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Review Article

Imperative Role of Automation and Wireless Technologies in Aquaponics Farming

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Food and agriculture are significant aspects that can meet the food demand estimated by the Food Agriculture Organization (FAO) by 2050. In addition to this, the United Nations sustainable development goals recommended implementing sustainable practices to meet food demand to achieve sustainability. Currently, aquaponics is one of the sustainable practices that require less land and water and has a low environmental impact. Aquaponics is a closed-loop and soil-less method of farming, where it requires intensive monitoring, control, and management. The advancement of wireless sensors and communication protocols empowered to implementation of an Internet of Things- (IoT-) based system for real-time monitoring, control, and management in aquaponics. This study presents a review of the wireless technology implementation and progress in aquaponics. Based on the review, the study discusses the significant water and environmental parameters of aquaponics. Followed by this, the study presents the implementation of remote, IoT, and ML-based monitoring of aquaponics. Finally, the review presents the recommendations such as edge and fog-based vision nodes, machine learning models for prediction, LoRa-based sensor nodes, and gateway-based architecture that are beneficial for the enhancement of wireless aquaponics and also for real-time prediction in the future.

1. Introduction

According to the most recent United Nations forecasts, the world's population will expand from 6.8 billion now to 9.1 billion in 2050, representing a quarter more food is needed than there is today [1]. According to an FAO assessment, the primary problems for world agriculture in the future decades will be producing 70% more food for an additional 2.3 billion people while tackling hunger and poverty, utilizing finite natural resources more efficiently, and adjusting to climate change [2]. Globally, there are still adequate land resources available to feed the world's future population. However, FAO emphasized that much of the available acreage is only appropriate for cultivating a few commodities, and most of the unused land also suffers from chemical and physical restrictions, endemic diseases, and a lack of infrastructure, all of which are difficult to overcome. Healthy soils, land, and water are critical inputs in food production, and their scarcity in many parts of the world makes it critical to use and sustainably manage them [3]. The United Nations suggests that sensible water utilization through enhanced irrigation and storage technology, in conjunction with the creation of new drought-resistant crop types, can assist to sustain dryland output [4].

Aquaponics farming is a type of sustainable agriculture that involves a symbiotic link between fish and plants [5].

When the fish produce waste, it is cycled out of the fish tank into the grow bed, where bacteria convert ammonia into nitrates that plants require to grow (Figure 1). The water is subsequently purified and restored to the fish tank, contributing to the highly efficient, zero-waste process of cultivating fish and plants together [6]. When compared with the traditional farming method, it uses 80 to 95% less water, and also, the water usage efficiency can be increased; the use of pesticides and fertilizers can be reduced in this method [7]. Aquaponics is a closed-loop and soil-less method of farming, where it requires intensive monitoring, control, and management [8]. So, it is recommended to implement wireless technologies in aquaponics for effective monitoring, control, and management [9]. Currently, the advancement of wireless sensors and communication protocols empowered to implementation of an IoT-based system is continuously monitoring and analyzing the complete system to produce vegetables and plants that are needed for human use in a well-planned and well-maintained ecosystem with optimum use of water and minimum farmlands [10].

With motivation from the aspects, this study is aimed at providing a review of the significance and implementation of wireless and intelligent technologies in aquaponics farming. The study is drawn in such a way that it will provide a sequential way of understanding the various trends of wireless and intelligent technologies in aquaponics. The motive of this review is to bring various aspects that are specifically related to the effective real-time implementation of the aquaponics system. The major goals of this review paper are to identify (a) critical parameters that are suitable to monitor and control the growth of plants as well as fish; (b) to identify and discuss the growth of wireless technologies like IoT, edge, and fog computing implementation in an aquaponics system; and (c) evaluation of the progress of machine learning implementation in an aquaponics system that is used for real-time prediction of water quality identify suitably monitored and controlled parameters for effective growth of plants and fishes. This review also discusses the limitations of the previous studies and recommends a few suggestions such as edge and fog-based vision nodes, machine learning models for prediction, LoRa-based sensor nodes, and gateway-based architecture for the future enhancement in aquaponics. The contribution of the study is as follows:

(i) The environmental and water-based parameters that affect the growth of the organisms in aquaponics are discussed

(ii) The significance and function of the wireless-based systems for remote monitoring are discussed in this study with architecture

(iii) The significance of machine learning algorithms and edge and fog computing for real-time prediction in aquaponics are presented

The organization of the paper is as follows: Section 2 discusses the methodology of the review. Section 3 covers the parameters to be monitored in an aquaponics system. Section 4 covers the IoT systems and remote monitoring interfaces used. Section 5 covers the edge and fog-based architecture used. Section 6 covers the machine learning techniques that are used in aquaponics. Section 7 covers the recommendations and proposed architecture, and finally, the article concludes.

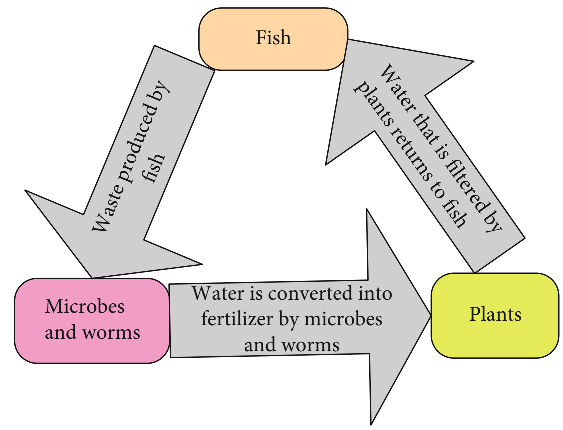

Figure 1: Aquaponics system cycle.

