.

3.2. Pest Control Methods. Pest control methods are divided into three main categories.

To control these insect pests to save the crops from being damaged, farmers use several techniques as discussed above. Heavy use of pesticides affects underground water and us humans as we benefit from these crops in our daily lives, and the pesticides are also not environmentally friendly. Since farmers do not know the proper amount of pesticide

Table 3: Pests of wheat.

Pests of wheat	Damage done
Armyworms	Feed initially from the leaf surface; wheat head armyworm is very capable of damaging wheat kernels
Cutworms	Feed on the leaves of the plants and completely cut the plant below the soil surface
Aphids	Curling and sucking the young leaves
Grasshoppers	Serious threat to crop and affects kernels. Damaged kernels appear partially hollowed
Cereal leaf beetles	Cause damage by stripping off green tissue between leaf veins and skeletonizing leaves
Wireworms	They feed on grassroots and attack when wheat crops are to be grown immediately following the sod
Hessian fly	Feed on the lower leaves and can cause heavy damage

Table 4: Major harmful pests of rice.

Pest	Damage done
Yellow stem borer	It causes dead hearts or drying of the central tiller during the vegetative stage and causes whiteheads at the reproductive stage.
Rice bug	Dead hearts or drying of the central tiller is produced during the vegetative stage, while whiteheads are produced during the reproductive stage. Eating florets and sucking sap from developing rice grains can help reduce tough rice production.
Rice water weevil	Leave small longitudinal scars parallel to the midrib of the leaf on the top surface of rice leaves.
Rice case worm	To build leaf casings, they might chop off the tips of the leaves. Cut leaves at an angle like a pair of scissors with their feeding harm.
Rice leaf roller/leaf folder	Infested plants are less able to compete with weeds because of the damage caused by leaf miners.
Rice thrips	Plant growth is slowed down, vigour is reduced, and the damaged plants become less competitive with weeds. They feed on the rice crop’s leaves, producing damage such as leaf bending and discolouration.
Gall midge	At the base of the tiller, the gall midge creates a tubular gall known as an onion leaf or silver shoot.
White-backed planthopper	Planthopper damage results in yellowing and rust-reding of the plants, which spreads from the leaf tips to the rest of the plants.

Table 5: Major pests of corn.

Pest	Damage done
European corn borer	Young larvae’s tassels, whorls, and leaf sheath tissue are their primary source of food; they also mine the midribs and ingest pollen that accumulates behind the sheath.
Corn earworm	Take care during feeding, as an injury to half of an animal’s ear might occur before larval growth is finished.
Fall armyworms	As a general rule, larvae prefer to eat vegetation, although they can also feed on maize ears amid strong infestations.
Cutworms	Larvae prefer foliage as a food source, although they may also feed on maize ears when heavy infestation occurs. The stems of immature plants can be gnawed at or near the soil surface.
Corn root webworm	These animals may also chew on plant stems that are slightly above or below ground level. Deformed plants are common as a result of this.
Corn flea beetle	Feeds by slicing off the leaf’s uppermost layer of plant tissue. As a result of this process, the leaf’s surface is etched with grey to brown lines or “tracks.”
Western corn rootworm	Feeds primarily on root hairs and outer root tissue; root tips will appear brown and are often tunnelled into and chewed back to the base of the plant.
Spotted cucumber beetle	Large, deep-rooted plants are less vulnerable to damage than smaller ones.
Corn leaf aphids	The sooty residue is left behind by honeybees after suckling on honeydew, which is black and sticky. Those maize leaves that are severely damaged have swollen, yellow discolourations on them.
Seedcorn maggot	Before sprouting, remove the germs from the seeds by digging into them. Damaged seeds may sprout, but their nutritional supplies are depleted; therefore, the plant will not be able to thrive.

