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Review Article

Monitoring and Control Systems in Agriculture Using Intelligent Sensor Techniques: A Review of the Aeroponic System

Imran Ali Lakhiar [1], **Gao Jianmin** [1], **Tabinda Naz Syed** [1], **Farman Ali Chandio** [1], **Noman Ali Buttar** [1], **and Waqar Ahmed Qureshi** [2]

[1] *Key Laboratory of Modern Agricultural Equipment and Technology, Ministry of Education, Institute of Agricultural Engineering, Jiangsu University, Zhenjiang, 212013 Jiangsu, China*
[2] *Research Centre of Fluid Machinery Engineering and Technology, Jiangsu University, Zhenjiang, 212013 Jiangsu, China*

Correspondence should be addressed to Gao Jianmin; gaojianminujs@163.com

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In recent years, intelligent sensor techniques have achieved significant attention in agriculture. It is applied in agriculture to plan the several activities and missions properly by utilising limited resources with minor human interference. Currently, plant cultivation using new agriculture methods is very popular among the growers. However, the aeroponics is one of the methods of modern agriculture, which is commonly practiced around the world. In the system, plant cultivates under complete control conditions in the growth chamber by providing a small mist of the nutrient solution in replacement of the soil. The nutrient mist is ejected through atomization nozzles on a periodical basis. During the plant cultivation, several steps including temperature, humidity, light intensity, water nutrient solution level, pH and EC value, CO_2 concentration, atomization time, and atomization interval time require proper attention for flourishing plant growth. Therefore, the object of this review study was to provide significant knowledge about early fault detection and diagnosis in aeroponics using intelligent techniques (wireless sensors). So, the farmer could monitor several paraments without using laboratory instruments, and the farmer could control the entire system remotely. Moreover, the technique also provides a wide range of information which could be essential for plant researchers and provides a greater understanding of how the key parameters of aeroponics correlate with plant growth in the system. It offers full control of the system, not by constant manual attention from the operator but to a large extent by wireless sensors. Furthermore, the adoption of the intelligent techniques in the aeroponic system could reduce the concept of the usefulness of the system due to complicated manually monitoring and controlling process.

1. Introduction

Agriculture has an ancient history nearly dates back to thousands of years. Moreover, its advancement has been pushed by implementing the several new systems, practices, technologies, and approaches with the time. It employs over one-third of the global workforce [1]. The agriculture is the backbone of an economy for many countries and executes a significant contribution to the development of the economy for underdeveloped countries. Besides, it steers the process of economic prosperity in developed countries. Several research studies concluded that overall world agriculture uses approximately seventy percent per year available fresh water to irrigate only seventeen percent of the land. Another side, the total available irrigated land is gradually decreasing due to the rapidly increasing of food requirements and effects of global warming [2, 3]. In other words, agriculture is dealing with new main significant challenges. Foote [4] said FAO reported that world food production must be increased by seventy percent to provide sufficient food production for the fast-growing population and urbanisation. The expected world population growth for the half of the present century is daunting. However, depending on the estimate, it could be expected to rise above the nine billion people by midcentury. As many studies reported that the population is increasing very fast, the global population was one billion in 1800,

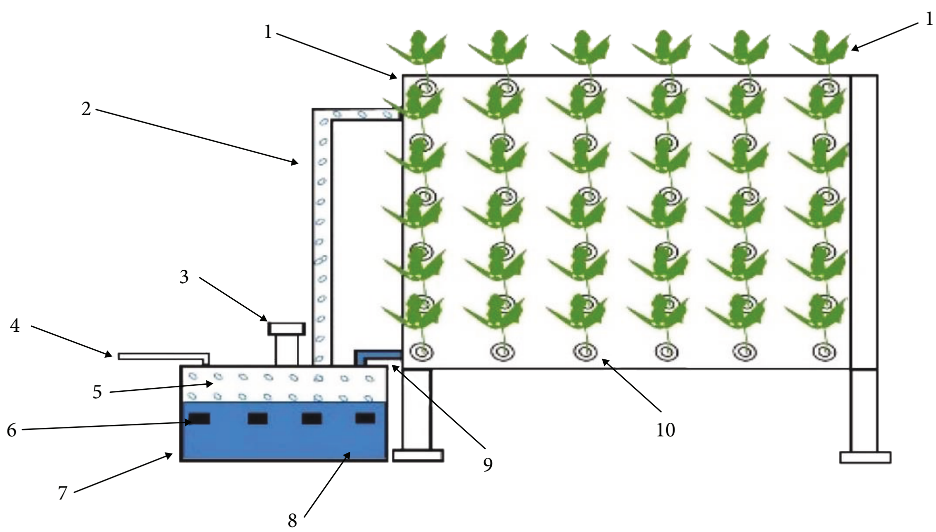

Figure 1: Basic diagram of the aeroponic plant cultivation system by Lakhiar et al. [15]. 1. Growth chamber. 2. Nutrient fog transmission pump. 3. Misting fan. 4. Power supply line. 5. Nutrient fog. 6. Ultrasonic atomizers. 7. Nutrient reservoir. 8. Nutrient solution. 9. Nutrient recycle line. 10. Plant holder. 11. Plant.

and it increased to seven billion people in 2012. However, studies report feared that at the end of the current century, it could be expected to reach eleven billion people and there could be many, many more mouths to feed soon. Thus, the rapid increase of the population, alongside the decrease in agriculture land, intensification of global climate changes, and exacerbation of water resources, declines labour force and energy crunches are posing tremendous challenges and hurdles to the agriculture sector [5, 6]. Furthermore, the developing and developed countries will deal with substantial water crises and issues due to rapid urbanisation and industrialisation. The available fresh water for irrigated agriculture land is supposed to decrease in future [7, 8]. Besides, the unpredictable climate changes include extreme weather conditions, intense storms, heat waves, and floods will have a substantial adverse impact on world agriculture sector. We need more production from agricultural systems to meet the growing food demands. Otherwise, we will suffer from food insecurity problems which will be the biggest threat. Moreover, Qiu and coworkers [9] revealed that the progress of the agriculture production is not only significant for to producing food to feed the population, but it is also essential for the industrial sector. Similarly, the agriculture is the main source to produce the raw material for many industrial sectors. Therefore, it must be understood that industrial and agricultural developments are not alternatives. However, both sectors are complementary to each other on the path to achieving the food security issues.

As the evolution of humankind from hunters and gatherers to agrarian societies, the efforts have mainly focused on improving the plant yield and productivity by either genetic changes, cultural or husbandry, management practices, or by developing and introducing plant protection measures. Accordingly, in the last and present century, peoples have started exploring the possibilities by adopting different modern techniques in agriculture. The adoption of the precision farming methods in agriculture is one of the excellent examples. The purpose is to try and mechanise them in agriculture to prevent the crop losses due to sudden climatic changes, soil-borne diseases, pest attaches, and so on. However, many research studies have been suggested and reported that problems and challenges of agriculture could overcome by adopting the precision farming methods. At present, several countries are increasing their farming productivities by implementing the precision farming methods.