2. Methods

In this section, the discussion of methods and approaches are implemented for carrying out the review. The objective of this review is to discuss the significance of wireless technologies implemented by previous studies. In the field of an aquaponics system, there is a scarcity of quality articles from the reputed journals, so in this review, the conference articles are also included. The articles on aquaponics are obtained from the Web of Science, Scopus, ScienceDirect, IEEE Xplore, and Google Scholar. Initially, all studies related to the aquaponics are examined, and only those articles that satisfy the selection criterion such as the abstracts of studies that were available are selected but not the full text of the study not examined for review; research that proposes methodologies but does not conduct experiments or validation is not eligible for review; dissertation work and thesis completed at the postgraduate and graduate levels are not reviewed; non-peer-reviewed research articles are not considered for review, and book chapters, patent applications, and communications are not reviewed.

3. Significance of Water and Environmental Parameters

The aquaponics system is a combination of both aquaculture and hydroponics where plants and fish live in an integrated environment. The parameters related to both the water and the environment are to be monitored to ensure the proper growth and also to be healthy.

3.1. Water-Based Parameters. In an aquaponics system, the quality of water is the main factor that is to be considered [10]. Water is the medium through which nutrients are provided to the plants. Considering automation regard, water is considered to be a complex factor as many parameters are dependent on one another. Aquaponics which is the integration of both aquaculture and hydroponics techniques is individually developed and adopted widely. For increasing the efficiency of water and sustainability, RAS design has been developed. But the ammonia present in the water begins to gather at the levels that are dangerous for the fish. So, for recirculating water, biofilters are being used. But the plants require nutrients and elements, which cannot be produced by water in the absence of fertilizers. But the use of fertilizers can lead to the disposal of water and replacement. The waste produced by fish can be used for the growing of plants. This process occurs indirectly and is called nitrification. To assure the standard quality in the solution of water, to make the process of nitrification favorable and growth of plants and keep fishes healthy at the same time, it is required to keep the right nutrient quantity, temperature, dissolved oxygen, pH, temperature, and salts during the complete process.

3.1.1. pH. Measurement of the concentration of hydrogen ions is known as pH. It is the alkalinity or acidity measurement of the solution. The rate at which nitrification occurs and the availability of nutrients to the plants are affected by the pH of water [11]. To measure the pH in a solution, a pH meter is used [12]. Manual electronic probes, test strips, and automatic probes in controllers are three different methods by which the measurement of pH values is obtained. The value that is acceptable for the pH of water in the aquaponics component can be from 6.5 to 9.5, and the acceptable value is 5.5 to 10, but this value may be varied slightly depending on the fish species. In slightly acidic solutions, the reproduction rate of fish may be decreased [13].

The optimum value is around 6.0 in the hydroponic component. Precipitation of Fe or Mn will occur if pH is more than 7.0, and root injury occurs if pH is less than 4.5 [14], and deficiency of nutrients is observed in plants [15]. The pH value is to be 7.0 to 9.0 for the nitrification process to occur. In an aquaponics system, the adjustment of pH values can be made by bases such as calcium and potassium because they act as a base for the nutrients [15, 16]. Minute changes in pH values (<0.3) in short time intervals can affect fish health very highly [15]. To the controller, the pH meter is connected to an automated system; the controller gets the change in output of the pH meter in millivolt and milliampere. The pH meter is then contacted with the controller and is tested in a solution to find the pH value. The value of output that is obtained is connected to the pH unit to the controller programming unit.

A pH meter named B&C Electronics-SZ 1093 gives a range of 0-13, a maximum temperature value of 80°C, and a maximum pressure of 7 bars [17]. The performance provided by a digital pH meter of 0.01 resolution and an ISFET ion-sensitive field-effect transistor is the same. A less percentage of error is provided by the Atlas EZO pH Sensor. Nonetheless, other options still exist [18]. An OMEGA PHE-45P pH sensor with lower maximum temperature resistance (60°C can be used in the aquaponics system [5]) and an Orion 3 Star meter from Thermo Fisher Scientific can be used to find the pH [11].

3.1.2. Dissolved Oxygen. The measure of the amount of oxygen that is dissolved in water which is available for living things in aquatics is dissolved oxygen. The organisms that share the environment of aquaponics are fish, bacteria, and plants for which dissolved oxygen is the most required parameter. The ability to support the life of aquatic organisms is determined by the oxygen amount present in water along with the level of water [19] At very low concentrations, oxygen is dissolved in water (in parts per million) and is considered to be the parameter that has an instant and extreme impact on the aquaponics [15]. Oxygen is made naturally in algae and green aquatic plants by photosynthesis. In every aquaponics system, it is mostly required to monitor the value of dissolved oxygen as its value changes sharply in small time intervals [19].

The temperature of the water and dissolved oxygen is strongly related to each other. Warm water has less oxygen. The intake of dissolved oxygen rises when fishes are taking food. For nitrifying bacteria, optimum levels are 4-8 milligrams/liter. Plants require dissolved oxygen of greater than 3 milligrams/liter [15]. If the oxygen is lowered, the fungus appears, and the roots of plants die. Dissolved oxygen of greater than 5 milligrams/liter is required by most species of fish. If the concentration of dissolved oxygen is low, the production of TAN will be perished [20].

The optical sensors detect the interaction of oxygen with particular luminous dyes. Because oxygen molecules interact with the dye when dissolved oxygen is present, the wavelengths that are returned are changed [21]. Galvanic and polarographic electromechanical options for measuring dissolved oxygen content exist. The existence of dissolved oxygen is determined by changing the electrical signal after applying a voltage to polarize or not polarize the system. Measurement systems for dissolved oxygen concentrations are costly. The data is transferred via a DO sensor coupled to a Modbus and TCP/IP technology [10]. In an aquaponics system, an Atlas DO probe with a capacity range of 0-100 milligrams/liter, maximum pressure of 3447 kPa, and 343 m of maximum depth is employed [18].