required in an area to kill these harmful organisms, they simply spray the pesticides over the entire area where its requirement is not necessary, and hence it is dangerous. This lack of knowledge also kills some beneficial insects that help pollinate plants. If these insecticides are used in a limited amount, they will not be harmful. If the behaviour of insects can be monitored, which easily distinguishes between the harmful and beneficial organisms, then these beneficial organisms can be saved. So here we implement an intelligent monitoring system that reads out insects’ behaviour, such as their colour, sound produced by them, chemical they release, and flying or crawling speed, and, based on this behaviour, we can classify insects as beneficial or harmful, and also the amount of pesticide needed can be calculated depending on the category of insect: whether it is more or less harmful. This system is implemented along with WSN sensors which calculate the temperature, soil moisture, water level, and so forth to form a complete monitoring system.

Table 6: Major pests of tomatoes.

Pest	Damage done
Fruit borer	The larvae scrape tomato leaves until the early or late stages of the second instar. The fruit is rendered unmarketable since the larvae have eaten its flesh.
Thrips	To get the tomato spotted wilt virus to feed on tomatoes, thrips pierce the plant's outer layer with their mouthparts and suck the plant's cells. This results in white or brown blotches on the leaves, indicating the plant's cell death location.
Corn earworm	Take care during feeding, as an injury to half of an animal's ear might occur before larval growth is finished.
Whitefly	Feed on leaves and cause yellowing and curling and glossy or blackened leaves by creating honeydew on them.
Aphids	The plant's young leaves are curled and sucked, weakening them till it eventually dies.
Leafhopper	Plants get stunted, and their leaves become covered in yellow triangles ("hopper burn").
Tomato psyllid	To remove the surplus water and sugar, psyllids inject stylets into the plant and suck the sap out of the plant.
Tomato russet mite	Remove the contents of the cells in the leaves, stems, and fruit that you have harvested. Leaves become golden in hue and eventually perish.

Figure 2: Insect pest of tomato.

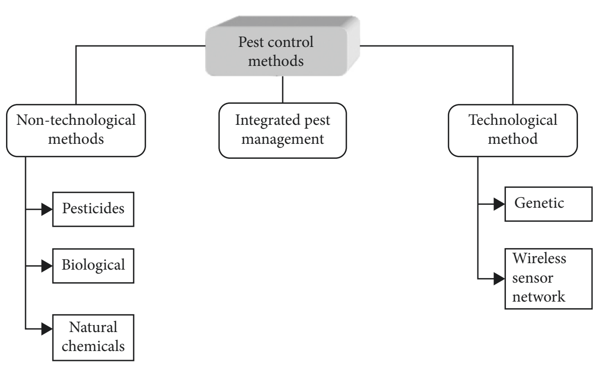

Figure 3: Pest control methods.

For this purpose, we have collected the behaviour patterns of several insects of major crops such as wheat, potato, tomato, corn, and rice; in this research, we mention the features of 28 insects. Image sensors are employed in the fields that timely capture images of crops, and when any insect pest is detected, it is sent to the base station for further processing through an artificial neural network [28]. The features on which research was done include insects' behaviour such as colour, sound made by them, their host plant, chemical released by them, their speed of flying/crawling, their size, and their category: whether they are harmful or beneficial. Based on these data, it is easier for an expert to differentiate between various pests. These data are further processed by using software, and we use MATLAB processing tool in our research. This software calculates the exact amount of pesticide required for each insect with the help of programming and a matrix table.

3.3. Neural Network. Inspired by the human learning technique, neural networks are based on the human brain nervous system. An ANN's network structure is constructed in a manner comparable to that of the nervous system in humans. As an example-based system, the learning process takes place. The structure of the neurons in the neural network is dispersed. Both neurons and spikes contain a great deal of information. At the highest level, both calculations and plasticity are on display.

To put it another way, weight in the brain corresponds to the number of synapses. When something has a lot of weight in a neural network, it is being utilized to store information there.

Table 7: Metrological data from agriculture department.