Baudoin et al. [10] reported that the artificial plant growing method (e.g., greenhouse and factory farms) is one of the fundamental types of precision agriculture. Nowadays, the method is receiving importance and gaining the intention of the growers. The method can provide sufficient food supply throughout the year. In the system, the plant grows around the year by artificially adjusting and controlling the surrounding environmental conditions such as temperature, CO_2 (carbon dioxide), humidity, light intensity, airflow, and nutrients supply within the confined facilities [11, 12]. Besides, the system minimises environmental impact and maximises the crop yield with significant results as compared with traditional (open-field) cultivation system [13]. Savvas and team [14] informed that at present soilless plant cultivation is one of the most disruptive inventions ever presented in the field of artificial plant growing system. The soilless system refers to plant cultivation techniques without the use of soil by providing artificial solid material or water nutrient solution as a growing medium instead of soil. However, the water culture is related to the process of hydroponic and aeroponic plant cultivation (Figure 1). In both methods, the roots of the plant are continuously or intervalley nurtured with or within water nutrient solution by providing a specific control environment in artificial supporting structure [16, 17]. Both methods provide many benefits to the grower such as full control of nutrient concentration and supply and prevention of many soil-borne diseases and infections to plant, thus resulting in increased plant yield with significant returns, high quality, and more efficient use of available natural resources [18, 19].

Several studies reported aeroponic and hydroponic systems as a modern and innovative plant cultivation techniques under the soilless system. By adopting these techniques, the growing food crises could be resolved [20, 21]. Moreover, the hydroponic system to grow initially leafy green vegetables was the first to emerge, which started taking commercial exploitation routes in industrialised countries in west and east but eventually was found to have particular defects and problems that forced people to discover and experiment with newer variations and techniques like the aeroponic system. According to the NASA report, the aeroponic system could reduce water, nutrient, and pesticide usage by 98, 60, and 100 percent, respectively, and increase the plant yield by 45 to 75 percent [22].

The primary motivation of this review article is to provide an idea about the use of intelligent sensor techniques in the aeroponic system. It could provide an opportunity for full automation, scalability, anytime-anyplace access monitoring, and fault diagnostics in the aeroponic system. Moreover, it would be helpful for the local farmer and grower to provide timely information about rising problems and influencing factors for successful plant growth in the aeroponic system. The farmers could start to understand their crops at a micro scale and able to communicate with plant through accessible technology. To the best of our knowledge, this is the first work to provide a brief review of the use of intelligent sensor techniques in the aeroponic system. However, the rest of the paper is organised as follows: Section 2 describes the current work in the aeroponic system with intelligent sensor techniques. In Sections 3, 4, and 5, we present the brief description about the aeroponic system, application, and working protocol of wireless sensor network in the aeroponic system. Sections 6, 7, 8, and 9 describe the advantages, future application, application of artificial intelligence in agriculture, and conclusion.

2. Related Work

Aeroponics is the new plant growing technique of modern agriculture. Until now, it is not entirely implicated among the farmers. Mostly, it is practiced by the researchers for performing the experimental studies. Their study reports concluded that it could be well accepted in agriculture as a modern-day plant cultivation activity where the modern farmer does not need soil to grow the plant. However, the aeroponic system has some substantial vulnerability like a failure of water supply pumps, nutrient distribution line and preparation, and atomization nozzle clogging, which require special knowledge and attention to avoid damage, rapid plant death, and failure of the system [23]. Furthermore, the integration of the intelligent agriculture techniques could be the best solution to avoid or deal with the abovementioned issues without any technical expertise. Xiong and Qiao [24] reported that the integration of the intelligent agriculture systems could be an effective approach for solving complex problems of agriculture domains. Zhai et al. [25] reported that presently, several research studies had been conducted on the use of intelligent techniques in agriculture especially in the last two decades. Besides, several new techniques and application have been introduced and patented to improve the traditional agriculture practices. However, experts mainly focused and monitor the climatic condition, soil properties, water quality, plant development, livestock management, and fertilizer application, pesticide application, and illumination control through various intelligent techniques [26–32]. Meanwhile, it could be concluded that traditional agricultural logistics is improved and upgraded by introducing and implementing the several modern technologies and techniques in agriculture domains [33]. Basnet and Bang [34] reported that the collecting information through sensors and communication technology played a vital role in improving agricultural production. It has shifted agriculture from input-intensive to knowledge-intensive, and agriculture becomes more networked and decision-making. Both small- and large-scale farmer can benefit from introducing this technique into the agriculture value chain, having their productivity increased, quality improved, services extended, and costs reduced. It provides insights into various issues in the agriculture like weather prediction, crop and livestock disease, irrigation management, and supply and demand of agriculture inputs and outputs and helps in solving those problems. Rehman and Shaikh [35] concluded that at present, several information technologies including satellite navigation, grid and ubiquitous computing, and sensor network are exercised in agriculture. However, the application of the sensor network is supporting agriculture practices and activities in a very positive direction [36, 37]. Zhang and coworkers [38] used a sensor network to monitor air temperature, humidity, ambient light, and soil moisture and temperature. Also, the aeroponic system is the new application of the soilless agriculture. Besides, several studies had been successfully designed the aeroponic system by using various information technologies approaches such as Tik and coworkers [39] designed and implemented a wireless sensor network to monitor the aeroponic system. They used temperature, light intensity, pH, and EC monitoring sensors. Moreover, the study reported that the wireless sensor network offers a wide range of information which could be required for the horticulturist to provide a greater understanding of how these environmental and nutrient parameters are correlated with plant growth. The real-time information obtained from sensor nodes can be utilised to optimise strategies to control the temperatures and the other properties of the nutrient solution. A study by Pala et al. [40] proposed an approach to monitor automation and early fault detection tools in the aeroponic system through intelligent techniques. In the protocol, they designed a highly scalable aeroponic system and coded as aero-pot prototype. They developed software based on a genetic algorithm to optimise power consumption of the aeroponic system. Their study concluded that using this software user can define various properties and virtually configure the aeroponic system. The developed software can allow the user to add and remove the lights and pumps and define consumption of added devices with minimum grower effort. Laksono et al. [41] designed a wireless sensor and actuator network for the controlling, monitoring, and conditioning of an aeroponic growth chamber. The designed wireless protocol was based on ZigBee technique. They also designed a data transmission system to transfer the data from the database server to administrator through text message. The proposed system was based on the sensors, actuators, communication system, and database server. The experiment results showed that the proposed wireless protocol based on ZigBee techniques was a useful tool of the wireless sensor network to monitor the aeroponic system. Jonas et al. [42] developed an automatic monitoring system to control the environmental and nutrient supply of the aeroponic system. The designed wireless protocol was based on Arduino development board. Their study concluded that the proposed system can control the nutrient atomization frequency based on the root chamber moisture content. However, the system can automatically transfer all the gathered information to a web server and also share on Twitter. Sani et al. [43] recommended a web-based control and monitoring system for the aeroponic system. Their system was composed of microcontrollers (using Arduino IDE program), actuators (two relays include atomization spray and fan on/off on specific time), the sensor (temperature and pH sensor), LDR (light intensity sensor), and communication modules (GSM/GPRS/3G modem). The present study concluded that our proposed design was able to monitor and measure the temperature, pH, light intensity, atomization time and interval time, and fan activation time and interval time in the aeroponic system. The proposed method was able to directly send the real-time information from the sensor to the server via the Internet using GSM. Anitha and Periasamy [44] designed wireless sensor technique to monitor the aeroponic system. The technique was based on the ZigBee prototype. The proposed network architecture was based on temperature, pressure, humidity, water level, and pH monitoring sensors. The sensors transmitted the gathered data to the GSM (Global System for Mobile) node or coordinator node, whereas the gateway device was used to transfer the data to the personal computer. However, a server was connected to the database where the maximum and minimum threshold values of pH, water level, and temperature were fixed. Furthermore, if the monitored value reaches above or below the threshold values stored in the database, thus, the system was able to start the alarm sound to aware the farmer. Another study in 2016 by Kernahan and Cupertino [45] invented a system to monitor and control the aeroponic system using wireless techniques. They concluded that a reliable aeroponic system provides a wireless connection between its subsystem for the exchange of data and commands. The various subsystems manage one or more plants growing atriums include nutrient atomization on hanged roots, maintenance, control of nutrient solution level, the addition of various nutrients, and control of the light quantity and cycle. A study by Montoya et al. [46] designed a wireless sensor system to monitor the aeroponic system. The system protocol was based on the Arduino development board. They used analog and digital sensors for monitoring temperature, nutrient atomization, EC, and pH fluctuations and level of nutrient solution in the nutrient reservoir. In order to acquire data and automation system, the two Arduinos were managed in a master-slave configuration and connected to each other through wireless by Wi-Fi. All the recorded data was autosaved in microSD memory and sent to a web page. Their study concluded that the proposed protocol could be used for automation and could monitor the aeroponic system. Kerns and Lee [47] firstly designed and introduced an aeroponic system using IoT (Internet of things) to automate the system. The proposed system is comprised of a mobile application, service platform, and IoT device with sensors (pH balance, temperature, and humidity). They used Raspberry Pi Zero device and designed a system to monitor and measure the selected parameters. The gathered data was autosaved into the database server by sending an SQL query. Their study concluded that the proposed system could help farmers to control and monitor the aeroponic system remotely. Furthermore, Karu [48] also designed and implemented a high-precision system for small-scale aeroponic plant cultivation. The system is allowed to precisely control the nutrient solutions, pH, and EC levels and gives data about humidity, temperature, pH, and EC concentration and amount of the nutrient solution in the reservoir. A recent study by Martin and Rafael [49] also proposed and suggested systems, methods, and devices for the aeroponic system. Mithunesh et al. [50] proposed an intelligent control system for an aeroponic system. The system protocol was based on an open-source development board called Raspberry Pi. Their study concluded that the developed system provides the simple management and high availability established by using both the local and global systems. Idris and Sani [51] designed monitoring and control system for the aeroponic system. They concluded that the developed system is able to monitor the aeroponic system working parameter such as temperature and humidity by sending the data in real time from sensor to the display system. Janarthanan et al. [52] concluded that the problems of the aeroponic system could be solved by the use of wireless sensor and actuator system. It allows the user to monitor and interact with the system through mobile app and a web interface. However, Liu and Zhang [53, 54] designed an aeroponic system for automatic control of water-fertilizer and temperature. They concluded that system supplies an experimental platform with features of simple structure and convenient control.