3.1.3. Temperature. In an aquaponics system, the temperature of the water is interconnected with many parameters that are related to water. The optimum value of temperature is in the range of 17-34°C for nitrification to take place. The nitrification process does not occur correctly, and bacteria productivity goes down if the temperature is below the value. A value of 18-30°C temperature is appropriate for the hydroponics component. A proper temperature value is to be maintained which decreases the disease risk in fish. Based on the type of fish, the suitable value of temperature changes. A temperature value of 22-32°C is favorable for tropical fish; for cold-water fish, the temperature to be maintained is 10-18°C. For other species, a temperature value in the 5-30°C range is favorable [15]. Calcium absorption is resisted in plants if the temperature of the water is high.

To measure the temperature of water, the method used is to examine the temperature range, tolerance of salinity, and resolution. The sensor resolution is the factor that is important in the selection because many of the water temperature sensors have the required range covered. The sensor must not be waterproof only but should be designed to be submerged for a long time. A DS1820 temperature sensor along with an Arduino controller is used. The range of temperature in this sensor varies from -55°C to 125°C, and the resolution is about ±0.5°C. An IC named LM35 is used as temperature [18, 22, 23].

3.1.4. Ammonia. In surface and wastewaters, ammonia is present as a dissolved gas [13]. The protein that is given to the fish, only 10% of it is transformed into ammonia [24]. In an aquaponics system from the waste that is excreted by fish, ammonia is produced and acts as the main part as it is the main element for nutrients in the plants. For the fish, ammonia is very toxic, if present in small quantities. It is most noticeable when it changes as strongly acidic or alkaline. For fishes, the advisable range is 0 to 2 mg/L [13]. The optimum range of TAN is <3 mg/L for fish in warm water and 1 mg/L for fish in cold water. For bacteria that oxidizes ammonia and nitrite, the optimum range is <3 mg/L and <30mg/L [15].

Since ammonia is present in little quantities and does not have any color or odor, to know whether it is present or not, sensing it is required. The sensor has a wire electrode inside a filling solution. The solution is separated from the medium which has the sample by an ion-selective membrane, mixed with ammonium ions [25] The pH of water and water temperature is to be known necessarily to increase the accuracy of measurement of ammonia. The ammonia amount present in the water solution creates a data synthesis problem between ammonia sensors, temperature sensors, and pH sensors. Since the ammonia concentration before the biofilter is not considered, these sensors are to be placed in the water tank.

3.1.5. Nitrification. For plants, the main required nutrient inorganic is nitrogen. For the nitrification process to occur, ammonia is required which comes from the waste of the fish. It is in the form of ammonium and ammonia which is the function of pH, temperature, and salinity of water [26, 27]. Total ammonia-nitrogen concentration (TAN) is the sum of ammonium and ammonia [28]. Nitrification is the process in which the TAN is changed to nitrates [28]. With the help of ammonia-oxidizing bacteria, first TAN is oxidized into nitrite, and then, nitrate is converted into nitrates with nitrite-oxidizing bacteria [27]. So in an aquaponics system for nitrification, a biofilter is required. A hydroponic component, a biofilter for nitrification, and an aquaculture component are the constituents of an aquaponics system [29].

3.1.6. Nitrate. By nitrite-oxidizing bacteria, from ammonia, nitrate is obtained, the form in which plants can take the component of nitrogen that is required. For fish, nitrate is not dangerous. If the nitrate value is below 90 mg/L, it should not lead to health issues in fish [13], and the optimal range is 50-100 ppm. When designing a biofilter, this value is considered to be important. If the nitrates are present in large quantities, it means that it is dangerous to fish, and the biofilter is undersized [20]. To measure the nitrite concentration, the sensor that is used for knowing the ammonia concentration is used.

3.1.7. Nitrite. By ammonia-oxidizing bacteria, from ammonia, nitrite is obtained. For aquatic life, nitrite is considered to be dangerous [20]. The required value of nitrite in water for the bacteria, fish, and plants to survive is 0-1 mg/L [13]. For the proper growth of plants and the bacteria to survive the same value of nitrite is required. The nitrite that is present should not make a problem when it is provided in the optimum range. The mix of nitride-ionized electrodes and the element used for sensing are made of polyvinyl chloride membrane, works as an exchange of ions, and reference electrode forms nitrite concentration sensors. The sensor will develop electrical potential which is proportional to the nitrite ion concentration in solution and provides the concentration of nitrite in water.

3.1.8. Electroconductivity. Electroconductivity is a metric that measures a medium's ability to conduct electric current (EC), and in aquaponics, this is related to salinity [5, 30]. If the electrical conductivity changes, the fish are affected. The death of fish may occur if the level of electroconductivity is high, and this indicates that the water is polluted. To have a balance, there should be minimum content of salt. For fishes, the range of optimum level is 100-2000 mS/cm. The range of 30-500 mS/cm is also accepted [13].

A method was proposed for controlling the nutrient solution in the hydroponics system by monitoring the electrical conductivity [14]. Enshi-shoho nutrient solution was used to provide control over EC, as it has a known EC of 2400 mS/cm. These electroconductivity meters generally use a potentiometric method and four platinum electrodes. The use of this parameter is recommended to use [30].

3.1.9. Level. In an aquaponics system, the amount of water required is decided by the component size, i.e., fish tank. The health, growth of fish, and stress in fish are caused due to stocking density. The stocking number of fish is 20 kilograms of fish per thousand liters of water [15]. Removal of fish waste, evapotranspiration in plants, evaporation, and splashing of fish while feeding are the main causes of the water loss in all the aquaponics systems. The amount of water that is consumed daily in a hydroponic system is 0.1 to 0.3% which depends on the fish tank, hydroponic ratio, the flow of water, temperature of water specifies of fishes and plants used, and the hydroponic type of system that is used [31].