Size	Speed	Sound	Colour intensity	Chemical release	Categories
7.5	8.04	6.46	3.75	3.59	1.54
20	7.72	9.56	4.55	4.36	1.54
6	7.57	9.19	4.13	3.96	1.54
100	7.69	9.56	4.25	3.96	1.54
11.3	9.1	9.27	4.15	3.96	2.67
20	7.62	9.34	4.18	3.96	1.54
150	7.98	9.62	4.27	4.23	1.54
31.5	7.63	9.62	4.28	3.62	1.54
15	7.61	9.3	4.16	3.43	1.54
32.5	8.06	9.62	4.28	4.05	1.54
15	8.77	9.56	4.41	4.16	1.95
38	9.23	9.99	4.77	4.87	1.95
10	8.98	9.5	4.02	4.87	1.95
15.4	8.88	6.65	4.02	2.41	2.17
48.5	8.9	6.68	4.04	2.41	2.17
16.3	8.88	6.65	4.02	2.41	2.17
12.8	8.87	6.64	4.02	2.41	2.17
32.6	8.9	6.67	4.03	2.42	2.17
35.5	8.9	6.67	4.04	2.42	2.17
90	9.32	7.3	4.23	4.8	1.54
16	10.22	10.5	4.45	4.1	1.95
25.9	9.9	8.34	4.77	6.37	1.54
24.6	9.9	8.33	4.77	6.37	1.54
7.7	9.88	8.3	4.76	6.37	1.54
8.2	9.88	8.31	4.76	6.37	1.54
9.7	9.88	8.31	4.76	6.37	1.54
2.2	9.85	8.27	4.74	6.37	1.54
3.5	9.86	8.28	4.75	6.37	1.54
66.6	9.92	8.36	4.78	6.37	1.54
100	11.35	9.94	4.33	4.26	4.14
100	11.43	10.02	4.44	4.28	3.5
19.7	9.9	8.33	4.77	6.37	1.54
66.6	9.92	8.36	4.78	6.37	1.54
29.5	9.9	8.34	4.77	6.37	1.54
5.5	9.86	8.3	4.74	6.37	1.54
10.4	11.37	8.45	4.75	7.35	2.17
14	9.88	8.32	4.76	6.37	1.54
6.5	10.22	9.95	4.79	5.54	1.95
13	10.16	9.83	4.44	5.54	1.95
8	10.13	9.76	4.42	5.54	1.95
177.9	23.19	17.26	10.15	9.48	4.54
302	25.49	17.3	12.65	15.51	4.36
282.1	18.43	12.36	6.31	12.74	4.36
284.7	18.79	16.02	9.01	13.37	4.36
79	23.23	26.26	12.56	14.36	3.42

Initially, random values are used to set the weights, and then the new weight, bias, and neuron are discovered using the prior weights. The input to the transfer function is the sum of the input and the bias. With the aid of the activation function, the output is obtained using the transfer function. The weight and behaviour of the activation function are critical to the overall processing of neural networks. How active a cell is is entirely determined by the function that activates it in the first place. There is an activation function for every layer.

3.4. Neurofuzzy Approach. It is a hybrid approach in which two technologies are merged or one can be used after another. This approach can be implemented with the help of multilayer feedforward neural networks. In this paper, sequential hybrid system has been used as it makes use of technologies in a pipeline manner. Thus the output of one technology becomes the input of another technology. This is considered the weakest form of hybridization as the integrated form of technologies is not present. Similarly the

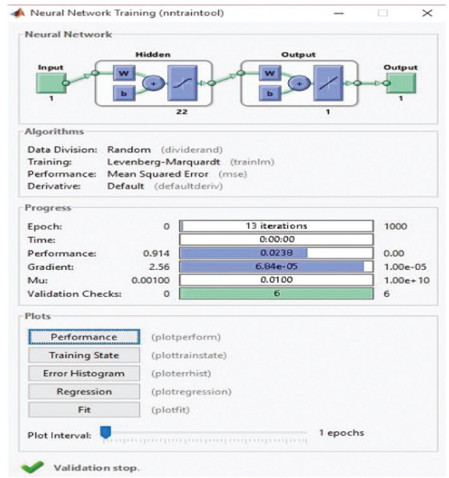

Figure 4: Train the neural network and provide learning.