3. The Aeroponic System

The aeroponic system is one of the techniques of the soilless culture, where the plant grows in the air with the assistance of artificial support instead of soil or substrate culture. It is an air-water plant growing technique where lower portions such as the roots of the plant are hanged inside the growth chamber under complete darkness in controlled conditions. However, the upper portions of the plant such as leaves, fruits, and crown portion are extending outside the growth chamber. Usually, the artificial supporting structure (plastic or thermofoam) is provided to support and divide the plant into two parts (roots and leaves). In the system, plant roots are openly exposed in the air and directly irrigated with a small droplet size of the water nutrient at interval basis. The nutrient solution is supplied through different atomization nozzles with or without high air pressure. Moreover, several studies considered aeroponics as a modern-day agricultural activity which is practiced in an enclosed growth chamber under entire controlled conditions, as it could eliminate the external environmental factors as compared with traditional agriculture activity. Hence, it is no longer dependent on large-scale land use, and it could be set up in any place, a building that has lifted global climate without considering the current climate such as rainy season and winter [23, 55–59]. Buer et al. [60] reported that atomization nozzle uses the tiny amount of the water nutrient solution and provides an excellent growth environment for the plant. Zobel and Lychalk [61] said it is a modern-day agricultural research tool which provides several agricultural research opportunities for a researcher with significant results by providing artificial growth conditions. However, Table 1 shows the essential monitoring and control parameters in the aeroponic system. Hessel et al. [62] and Clawson et al. [63] studies discovered that aeroponics contributes to the advances and developments in many areas of plant root studies. It provides an excellent chance for plant researchers to deeply study the behavior of plant root under different conditions and without any complications. Until now, many researchers had conducted plant root research and experimental studies root response to drought [64], effects of different oxygen concentrations on plant root development [65, 66], root microorganism [67–69], arbuscular mycorrhizal fungi production [70], and legume-rhizobia interaction [71]. Furthermore, studies also practiced the technique by growing vegetables, fruits, herbs, and medicinal root-based plant [72–74] such as tomato, potato, soybean, maize, lettuce, *Anthurium andreanum*, and *Acacia mangium* [15, 59, 75–79].

3.1. Present Status of the Aeroponic System. The aeroponic system is one of a holistic production management method in agriculture which promotes and improves agroecosystem, health, and biodiversity. The system has a paramount reputation in the horticulture department, because of its implications on the economic and technical aspects in the agriculture. Among all agriculture systems, only the aeroponic system is receiving the full attention of farmers, policymakers, entrepreneurs, and agricultural researchers. The grower could reduce the requirements of chemical inputs including fertilizers, herbicides, pesticides, and other agrochemicals. The grower could obtain higher cultivated plant yield and quality as compared with other growing methods. However, the aeroponic system is labour-intensive. It offers many opportunities for the farmers to increase rural employment. The farmer can grow a plant in their homes by providing artificial growth environment. Anitha and Periasamy [44] reported that nowadays many families are practicing the aeroponic system on their terrace. Besides, several countries of the world are using aeroponics for making an expansion in nourishment creation managing the monetary issues and making the nation naturally amicable to have their particular food supply. While some years ago, the use of the aeroponic system was limited almost around the world [84]. At present, the system is acquiring more attention from the farmers and several countries are being effectively adopting as an economical and environmentally friendly vegetable and fruit growing system. However, it is practiced in following countries: Abu Dhabi, Australia, Bhutan, Bolivia, Brazil, Bangladesh, Burkina Faso, China, Canada, Colombia, Ecuador, Egypt, Ethiopia, France, Germany, Ghana, Greece, Indonesia, Italy, India, Iran, Japan, Israel, Kenya, Korea, Malaysia, Mongolia, Malawi, New Zealand, Nigeria, Peru, Philippines, Poland, Russia, Rwanda, Saudi Arabia, South Africa, Spain, Singapore, South Korea, Slovakia, Sri Lanka, Taiwan, Thailand, Uzbekistan, and Vietnam. Besides, attempts are made to represent the system in other countries of the world [23].

3.2. Key Problems and Difficulties of the Aeroponic System. Aeroponic cultivation is performed in an outdoor and indoor installation and or in a greenhouse under controlled conditions. It may be carried out within a facility that includes the provision of light for plant growth, the centralised delivery of nutrient solution, and electrical power. The growing plants are set in a growth chamber and periodically soaked with nutrient solution small mist ejecting through atomization nozzle (Figure 2). In addition, the aeroponic system gives the chance to control the entire growth chamber environment precisely. The aeroponic system is the modern technique of the agriculture which is still under development. Until now, limited studies have been performed, and conducted studies concluded that the system has some problems and issues. Studies suggested that aeroponics is performed without soil or any solid media; thus, the main observed problems are water and nutrient buffer, any failure of the water pumps, nutrient solution distribution and preparation, atomization nozzle clogging, and so on, which lead to rapid death of the grown plant [40]. Kernahan and Cupertino [45] reported that the aeroponic system provides better control of the plant growth and nutritional availability and prevents the plant from various diseases and root rot. However, during plant growth from sowing to harvest time, the methods adopted in the aeroponic system require a little hand-operated contribution, interference regarding physical presence, and expertise in domain knowledge of plants, environment control, and operations to maintain and control the growth of the plant.