By using a slight glass or floating device, the level of water in the tanks is measured manually. Ultrasonic sensors, laser, and radar-based sensors are the most advanced sensors for measuring the level of fluid. K8AK-LS1 water level controller is used which has a maximum temperature tolerance of 50°C [17]. A water level sensor that gives an analog output when connected to an Arduino controller is used [32]. To know the level of water in the tank, an array of sensors is used [22]. A circuit built with a BC546 NPN transistor is used to construct a water overflow level sensor [33]. An ultrasonic sensor is used to control the levels of water in the tank [23, 34].

3.1.10. Total Dissolved Solids. In water, the dissolved salts are present naturally. The number of dissolved materials, organic matter, and inorganic salts in the water represents total dissolved salt levels [35]. The desired amount of TDS for the fish is 1000 milligrams/liter but values below 2500 milligrams/liter are acceptable [13]. For many species of fish, TDS (>1000 mg/L) can be toxic. For the measurement of TDS, TDS meters are used as sensing units to measure the value of TDS in portable water. TDS can be measured using the sensor used for the measurement of electroconductivity.

3.1.11. Flow. To calculate the proficiency of filtration (solids) and biofiltration (nitrification) and to decide the availability of nutrients for plants, the flow of water in an aquaponics unit is needed. In the unit, constant flow is to be maintained to avoid deficiency of nutrients in the plants and also stress in the fishes. The measurement of flow between the grow bed and the filters is most required. Depending on the system that is adopted, the flow rate varies. Water flowing must be in such a way that more amounts of nutrients and oxygen are obtained by the plants in systems based on NFT. The flow of water must be smaller than 1-2 L/min in an NFT system [15]. To clean the water, a siphon is used in the media-based technique. To clean the water each hour, the water flow rate is to be set.

The flow of water is because of gravity in systems based on DWC. To guarantee the sufficient amount of nutrients received, the flow of water through the channels should be 1 to 4 hours. Depending on the size of the channel used and the capacity of water, the optimal flow rate of water is determined. To know the water flow between the fish tank and grow bed, a water sensor is used [4], and in between the grow bed and fish tank, the flow meter is kept [36].

3.1.12. Salinity. The quantity of salt concentration present in the water is salinity [30]. The growth and density of the fish are affected by salinity [20]. Like TDS, salinity is obtained by electroconductivity. Depending on the fish species, the required value of salinity changes.

3.1.13. Alkalinity. In an aquaponics system, the measurement of the concentration of the bases, mainly carbonate as well as bicarbonate, is alkalinity. The measure of the negative ions is the alkalinity, and the measure of positive ions is the hardness. The ability of water to withstand changes in the pH or the ability to neutralize acids is also referred to as alkalinity. There is a very high value of pH even if low levels of the acids are present [20]. The ammonia becomes toxic if the alkalinity level is high. 50 to 150 milligrams/liter of CaCO3 is the required range [13].

3.1.14. Water Hardness. The amount of the positively charged magnesium salts and calcium in the solution is measured because they are necessary for the fish metabolic reaction and also for the formation of scale and bone. Stress in fish is caused due to low levels of water hardness, and high levels are harmful because it increases the pH of water, which results in a reduced rate of absorption and nitrification in plants. The range for the hardness of water can be from 50 to 150 milligrams/liter, but for many of the species, the value > 10 milligrams/liter is acceptable [13]. TDS or electroconductivity can be used to determine water hardness [37].

3.2. Environment-Based Parameters. For obtaining stability and for better development of the fish as well as plants, it is required that the parameters related to the environment are to be monitored and controlled [7].

3.2.1. CO_2. In photosynthesis, carbon dioxide is a necessary component. The CO_2 in the air is used by the plants in indoor systems which are in large numbers. So, CO_2 is used artificially, and it is required to control the amount used. The optimum range level for many crops grown indoors is in the range of 340-1300 ppm [38]. The different amounts of CO_2 are required because it depends on the crop type, the available light, the temperature of the air, and RH. For the proper growth of fish, the carbonic acid levels should be less than 5 mg/L [20, 39]; otherwise, it is dangerous for fish. A sensor named MG811 is used to measure the amount of carbon dioxide in the air [30].

3.2.2. Air Temperature. Plant health is affected by the temperature of the air. In the aquaponics unit, the required temperature to grow the vegetable plants is 18-30°C. At temperatures greater than this, they start flowering and then to seeds [15]. For the proper transpiration of the plants, the temperature of the air is needed. When selecting temperature sensors, the range of temperature, the sensing element, the contactless or contact, and the method of calibration are to be checked. A thermistor is used to measure the temperature of air and humidity together in an aquaponics unit. A DHT11 thermistor [23] and a DHT22 thermistor are used which is having more accuracy and a range of values greater than DHT11 [38].

3.2.3. Relative Humidity. The amount of moisture in the air is relative humidity [40]. Depending on the stages of growth and the crop type used, the optimum level of relative humidity varies. Commonly, 50-80% is considered but it depends on the indoor temperature of the system. The air temperature sensor also provides relative humidity. In an aquaponics system, the DHT11 sensor is used to measure the relative humidity values [41].

3.2.4. Light Intensity. In indoor provisions, the sunlight is not available or available in less amount, which is essential for plants. In an aquaponics system to make the sunlight available to the plants, artificial lighting is used. Light is measured in intensity. Only some part of the light spectrum is used by the plants known as photosynthetically active radiation (PAR). It is the solar radiation spectral range where the photosynthetic organisms can process [42]. For a day, the crops require light for 14 to 18 hours. A light-dependent resistor (LDR) can be used for measuring the lighting system's radiation intensity. To measure the ambient light intensity, LDR is used [22, 23].

3.2.5. Media Moisture. The content of water in soil present in the media base is the media moisture. If a media-based type system is used, then it is necessary to measure the moisture of the medium. A soil moisture sensor is good to be used for this type which gives the accurate amount of water needed for the plants. The capacity of water that the soil holds is recommended to be checked. It was found that depending on the type of soil, the optimum ranges vary from 30 to 60 cbars [43]. An FC-28 can be used as a moisture sensor to measure soil moisture [38]. From the studies, the aquaponics system parameters that are required and their optimized ranges are summarized in Table 1.