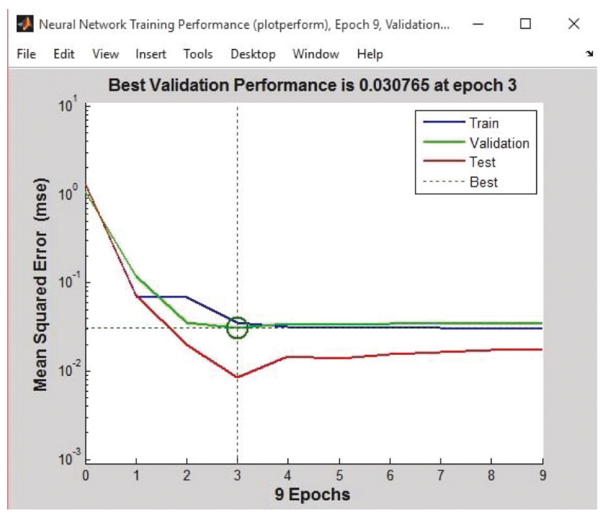

Figure 5: Performance plot observed after training of neural network.

output of a different kind of project risk is given as the input to the neural network for detecting the overall risk in the software project. The output of the partially integrated technologies is the overall predicted risk probability between low and high, which is between 0 and 1.

4. Experiments and Results

4.1. Software Implementation. Pests play a crucial role in the agriculture field; some insects are useful for crops, whereas others harm the crops. New technology was introduced, that is, through the MATLAB tool, which is an image processing tool. This image processing tool gives us the feature of neural network monitoring for the detection of various pests and solutions to control them. It does so by simply extracting the various features of crop feeding insects which are recorded with the help of different sensors available on the market for the detection of insects. With these sensors, data are recorded and sent to the base station for further processing in MATLAB using a neural network, as shown in Table 7.

Step 1: Load the main function by typing “nftool” in the command window of the MATLAB toolbox.

Step 2: Click next, and validation and test data window will open. Choose validation, training, and testing according to the requirement.

Step 3: Now train the network by clicking on the “Train” tab.

Step 4: Train neural network and provide learning

Figure 4 shows the neural network tanning for mean, accuracy computation.

4.2. Analysis of Result. Figure 5 shows that training stopped when the validation error increased for six iterations, which occurred at iteration 10.

If you c1ick Performance in the training window, a plot of the training errors, va1idation errors, and test errors appears. In this, the result is reasonable because of the following considerations:

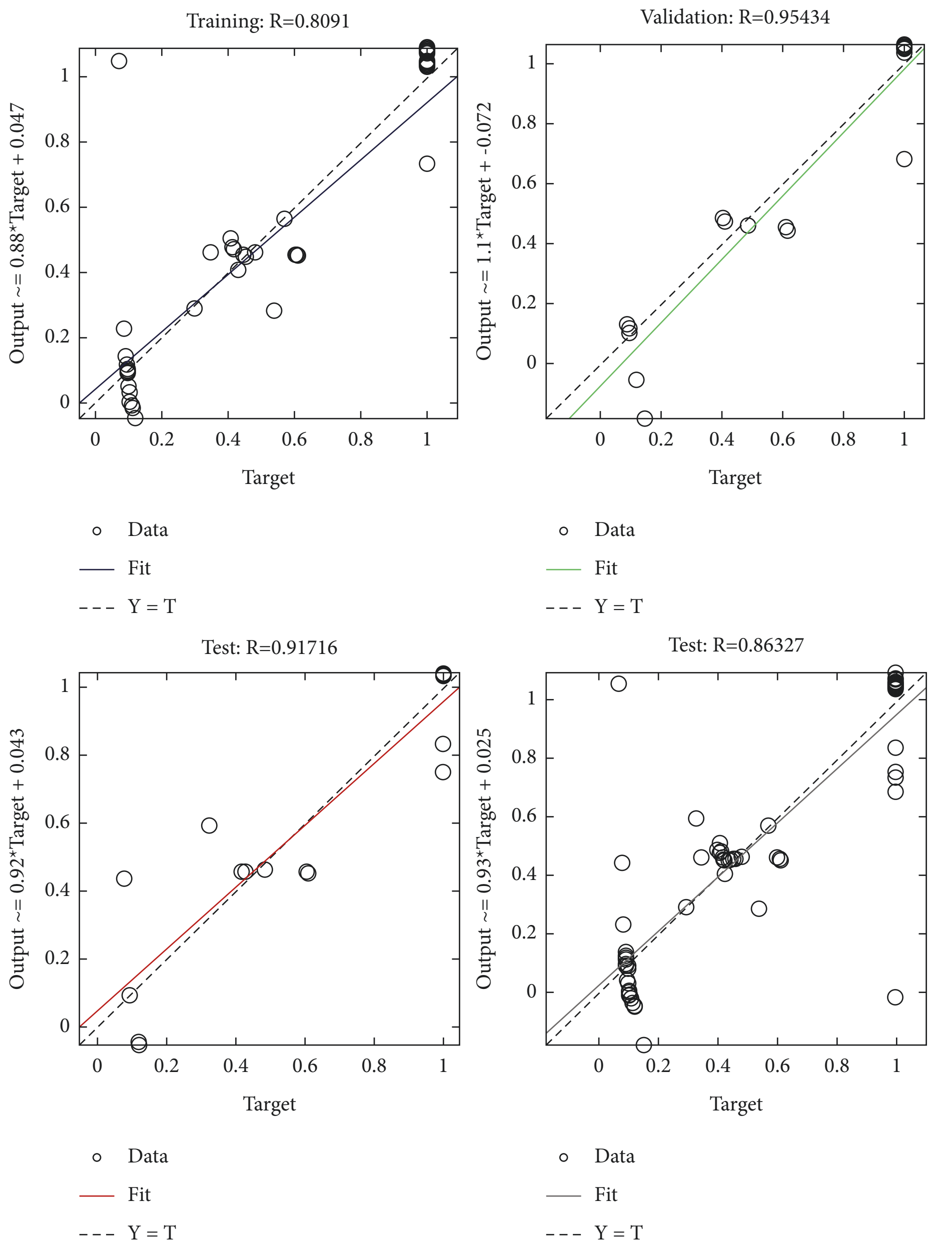

Figure 6: Regression plot observed after training of neural network.

(i) The final mean square error is small.

(ii) The test set error and the va1idation set error have similar characteristics.

(iii) No significant overfitting has occurred by iteration 10 (where the best validation performance occurs).

In Figure 6, the regression plots display the network outputs concerning targets for training, validation, and test sets. For a perfect fit, the data should fall along a 45-degree 1ine, where the network outputs are equal to the targets. For this problem, the fit is reasonably good for all datasets, with R values in each case of 0.15 or above. If even more accurate results were required, you could retrain the network by clicking Retrain in nftool. This will changes the initial weights and biases of the network and may improve the network after retraining.

5. Conclusion and Future Work

The findings of this study demonstrated the viability of automatic insect pest monitoring in the agricultural field using wireless sensor networking. Our main goal is to create a pest monitoring and control system that uses WSN to monitor the insects early and notify the farmer about the location where the infestation is occurring, reducing the farmer's labour of inspecting every part of their field. To identify the pest based on sensory data collected in the field, an automatic detection and classification technique based on an artificial neural network was presented. The presented system is simple and effective to use. In the future, we can create hardware for the proposed sensor circuitry to be used in agriculture. Along with this, GPS and GSM technology can be combined with hardware circuitry to pinpoint the exact location of the infestation, and an emergency message can be sent to the farmer to notify them of the location in their field, allowing them to take the necessary steps to protect the crop and increase productivity.

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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