Moreover, there is a requirement to sustain and keep retain the nutrient solution parameters which include nutrient temperature, pH, and EC concentration in a narrow range of preferred values for optimal growth. If these parameters drift outside the desired range, it will create several problems for plant growth. In addition, some supplemental parameters can adjust to optimise the plant growth further. The additional parameters are atomization time, atomization interval time, air temperature, relative humidity, light intensity, and carbon dioxide (CO_2) concentration which make the system complicated and time-consuming with high human energy and with the higher level of expert training and skill for operating the system. However, the grower has the responsibility to control and monitor the fluctuations of the above parameters in the desired range to achieve the suitable growth conditions for the specific plants. A failure to accurately control and monitor the parameters could

Table 1: Basic monitoring and control parameters in the aeroponic system [23, 80–83].

No.	Parameters	Common value	Instruments
1	Nutrient atomization	Mist/spray/aerosol/droplet size at high pressure from 10 to 100, low pressure from 5 to 50, and ultrasonic foggers from 5 to 25 microns, respectively	Atomization nozzle (high and low pressure, atomization foggers)
2	Growing medium	Plant holder	Any artificial root supporting structure
3	Desirable pH of the nutrient solution	The pH value depends on the cultivar (onion 6.0–7.0, cucumber 5.8–6.0, carrot 5.8–6.4, spinach 5.5–6.6, lettuce 5.5–6.5, tomato 5.5–6.5, and potato 5.0–6.0)	pH measuring device
4	Desirable EC of the nutrient solution	The EC value depends on the cultivar (onion 1.4–1.8, cucumber 1.7–2.2, carrot 1.6–2.0, spinach 1.8–2.3, lettuce 0.8–1.2, tomato 2.0–5.0, and potato 2.0–2.5 $ds{\cdot}m^{-1}$)	EC measuring device
5	Humidity	Provide 100% available moisture	Humidity measuring device
6	Temperature	Optimum 15°C–25°C and should not increase to 30°C and less than 4°C	Temperature measuring device
7	The light inside the box	The light inside the growth box must be dark enough	Cover the growth chamber with locally available material
8	Atomization time	Depends on the cultivar growth stage	Manually operating the system with timer
9	Atomization interval time	Depends on the cultivar growth stage	Manually operating the system with timer

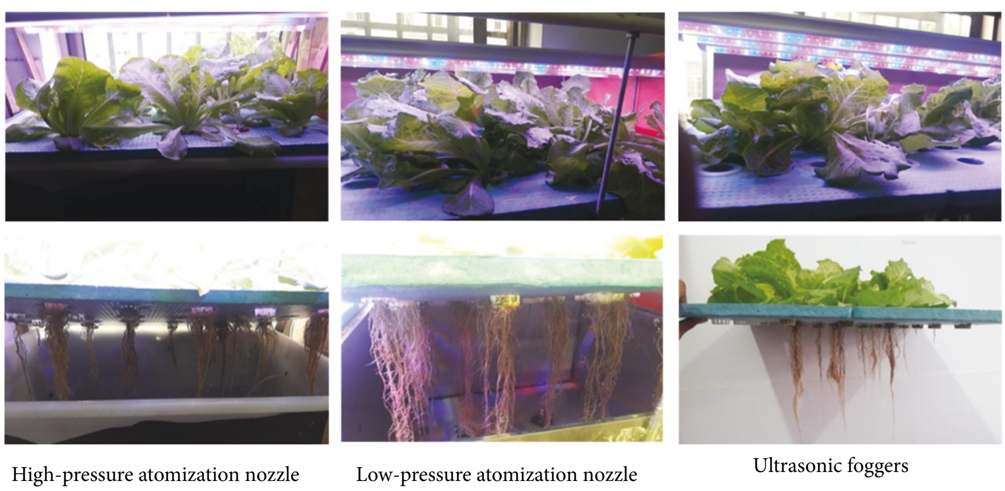

Figure 2: Aeroponically cultivated lettuce by Lakhiar et al. [23].

significantly affect the growth of the plant and cause financial loss. If any component failure occurs while the operator is not present on site, it may be detected too late to prevent harm, because systems generally include some automated means for periodically providing nutrient mist to the plant roots, refilling a nutrient reservoir, and managing light cycles and intensity. Therefore, the aeroponic cultivation considered hitherto to be somewhat unsuitable for the local grower and due to the above reasons and it is not common to find an installation. However, the main reason for the low acceptability of the aeroponic system is not a cost, but the main drawback is the amount of attention required of the grower with a high level of expertise and judgment. For the above-discussed reasons, more sophisticated and advanced monitoring techniques have implemented in the aeroponic system for early fault detection, real-time monitoring, and control and automation of the system. Hence, it would be advantageous to use artificial intelligent tools (Figure 3) in the aeroponic system to detect fault and diagnosis problems on time. Thus, it could help to avoid rapid damages to grown plants and help to fully automate the aeroponic system.

4. The Aeroponic System and Sensor Network

In recent years, early fault detection and diagnosis using an intelligent agricultural monitoring system is considered as the best tool to monitor plant without any complicated operations and laboratory analysis which required domain expertise and extensive time. The development of these convenient features has attracted much attention in the agriculture. The system is based on a wireless sensor network which comprises of a data server, a wireless convergence node, a plurality of wireless routers, and a plurality of wireless sensor nodes. However, the wireless sensor nodes are used as the

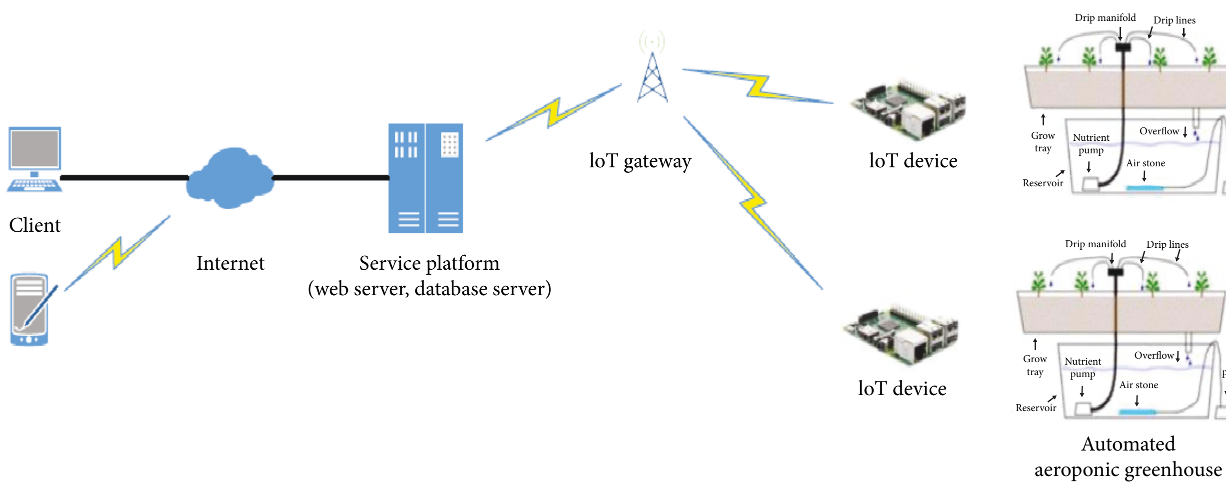

Figure 3: The aeroponic system using IoT technology by Kerns and Lee [47].