Table 1: Aquaponics parameters and their optimal range.

Parameter	Optimal range
Temperature of water	17°C-30°C
Relative humidity of air	60%-80%
Dissolved oxygen level	>4 mg/L
Temperature of air	18°C-30°C
Level of water	0.02 kg/L
Salinity of water	0-2 ppt
Hardness of water	50-150 mg/L CaCO3
Flow of water	1-2 liters/min
Total ammonia-nitrogen	<2 mg/L
Nitrites	<1 mg/L
Nitrates	50 ppm to100 ppm
Alkalinity of water	50 to 150 mg/L CaCO3
Electroconductivity	100 to 2000 μS/cm
Level of carbon dioxide	340 ppm to 1300 ppm
Intensity of light	600 PPFD-900 PPFD
pH of water	6.5-7.0
Total dissolved solids	<1000 mg/L

4. Real-Time Monitoring Systems

Internet of Things, otherwise called the IoT, is an idea that plans to grow the advantages of persistently associated web networks. The integration of a controller, sensors, and the Internet into physical objects such as food gadgets and equipment allows for global information sharing. This additionally utilizes the idea of IoT because the data from the estimation of the sensor can be obtained through cell phone applications and sites from any place with the Internet association. With the presentation of computerization, keen techniques, and availability in the cultivating business, another entryway was opened for the upgrading of these aquaponics frameworks. The normal advantages of keen mechanization are a critical decrease of difficult work and a more vigorous control of the interaction by expanding the availability and availability of the boundaries and utilizing PC abilities to settle on information-driven choices [44].

4.1. Interfaces for Remote Monitoring. Checking interfaces are ordinarily a climate (intelligent or not) that shows a portion of the intrigued boundaries with regard to the cycle to the client or partner. This perception cycle is critical to ultimate choice making. IoT innovation empowers these observing interfaces to show esteems through remote organizations, even continuously.

A web application that exhibited a dashboard associated with a microcontroller to screen chosen hydroponics boundaries is used [5]. In the very year, a Raspberry Pi is used to do all the framework estimation units; at that point, the sensors' information is shipped off an electronic stage where it is put away and shown [45]. After a year, an iOS application that permitted to screen the framework climate persistently by getting information straightforwardly from the frameworks' microcontrollers is used [46]. The course of these joint efforts is going towards continuous dependability and portability (online as well as an application for cell phones).

4.2. Applications That Are Controlled Remotely. Controller applications are characterized by their capacity to flag framework actuators to communicate or modify some boundaries. With controller applications, administrators can on or off the water siphon or light when essential, change estimations of basic clocks to adjust the plants' development cycle, etc. From the inspected papers, a GSM and Arduino-based observing and controlling framework is used which sends ready message to administrators when estimations are outside explicit reaches. Graphical UIs are intended to show the data and information that could be separated from the framework [30]. The coordinated effort was utilizing Blynk, a multilanguage stage that empowers controllers of various microcontrollers like Arduino and Raspberry Pi [47]. A microcontroller along with a GSM receptor in a hydroponics framework is used. Accordingly, administrators can send messages to the receiver so continuous authority over the supply of water or temperature is attained [48]. An Arduino associated with a web worker through an Ethernet Shield, a UI was made to permit ongoing checking and control of the water-related sensor estimations, for example, switching on or off the fumes, siphons, and fog creators [38]. An IoT-based hydroponics framework that permits distant checking and control of the framework boundaries was made. The creators utilized a Modbus TCP standard convention to pull estimation information from the detecting hubs of an administrative PC [10]. A framework with a microcontroller associated with a Ubuntu IoT Cloud. The framework could be gotten to screen and control the boundaries consequently dependent on the detected inputs [49]. The creators in this segment added the controlling boundary into the situation. As of now, the perception of the boundaries in the framework is not sufficient and is important to control such boundaries for a superior framework.

Architecture has been implemented by different studies as shown in Figure 2. The aquaponics sensor mote consists of different sensors to monitor the environmental parameters and water which are required for the healthy development of the plants as well as fish. The data that is sensed from the different sensor motes are sent through wireless communication to the gateway. The gateway receives the data and provides the information from which sensor node the data has been received and displays it on the display unit.

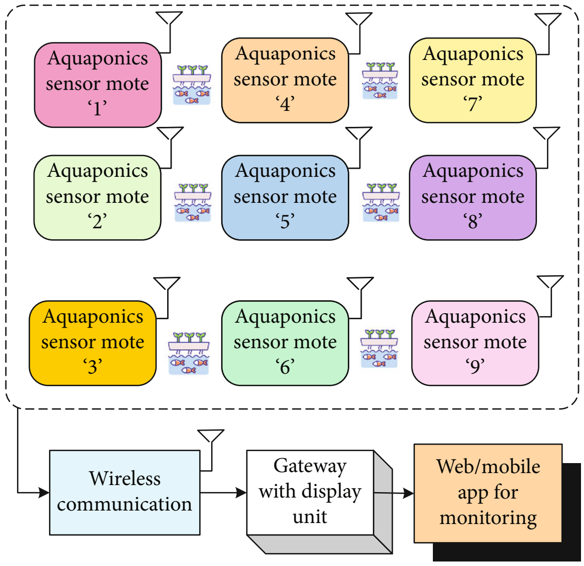

Figure 2: Remote monitoring of aquaponics system [50].

The data is then logged on the web or the mobile application Internet, and the user can monitor it from anywhere through the web/mobile app.