signal input of the intelligent agricultural monitoring system and are used to collect each selected parameter of farming operations to be monitored. Park et al. [85] stated that wireless sensor network-based systems could be a significant method to fully automate the agriculture system, because the sensors provide real-time significant information and believed to eliminate the considerable costs of just wiring. Another study by Kim [86] said that in agriculture, sensor network technique helps to improve existing systems installed in the greenhouse efficiently and smoothly by forwarding real-time collected information to the operator through the radio signals. The system optimises the transmission protocols more accurate and quick and maximises the application of energy to save the energy and reduce the consumption. Pala and team [40] suggested that the utilisation of artificial intelligence techniques in the aeroponic systems could lead not only to find early fault detection but also to fully automate the system without any or small interventions of human operators. The aeroponic system could gain more popularity among local farmers by deploying this technique in a system for monitoring and controlling purpose. However, it will conserve resources and minimise impacts on the environment. The farmers could start to understand their crops at a micro scale and able to communicate with plant through accessible technology. Therefore, in this article, we explored how wireless sensing technologies wove into the aeroponic system. Thus, the primary motivation of this review article was to provide an idea about different intelligent agriculture monitoring tools used for early fault detection and diagnosis for plant cultivation in the aeroponic system (Figure 4). Additionally, it would be helpful for the local farmer and grower to provide timely information about rising problems and influencing factors for successful plant growth in the aeroponic system. The adoption of the intelligent agriculture monitoring tools could reduce the concept of unsuitable for the amateur.

4.1. Number of Sensor Nodes and Input Parameters. At present, the utilisation of different sensor techniques is almost possible in every field of life due to the sharp progressions in the currently available technologies. Moreover, the sensor is a device that has capabilities to measure physical attributes and convert them into signals for the observer [87]. A WSN (wireless sensor network) traditionally consists of a few to dozens and in some cases thousands of the sensor nodes which are connected to one or more sensors [88]. Generally, it includes a BS (base station), which acts as a gateway between the WSN and the end users. Each sensor node is consisting of five main components, which are a microcontroller unit, a transceiver unit, a memory unit, a power unit, and a sensor unit [89]. Each one of these components is a determinant in designing a WSN for deployment. Furthermore, the microcontroller unit is in charge of the different tasks, data processing, and the control of the other components in the node [88]. Through the transceiver unit, a sensor mode performs its communication with other nodes and other parts of the WSN. It is the most dominant communication unit. The memory unit is another important part of the WSN system, which is used to store the observed data. The memory unit could be RAM, ROM, and their other memory types flash or even external storage devices such as USB. Lastly, the last one unit is the power unit. It is one of the critical components of the system which is for node energy supply. However, the power unit could be any source; it can store in batteries (most common) rechargeable or not on in capacitors. In addition, for extra power supply and recharging the power unit, the available natural resource could be used. The natural sources induce solar power energy in forms of photovoltaic panels and cells, wind power energy with turbines, kinetic energy from water, and so on. Last but not the least is the sensor unit, which includes several sensors for parameter measurements such as temperature, humidity, carbon dioxide, methane, and carbon monoxide [90]. However, in the aeroponic system, the total required number of sensors and actuators depends on the size and requirement of the operator.

4.2. Sensor Types and Monitoring Parameters. In this review study, we reviewed the previous work done on the aeroponic system using wireless sensor network technique. We found that the primary objective of a wireless sensor network

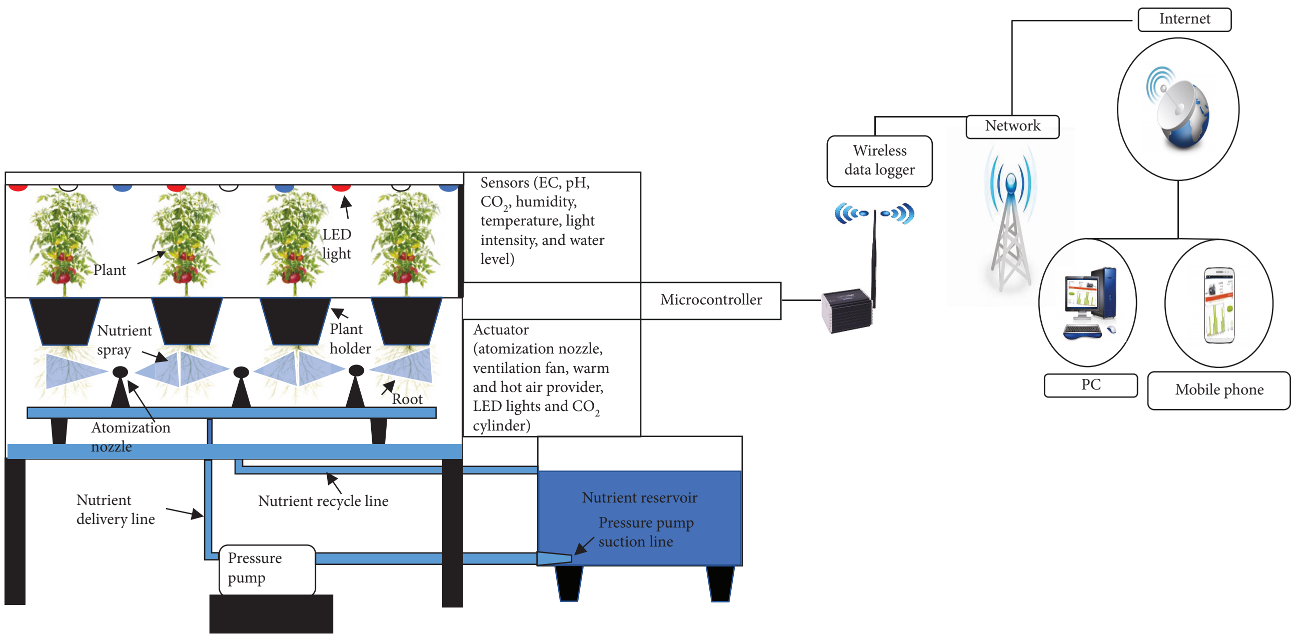

Figure 4: Aeroponic cultivation control system.

system for the aeroponic system is to control the growth chamber climatic condition as per the crop data sheet. However, the basic principle of the aeroponic system is to grow the plant by suspending in the closed, semiclosed, or dark environment in the air with artificial provided support. In the system, the plant stems, leaves, and any fruit grow in a vegetative zone above the suspension medium, and roots dangle below the suspension medium in an area commonly referred as a root zone [46]. Generally, closed cell foam is compressed around the lower stem and inserted into an opening in the aeroponic growth chamber, which decreases labour and expense. However, the trellising is used to suspend the weight of cultivated plant [44]. Ideally, the environment is kept free from pests and diseases so that the plants grow healthier and more quickly than other plants grown on techniques. Furthermore, the key to the success and high yields of the air gardening is a scientific grade monitoring of the conditions and accurate control of the growing environment. Each plant yields and needs a different environmental condition for growth. However, the plant growth is mainly influenced by the surrounding environmental and climatic variables and the amount of water and the fertilizers supplied by irrigation. There is a requirement to monitor and control liquid nutrient parameters in a narrow range of preferred values for optimal growth. The parameters include nutrient temperature, pH, and EC concentration. If the parameters drift outside the desired range, the plants can harm. Besides, there are some additional parameters which can be adjusted to further optimise growth, such as air temperature, relative humidity, light intensity, and carbon dioxide (CO_2) concentration. Idris and Sani [51] reported that the one solution to solve the problems of monitoring and controlling the growing conditions in the space environment is by applying some sensors. The sensor can detect and monitor a number of parameters such as temperature, humidity, light intensity, O_2 and CO_2 levels, direction, and wind speed. Aside from the sensors, there is also a requirement for the actuators to distribute nutrients and waters to plant roots or lower stems (Figure 5). The sensor collects the information of the various environmental conditions and forwards the signals to the actuator to take place and produce the outcome for the collected information to know the status of that parameter. The actuator can control the environment changes. The sensors store information that analyzes the environment and identifies the location, object, people, and their situations. The sensor provides multiple contributions in various domains that depend on a variety of attribute and variant in time [87, 91, 92].

4.2.1. Temperature Sensor. In the aeroponic system, the temperature is one of the critical factors significantly determining plant growth and development. A reduction in temperature below the optimal conditions often results in suboptimal plant growth. A different cultivar requires a different temperature level for the photosynthesis process and growth, which can advance the plant growth stage. It will eventually bring us substantial economic benefits. In the aeroponic system, the optimum growth chamber temperature should not be less and more than 4 and 30°C, respectively, for successful plant growth. The temperature fluctuations of aeroponic growth chamber can significantly affect the root growth, respiration, transpiration, flowering, and dormant period [93]. Therefore, the temperature sensors can be used to monitor the temperature fluctuations of the aeroponic system. At present, temperature sensors are used in many applications like environmental controls, food processing units, medical devices, and chemical handling. The temperature sensor is a device mainly composed of thermocouple or resistance temperature detector. The temperature sensor measures the real-time temperature reading through

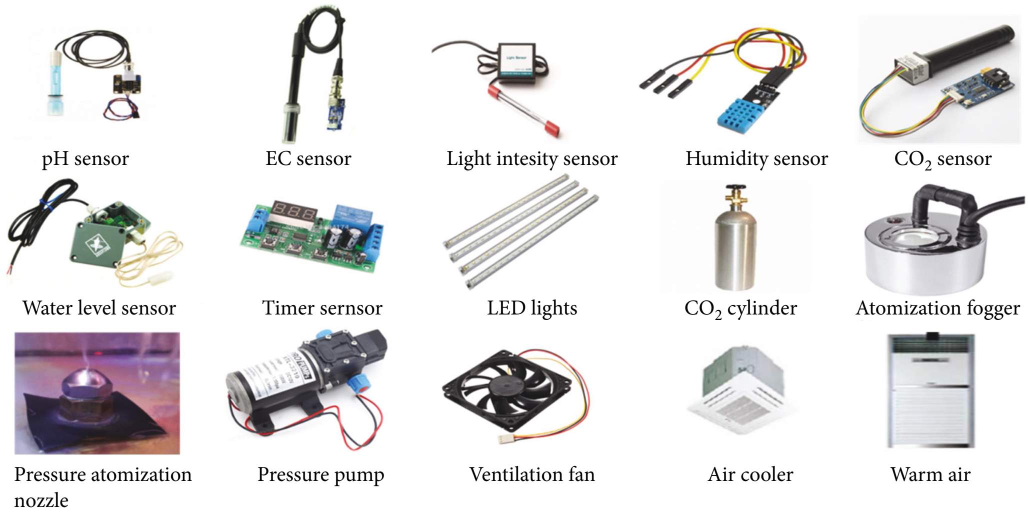

Figure 5: Sensors and actuators used in an aeroponic system.

an electrical signal. The sensors collect the data about temperature from a particular source and convert the data into an understandable form for a device or an observer. The temperature sensor accurately measures temperatures slower changing from critical applications such as facilities or rooms and sends them to the user's webpage.

4.2.2. Humidity Sensor. Aeroponics is the technique of cultivating plant by providing the water nutrient small spray in the air. Thus, the humidity is another important parameter of aeroponic growth chamber environments, and its control is recognised to be very important for significant plant growth. In the aeroponic system, the plant gets all available moisture in the growth chamber. Moreover, if the growth chamber has too high or less moisture content, both conditions will create many problems for the plant. Accordingly, an accurate and precise means of testing moisture content in the growth chamber will help farmers to monitor their crops and provide a suitable growth environment for the plant. Wang et al. [94] reported that a humidity sensor is a device that detects and measures water vapour present in the air within a room or enclosure. At present, humidity sensors are widely used in medicine, agriculture, and environmental monitoring. However, the most commonly used units for humidity measurement are relative humidity [95]. The development of humidity sensors has shown remarkable progress because of using various types of sensing materials in recent years. The sensing materials used in humidity sensors can classify into ceramics, polymers, and composites [96]. The humidity sensor could be placed in the growth chamber to maintain the moisture level. If the moisture level becomes less than the plant requirement, the sensors will forward the signals to atomization nozzles to perform their work.

4.2.3. Light Intensity Sensor. As we know, all vegetable plants and flowers require large amounts of sunlight, and each plant group reacts differently and has the different physiology to deal with light intensity. Some plant performs well in low light intensity and some in high light intensity. However, the aeroponic system implements in indoor conditions, so it is necessary for the farmer to provide sufficient light quantity of at least 8 to 10 hours for a day to grow the healthy plant. The artificial lighting is a better option to present enough intensity to produce a healthy plant [97, 98]. In the conventional aeroponic system, the control of the light quantity present in the growth chamber is mostly done by farmer through observing the plant condition. However, it is a time-consuming and challenging task for the farmer to provide the required light concentration accurately. It could be a better option to use intelligent agriculture techniques to monitor the light intensity in the aeroponic system. The intelligent agriculture techniques mean using the sensor system to control the light intensity. The light sensor is an electronic device which is used to detect the presence or nonpresence of light and darkness. There are several types of light sensors including photoresistors, photodiodes, and phototransistors. These light sensors distinguish the substance of light in a growth chamber and increase or decrease the brightness of light to a more comfortable level. Light sensors can be used to automatically control the lights such as on/off. By adopting the sensor network in aeroponics, the farmer could be able to monitor light intensity without any human interference. Because the sensors will perform all work such as if the light intensity in the growth chamber will be less than the required light quantity for plant growth, the sensor will automatically forward the signal to the LED light to turn on until the light quantity reaches to the desired level.

4.2.4. CO_2 Sensor. The appropriate oxygen concentration in the root environment is crucial to keep the root metabolism in nutrition solution. The available oxygen concentration for the root environment is a hugely significant factor since low concentrations affect the root respiration, nutrient absorption, and, consequently, the plant growth [66]. Thus, the CO_2 sensor could be used to monitor the carbon dioxide fluctuations in the aeroponic growth chamber. A carbon dioxide sensor is an instrument which is used for the measurement of carbon dioxide gas concentration. Bihlmayr

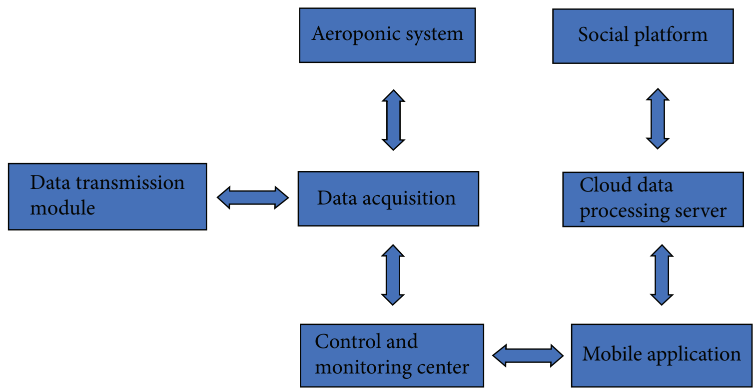

Figure 6: Schematic protocol of wireless network in the aeroponic system.