Table 2 illustrates the latest studies that is focused on IoT-based aquaponics platforms. From the table, it concludes that the majority of the studies implemented Wi-Fi as communication medium to transmit data to the cloud server for real-time monitoring and controlling. [51] implemented the edge computing technique in aquaponics with the ML for the automation in the aquaponics system; however, it is implemented in the small scale only. [52] implemented a technique for the optimization of the nutrients; however, they are no any information related to the data transmission from the Raspberry Pi to the cloud server. From the overall studies, it is identified that the customization hardware is necessary to carry out for meeting the requirements of aquaponics system.

In [54], the automatic triggering of a water pumping event has an accuracy of 0.9795 because of the ultrasonic sensor and soil moisture sensor, and in this study, the threshold for the intersection of union (IoU) is set to 0.5 to achieve higher accuracy, with an average precision (mAP) of 75.0 and an F1 score of 0.9556 [58]. The system appears to be functional based on the test results; nonetheless, several deviations are discovered, including an RTC test showing a delay time of 00.02.10 of RTC compared to the national standard time and an error of 2.4 percent identified on a calibrated TDS sensor testing [52]. When the lettuce's size and production were compared to those grown in uncontrolled aquaponics systems, the yield showed a considerable increase in size, with some of them reaching 40 to 45 inches in diameter, and also, the cost of managing nutritional parameters is reduced by more than 75%

4.3. Wireless Technologies. The remote innovations are seldom introduced and are generally connected to the two past areas. By the by, it was discovered that a few supporters were centered on creating some remote advances in aquaponics that improve availability. A design to screen and control a hydroponics framework with sensor data and Arduino is created. Information is effectively put away on WRT hubs and sent to OpenWrt workers utilizing the Wi-Fi module [41]. A hydroponics framework utilizing the 6LoWPAN convention and a remote sensor organization (WSN) was planned [59]. If pH and temperature values of the aquaponics exceed the threshold range [4], then GSM sends warnings to authorities and updates it on ThingSpeak. An online observing framework utilizing ThingSpeak IoT stage with Arduino Uno and ESP8266-01 that is Wi-Fi handset was built [23]. A Raspberry Pi alongside a Wi-Fi dongle to give a web network to the framework is used. The framework utilizes cloud-based stages for storing and controlling the assorted boundaries of the hydroponics framework [33]. The utilization of remote advances in the sensors or transmission of information makes way for enhancements in e-checking and control of boundaries. Table 3 illustrates the technical specifications of wireless communication protocol that can be implemented in IoT-based systems for aquaponics farming.

5. Edge-Assisted Architecture

Currently, the integration of a huge number of sensors and devices in the physical environment is generating a huge amount of data in the IoT. In traditional cloud computing, all data must be transmitted to centralized servers, and the findings must be transmitted downstream to the sensors and devices after computation [60]. This process imposes a significant load on the network, such as bandwidth, data transmission costs, and resources. Edge and fog computing overcome these challenges, as the data computation or storage is deployed at the edge of the network. Furthermore, the distributed architecture may control network traffic and prevent traffic peaks in IoT networks, lowering transmission latency between edge/cloudlet servers and end-users and reducing reaction times for real-time IoT applications when compared to standard cloud services [61]. A multilayered edge architecture is proposed to analyze the data between the cloud and the fog computing layers with low latency for IoT devices in real time [62]. An "offline-first" architecture for the low-cost and automated household aquaponics units is proposed. This moves the storage of data, machine learning, and computation away from the cloud platforms into the platforms that are preserving privacy [63].

Architecture is being implemented by different studies on edge-based computing as shown in Figure 3. The architecture consists of different sensor motes located at different locations. The sensor nodes consist of different sensors and actuators that are required for the sensing the different environmental and water-based that are required for the healthy growth of the plants and the fish. The data sensed by these sensors is sent to the edge computing node wirelessly. The data received is then analyzed and processed by the edge computing node, and also, predictive analytics is performed through computing, coprocessor, and AI model. From the

Table 2: Previous IoT-based platform for aquaponics.

Research	Objective	Advantage	Disadvantage
[53]	Automated aquaponics system to sense of pH, level, and temperature	Cloud server implemented to visualize the sensor data	Intel Edison microcontroller integrated is expensive
[54]	Automatic control of the aquaponics system using an ML algorithm	Edge computing is utilized to identify the parameter for the growth of plant and fishes	The proposed model is implemented in small scale, where the performance of system is skeptical
[55]	To control and monitor water quality and environmental parameters	Solar-based power supply for powering the nodes	Implementation of Wi-Fi in the sensor node increases the power consumption and also requires additional infrastructure for working on Internet
[56]	Remote monitoring systems using TDS sensor	Calibration of TDS sensors is carried out	Cloud server is missing in the IoT-based system
[57]	Optimizing nutrient supply using ML	Raspberry Pi is interfaced with Vernier sensors for the measurement of nutrients	No information available about data transmission and data storage

Table 3: Technical specifications of wireless communication IoT protocols.

Attributes	Zigbee	6LoWPAN	LoRa	Sigfox	NB-IoT
Frequency	868/915 MHz and 2.4 GHz	868/915 MHz and 2.4 GHz	915 MHz, 868 MHz, and 433 MHz	868/915 MHz	Licensed LTE bands
Modulation	Binary phase shift keying and quadrature phase shift keying	NA	Chirp spread Spectrum	Binary phase shift keying	Quadrature phase shift keying
Topology	Peer-to-peer, mesh, star, and tree	Mesh, star	Star of stars	Star	NA
Network	Personal area network	Personal area network	Low power wide area network	Low power wide area network	Low power wide area network
Standard	802.15.4	802.15.4	802.15.4 g	802.15.4 g	NA
Range of data transmission	10-50 meters	10-50 meters	5 km-20 km	10 km-40 km	1 km-10 km
Bitrate	20-250 kb/s	250 kb/s	50 kb/s	200 bp/s	200 kb/s