[99] reported that CO_2 sensors are used to measure indoor air quality in a building to perform demand-based ventilation. However, the CO_2 sensor data measuring range is in between 500 and 5000 parts per million. There are two main types of the CO_2 sensors which include nondispersive infrared carbon dioxide sensors (NICDS) and chemical carbon dioxide sensors (CCDS), whereas the NICDS detected CO_2 in a gaseous environment by its characteristic absorption and composed of an infrared detector, an interference filter, a light tube, and an infrared source. However, the CCDS of sensitive layers are based on polymer or heteropolysiloxane with low-energy consumption [100].

4.2.5. Water Level Sensor. The aeroponics is the method of the plant cultivation by providing a small mist of the nutrient solution in the growth chamber. Thus, there is no any use of soil; just water is required to cultivate the plant throughout the germination to harvest time. Therefore, the water nutrient solution reservoir is one of the major components of the aeroponic system which should be monitored throughout the growth period. In the conventional aeroponic system, the farmer checks the water nutrient level in the nutrient solution reservoir, and if he founds water level less than the desired level, he maintained accordingly. However, by adopting the precision agriculture techniques, the farmer will be able to monitor and control water nutrient level through the intelligent methods such as wireless sensors. The water nutrient level sensors detect the liquid level in the reservoirs and facilitate operator in collecting water nutrient level data in real time. The sensors will alert the operator about any potential property damage that results from any leaks and also allowing to know when a container is nearing empty.

4.2.6. EC and pH Sensor. In the aeroponic system, the plant productivity is closely related to nutrient uptake and the EC and pH regulation of the nutrient solution. The EC and pH concentration of the nutrient solution affects the availability of the nutrients to plants [101]. The pH and EC concentrations are controlled to prevent barrier growth. Their measurement is essential because the solubility of minerals in acidic, alkaline, and ion concentration of all the species in solutions is different and the solution concentration changes with solubility [102, 103]. The unmonitored EC and pH concentration of the nutrient solution will quickly lead to a situation where plants cannot absorb the essential nutrients, if not corrected this will eventually lead to harmful plant growth and poor productivity. Thus, the EC and pH concentration of the nutrient solution is a critical parameter to be measured and controlled throughout the plant growth. Moreover, in the conventional aeroponic system, the EC and pH value of the nutrient solution is mostly monitored manually by performing laboratory analysis or using advanced equipment which is a time-consuming process. For instance, when the EC of the nutrient solution decreased or increased, the control of nutrient solution concentration is mostly achieved by adding more high concentration nutrient solution or the fresh water, respectively, to the nutrient solution to maintain the EC level to the prescribed target range. Similarly, for pH, an acid solution and an alkali solution are used to control the pH fluctuation of the nutrient solution within a specified target range [101]. However, these conventional methods are time-consuming and challenging task for the farmer to maintain the EC and pH value at the desired range accurately. In addition, the EC and pH sensor could be used to deal with the above challenges.

5. Sensor Working Protocol in the Aeroponic System

Today, the world demands automatic tools to do most of the work for them without bothering its user for doing some task. So, the concept is all about a very high level of automation system which will be independent of its users to a very great extent, reduce human efforts, and save all kinds of resource utilisation, as monitoring and controlling will be done by computers leaving very few easily manageable tasks for humans, and it will interest more people to join this field [104–106]. Moreover, the monitoring and control system for the aeroponic system mainly consists of following sections which include the aeroponic system, data acquisition, controlling the equipment, data transmission module, cloud data processing server, social communication platform, and mobile application. A typical architecture of sensor nodes for controlling and monitoring the aeroponic system is shown in Figure 6. Furthermore, in architecture, the data acquisition section refers to some sensor nodes used in the system to establish a data acquisition module. The data acquisition module is placed in the aeroponic system or near the growth chamber to collect the real-time information from selected parameters (temperature, light intensity, humidity, nutrient solution level, atomization quantity, and photos of the growing plants) and transmit the gathered data to the control and management centre. However, the control and management section refers to the central processing unit (CPU) of the system. The CPU of the system consists of some primary functions such as Arduino and WRTnod protocols, whose work is to store, manage gathered data from collection nodes, process, and then accurately and automatically send to the web server in real time [104–109]. Thus, the system can help the farmer and grower to monitor and control the smart aeroponic system remotely using the mobile app. In other words, the plant will be able to talk with the farmer through a mobile app that whether the selected parameters are working well or not.

6. Advantages of Sensor Techniques in the Aeroponic System

The continuously increasing food demands require rapid improvement and development in the food production system. However, to enhance the quality and productivity of the cultivated crop, peoples are moving towards the modern plant cultivation technologies in agriculture. Thus, the aeroponics is one of the rising plant growing technologies in agriculture as a modern-day cultivation technique, where the plant is cultivated in an air environment, and no any soil support is provided. In the aeroponic system, a number of the parameters are required to control for successful plant growth because there is no any growing medium provided to the plant. For example, if the plant has some sudden stress and the farmer is not present at the site that means the plant will die. Therefore, the proper management of the crop is essential. In the conventional aeroponic system, grower uses his knowledge, skills, and judgment to adjust and maintain the parameters such as EC and pH meter, minimum and maximum temperature, light intensity, and humidity level through several instruments and checks the readings which are labour-intensive and time-consuming task. To deal with the above problems, the aeroponic system can be developed with a wireless sensor and actuator network for monitoring the key parameters at lower labour cost, time, and without any technical knowledge. The wireless sensor and actuator network offer several advantages including faster response to confrontational climatic conditions and better quality control of the crop that produces at a lower labour cost. This advancement in the aeroponic system through wireless sensor network for monitoring growth chamber environment is beneficial. However, the monitoring system also offers a range of information which could be required by plant scientists or grower to provide a greater understanding of how these environmental and nutrient parameters correlate with plant growth. It is now recognised that plant grower can perfectly and easily acquire the skills needed to operate an aeroponic system. It provides the full control of the system, not by constant manual attention from the operator but to a large extent by wireless sensors.

7. Future Application

Artificial intelligence agriculture techniques are considered as a high potential, improving technique for decision-making in agriculture. Nowadays, it is quickly getting peoples' intention, more and more visible in our society and dynamically turning our social awareness and lifestyle. The techniques provide several opportunities to monitor the plant growth and development from pre- to postharvest. Aeroponics is the new plant cultivation technology of agriculture which is still under development. However, we reviewed the literature and found that only limited study had been conducted on the implementation of the intelligent agricultural techniques in the aeroponic system. Moreover, until now, most of the studies had been designed the aeroponic system using a wireless sensor network using ZigBee and Arduino system with Bluetooth, global system of mobile and Wi-Fi, and communication modules. During a literature survey, we noted that no any single study had implemented the idea of the cloud computing and big data techniques in aeroponics to collect real-time information via the Internet. The techniques provide many advantages to the user such as reduction of the initial cost, allocation of the resources on demand, and maintenance and upgrade performed in the back-end, easy, and rapid development. The techniques present a chance to the operator to stay connected with the system using mobile accessories like a smartphone, tablet, and PCs at any location via the Internet which is not restricted by conditions, locations, and time. Furthermore, the system would be designed using additional artificial intelligence techniques such as image processing, automatic seedling transplanters, and harvesting and packing robots. The purpose of image processing and analysis is to measure and identify the physiology, growth, development, nutrient deficiencies, diseases, and other phenotypic properties of the plants through automated and nondestructive analysis.