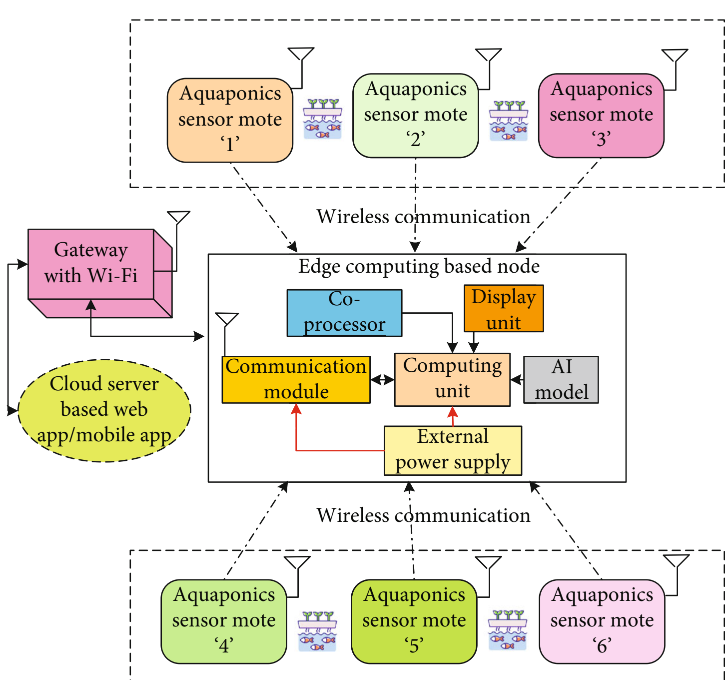

Figure 3: Edge-based computing node for real-time prediction for aquaponics.

edge computing node, the outcome/data is transmitted to the gateway. The gateway then analyzes the sensor node from which the data has been obtained, and using Wi-Fi, the data is sent to the cloud server.

6. Machine Learning Techniques Used in Aquaponics

Farmers can get more from the land by using resources sustainably with the help of artificial intelligence. Using artificial intelligence, farmers can know the conditions of temperature, weather, energy usage, water, and the condition of soil collected from their farm. Farmers are now able to use the sensor data that is captured to predict the yield and make them better equipped for natural disasters and climatic conditions using intelligent data processing techniques like machine learning. Machine learning is a branch of artificial intelligence that allows machines to learn from their mistakes. It uses computational approaches to learn directly from datasets rather than relying on a model of fixed equations.

A cloud-based monitoring system in aquaponics is developed which measures the temperature of the water, depth of water, and the value of dissolved oxygen. To monitor the fish activity, three infrared distance sensors were connected to the aquarium glass. Through the fish activity sensing, the fish metabolic rate was calculated using the regression analysis [64]. A real-time water quality monitoring system is developed based on assessing time series motion trajectories of live fish and using a neural network algorithm to estimate the frequency of pattern changes in these trajectories [65]. The author developed an ML-based IoT system for optimizing nutrient supply in the aquaponics system. The nutrient values were measured with Vernier sensors, and an actuator system was created to feed the nutrient into the environment in a closed loop. In this feature selection techniques like XG Boost classifier and recursive feature elimination with extra, tree classifier was used for ranking the features [66]. An aquaponics monitoring and control system is designed with fuzzy logic to evaluate the input and provide the proper outputs automatically. A genetic algorithm is used for the optimization of the parameters of the PDF and FPDF controllers. Better results were obtained in humidity and temperature control of the greenhouse when compared with the traditional PDF controller [67].

A method is proposed on *Q*-learning to get the control the factors that rely on the environment in the greenhouse and then combined with a CBR to get the optimal control of the temperature of the greenhouse [68]. A branch and bound search algorithm in a discrete model of the predictive control of greenhouse is proposed which reduced consumption of energy without affecting control accuracy [69]. A model is proposed based on a neural network based on the time series of a nonlinear autoregressive with a model based on external input. The control effect of humidity and temperature showed that the stability of the controller is more [70]. The Kalman filter algorithm was combined with the traditional PID control algorithm to control the temperature of the greenhouse which improved the control effect, the shorter response time and the higher system stability, and a better convergence [71]. Table 4 illustrates the ML model implementation in aquaponics for the water quality monitoring in the aquaponics system. Support vector machine (SVM), random forest (RF), k-nearest neighbor (k-NN), artificial neural network (ANN), Hammerstein-Wiener (HW), convolutional neural network (CNN), radial basis function (RBF), and recurrent neural network (RNN) are the few models that are addressed in the previous studies for water treatment and monitoring.

7. Recommendations

7.1. Sensors and Actuators. In an aquaponics system, the water-related and environmental parameters are to be monitored and controlled. In an aquaponics system, the sensors that are used to be much more accurate with less error because the development of plants as well as fish are affected if values are not accurate. The actuators should also be operated based on the sensor value obtained.

7.2. Communication Technologies. Wireless communication protocols play a very important role in monitoring the aquaponics units from a remote location. GSM/GPRS with personal area network technologies like Bluetooth and Zigbee is also used for transmission of the sensory data. The transmission range is limited to 100 m for these technologies. WPAN has the limitation of short-range, and GSM/GPRS has the limitation of high-power consumption. LoRa (long range) wireless communication overcomes these limitations in the technologies that have been used previously.

7.3. Edge and Fog-Based Vision Node. Edge and fog computing provides an opportunity for data processing in less time with enhanced latency. In aquaponics, the continuous monitoring of plants and fishes in terms of growth and health is highly demanded to enhance the better yield. To identify the growth and health of plants and fishes effectively, edge and fog-based vision nodes need to be incorporated. Edge and fog-based vision nodes enable to detect and predict the growth and diseases of fishes and plants in real-time.

7.4. ML Models for Prediction. Machine learning models have gained wide attention in the prediction of events based on real-time sensor data obtained from the sensors. In aquaponics, real-time prediction is highly required for maintaining the healthy growth of plants and fishes in order of enhancing productivity. The incorporation of the ML model in the vision node and edge-based sensor node enhances the system to predict depending on real-time image data and sensor data.