8. Application of Artificial Intelligence Techniques in Agriculture

Agriculture is the primitive and ancient application that humans started first after born on earth. It has an extensive history between numerous industries and very intimately linked to the human development on earth. Moreover, in the past, the agriculture sector was labour-intensive, but the next-generation farmers, researchers, and associated organisations proposed and applied new farming methods, technologies, skills, and knowledge in agriculture as a modern era to reduce labour-intensive task. Presently, the technology is considered as a key tool to overcome many challenges and eases the way how people live. In the past, the many problems of agriculture, especially in irrigation water management, crop yield production, environment predication, and decision-making, were decided by many factors. In addition, the fertilization often decided by the mathematical equations, formulas, or the experiences of the experts. The cultivation is represented by descriptive and causal knowledge, and diagnosis of pests and diseases is represented by uncertain knowledge. Thus, this knowledge and experience are illogically incomplete and imprecise, and the traditional procedures can not handle them. However, artificial intelligence has its superiority. It could be an effective approach for solving complex problems to the levels of experts using imitate experts [110]. The term artificial intelligence (AI) was developed in 1956, as "the science and engineering of making intelligent machines" [111]. It is a abroad discipline, which was developed for the interaction of several types of fields such as computer science, information theory, cybernetics, linguistics, neurophysiology, and psychology [112]. The main purpose of the creation of the intelligence techniques is to find the solutions for complex problems and to work, react, and respond like humans. It performed work better than a well-qualified person and brought positive economic and environmental results [112, 113]. Artificial intelligence (AI) tools have helped to predict the behavior of nonlinear systems and to control variables to improve the operating conditions of a system's environment [114–117]. A recently published report highlighted that artificial intelligence is emerging as part of the solutions towards improved agricultural productivity. The global artificial intelligence in agriculture is expected to grow at a significant level. It is employed to improve the efficiency of daily tasks in agriculture such as the adoption of robots and drones, crop health monitoring protocols, automated irrigation system, and driverless tractors [118]. At present, several research studies have been performed by implementing the artificial intelligent techniques in agriculture. Popa [119] revealed that some of the developed applications for agriculture are expert systems and software, sensors for collecting and transmitting data, and robotic and automation which are adapted from different industries into agriculture, whereas the expert systems and software is the planning process such as strategic or operational; it has benefited substantially, due to the expansion of personal computer and Internet use. The systems are generated through the structured knowledge base and reasoning mechanisms acquired from a human expert but with an enhanced computational power and speed [120]. These systems can demarcate management zones taking in consideration with relevant factors and able to recommend suitable crop rotations, optimal plant density, water requirements, appropriate fertilizer use, diagnosing pests and diseases for crops, and suggesting preventive or curative measures [121]. Huang et al. [122] discussed soft computing and applications in agriculture. The study reported that soft computing is the combination of the computing technologies, such as an artificial neural networks (ANNs), fuzzy logic (FL), and genetic algorithms (GAs). These techniques are opposed to the hard computing method which states to a huge set of stochastic and statistical methods. The hard computing provides inaccurate solutions and results of very complex problems through modelling and analysis with a tolerance of imprecision, uncertainty, partial truth, and an approximation. However, the soft computing techniques are used to achieve tractability and robustness. It provides a low-cost solution with a tolerance of imprecision, uncertainty, partial truth, and approximation [123–127]. Sui and Thomasson [128] developed a BP-trained feedforward ANNs to predict nitrogen status in cotton plants based on a data from a ground-based sensing system. Tumbo and team [129] used an on-the-go system for sensing chlorophyll status in corn using BP-trained feedforward ANNs and fiber optic spectrometry to acquire spectral response pattern data in corn fields. Tang et al. [130] developed a texture-based weed classification method consisting of a low-level Gabor wavelet-based feature extraction algorithm and a high-level ANN-based pattern recognition algorithm. El-Faki and group [131] established and tested ANN-based weed detection algorithms capable of detecting the leading weed species competing with wheat and soybean crops. A study by Krishnaswamy and Krishnan [132] predicted the nozzle wear rates for four fan nozzles using regression and ANN methods. Pearson and Wicklow [133] developed a neural network to identify fungal species that infect single kernels using principal components of the reflectance spectra as input features. Smith et al. [134] developed year-round air temperature prediction models for prediction horizons from 1 to 12 h using feedforward-style ANNs. Zadeh [123] introduced the concept of fuzzy sets as a mean for describing complex systems without the requirements for precision. Fuzzy logic may also be useful for descriptive systems, those that fall somewhere between hard systems and soft systems, such as biology and agriculture [135]. Studies reported that in agriculture, fuzzy logic is used for multicriteria analysis of the image, image classification, vegetation mapping, assessment of soil suitability, and planning forest harvesting [136–143]. Al-Faraj and coworkers [144] established a rule-based FL crop water stress index (CWSI) using growth chamber data and tested this method on tall fescue canopies grown in a greenhouse. Thomson et al. [145] and Thomson and Ross [146] developed a coupled sensor- and model-based irrigation scheduling method. Yang et al. [147, 148] informed on the development of an image capture/processing system to detect weeds and a fuzzy logic decision-making system to determine where and how much herbicide to apply in an agricultural field. Gil and team [149] applied multiple linear regression and FL inference models to evaluate the effects of micrometeorological conditions on pesticide application for two spray qualities (fine and very fine). Qiu et al. [150] established a fuzzy irrigation decision-making system using virtual instrumentation platform of sensors, test instruments, data logger, and LabVIEW. Generally, published studies use on/off controllers where the inherent complexity of irrigation process made it difficult to achieve optimal results [151]. Ali et al. [152] developed temperature and humidity controller inside the greenhouse using fuzzy logic. However, several studies have been conducted to develop many control strategies to optimise the greenhouse environment using artificial intelligence techniques such as neural network, fuzzy logic controller, adaptive predictive control, PID, and nonlinear adaptive PID control [153–159]. Zhu et al. [160] used the remote wireless system for water quality online monitoring in intensive aquaculture using artificial neural networks. The results demonstrate that online monitoring for water quality information could be accurately acquired and predicted by using the remote wireless system. Mahajan et al. [161] reported that agriculture is noteworthy that computer vision applications have grown due to reduced equipment costs, increased computational power, and increasing interest in nondestructive food assessment methods. The use of these techniques presents advantages when compared with traditional methods based on manual work; however, there are still some challenges to be overcome. Moreover, the principle of artificial intelligence in agriculture is one where a machine can perceive its environment, and through a certain capacity of flexible rationality, can act to address a specified goal related to that environment.

9. Conclusion

The objective of our study was to present the information about the use of automated monitoring and controlling technique in the aeroponic system. The aeroponic system is the new plant cultivation method of the modern agriculture. Its existence can allow producing food whole year without any interval. The system could create an excellent set which encourages the sustainable city life for those peoples who want to live in urban area. Moreover, during plant growth from sowing to harvest time, the methods adopted in the aeroponic system require a little hand-operated contribution, interference regarding physical presence, and expertise in domain knowledge of plants, environment control, and operations to maintain and control the growth of the plant. Therefore, the system is considered hitherto to be somewhat unsuitable for the grower, and due to the above reasons, it is not common to find an installation. We reviewed the literature and found that implementation of advanced monitoring technology tools in aeroponics could provide an opportunity for the farmer to monitor and control several paraments without using laboratory instruments, and the farmer can control the entire system remotely. Thus, it could reduce the concept of the usefulness of the system due to the complicated manual monitoring and controlling process. The technology offers incredible opportunities for the aeroponic system to increase the capability, reliability, and availability among the farmers and growers. We believe that our review article will contribute to the adoption of the advanced monitoring technology in the aeroponic system. However, the technique provides a range of information which could be required by plant scientists to provide a greater understanding of how these environmental and nutrient parameters correlate with plant growth.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

Acknowledgments

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