7.5. LoRa-Based Sensor Node and Gateway-Based Architecture. An architecture is proposed as shown in Figure 4. The proposed system consists of an aquaponics system to which different sensors are attached to sense the environmental parameters and also the water-based parameters such as humidity, temperature, light, pH, electrical conductivity, and water level. The sensors are altogether

Table 4: ML model implementation in the aquaponics system [72].

Model	Purpose	Application
SVM	Regression classification, supervised ML, and pattern analysis	Membrane-process parameter modeling, biological oxygen demand, dissolved oxygen modeling of rivers, aquaponics growth rate modeling
RF	Regression, classification, supervised ML	Adsorption process percent removal modeling, simple and hybrid dissolved oxygen modeling
k-NN	Classification, supervised ML	Classification of aquaponics growth phase
ANN	Regression, classification, supervised ML	Chlorine dosage/set-point, membrane-process parameter modeling and dissolved-oxygen concentration modeling
HW	Regression, ML model	Dissolved-oxygen concentration
CNN	Regression, classification, supervised ML, segmentation	DBP formation modeling
RBF	Regression, classification, ML function	Membrane-process parameter modeling, the adsorption process removal efficiency, and DBP formation modeling
RNN	Regression, classification, supervised ML	Suitable for time-series datasets and modeling, membrane-process parameter modeling, dissolve oxygen concentration modeling

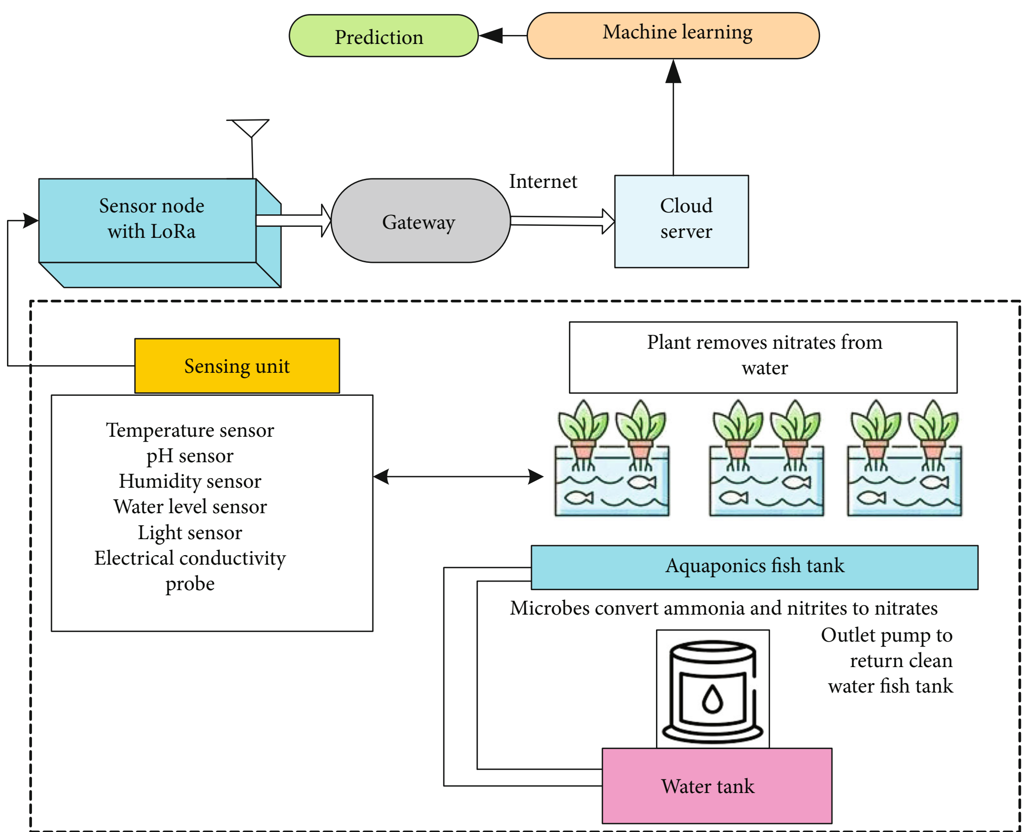

Figure 4: Proposed architecture for real-time prediction in aquaponics system.

considered a sensor node. The sensor node senses the required parameters from the different sensors. The sensed data from the different sensor nodes is collected, and the data is then sent with the help of a LoRa to the gateway. The gateway identifies the nodes from which the packets of data have been received and with the help of Wi-Fi connectivity is sent to the cloud server. The prediction is done on the data that is obtained from sensors using machine learning algorithms.

8. Conclusion and Future Scope

Food and agriculture are significant considerations that can meet the predicted food demand by the Food and Agriculture Organization (FAO) by 2050. Furthermore, the United Nations suggests that sensible water utilization through enhanced irrigation and storage technology, in conjunction with the creation of new drought-resistant crop types, can assist to sustain dryland output. Aquaponics is one of the sustainable farming approaches that use a closed-loop and soil-less method, so wireless technologies must be integrated for real-time monitoring, controlling, and managing from any remote location. With the motivation of the above aspects, this study conducts a review of the aquaponics system, and from the review, it has identified different critical parameters that are required for the effective growth of plants and fishes. In addition to this, the study discusses the significance of wireless monitoring with the integration of sensors and communication technologies. Edge and fog computing-based architectures for the implementation of ML-based wireless systems in aquaponics for real-time prediction are also discussed. Finally, based on the review, the discussion on the limitations is presented and also recommended a few suggestions for future enhancement in aquaponics monitoring such as edge and fog-based vision nodes, ML models for prediction, LoRa-based sensor nodes, and gateway-based architecture.

Data Availability

The data presented in this study are available on request from the corresponding author.

Conflicts of Interest

The authors declare that there is no conflict of interest regarding the publication of this article.

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