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Published on: 20 Apr 2020 - International Journal on Advanced Science, Engineering and Information Technology (INSIGHT - Indonesian Society for Knowledge and Human Development)

Topics: The Internet, Precision agriculture, Arduino and Bluetooth

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Article · April 2020

DOI: 10.18517/ijaseit.10.2.10249

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Universitas Padjadjaran

International Journal on Advanced Science Engineering Information Technology

Vol.10 (2020) No. 2
ISSN: 2088-5334

Greenhouse Monitoring and Automation Using Arduino: a Review on Precision Farming and Internet of Things (IoT)

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***Abstract*— The 21st century became the beginning of the development of information technology, where one of the revolutions was the presence of the Internet of Things. Internet of Things or abbreviated as IoT is a technology that combines electronic devices, sensors, and the internet to manage data and applications. The Internet of Things can be adopted in agriculture for crop management as a media for monitoring and controlling, especially in greenhouses and is called Precision Farming. The application of precision farming will be more effective in a greenhouse because it is easier to engineer similar environmental conditions. IoT development in greenhouses is using Arduino Microcontroller or Raspberry Pi Microcomputer. These devices are used because the price is low and easy to get on the market and can be designed so that technicians who have limited information technology knowledge can run it. To be able to manage greenhouses with IoT requires sensors as five senses that can detect changes that occur in the greenhouse. By using sensors, the hardware can detect what is happening in the greenhouse and make decisions based on the data acquired. Some sensors that are often used in Precision Farming are temperature and humidity sensors, soil moisture sensors, and light sensors. In the Internet of Things, the data that has been acquired by the hardware will then be transmitted wirelessly. The wireless connections used are Bluetooth, ZigBee Protocol, and Wi-Fi, where Bluetooth and Zigbee connections have a short distance between 10 - 100 meters, while Wi-Fi has a longer distance especially when connected to the Internet. The purpose of this paper is to understand the advantages and challenges of adopting IoT-based Precision Farming for monitoring and automation.**

***Keywords*— precision farming; automation; arduino UNO; protected cultivation; greenhouse.**

I. INTRODUCTION

Greenhouse monitoring and automation are currently one of the most discussed subjects in the agriculture sector. By using Google Scholar, we obtained search results for “greenhouse monitoring” reached 1,560,000, “greenhouse automation” reached 131,000, and “greenhouse monitoring and automation” reached 53,200 in September 2019. These results indicate that many researchers and practitioners center their attention on this topic. The focus of research in the subject area of agricultural automation occurs because, in the industrial sector, almost everything has been controlled and operated automatically. In agriculture, in general, it still uses a simple way of growing crops even though agriculture is one of the main fields that sustain a country's economy. That is why it requires the implementation of the latest science and technology in the agricultural sector to increase yields [1].

The system used to optimize crop growth in farming is called protected cultivation, which controls soil and climate, ecosystems by modifying soil, temperature, humidity, sunlight, wind, and air condition. The reason for developing this system is that plants do not have to grow in their original environment. The effects of which are faster plant growth, shorter harvest periods, longer plant life, improved yield quality, sustainable production, and can be developed on limited land [2].

Protected cultivation is practiced as a crop cultivation technique where the plant environment is partially or fully controlled depending on the growing period to maximize yields and preserve energy. The most practical protected cultivation method to accomplish this goal is the use of Greenhouses, which can engineer the original environment of plants to reach the optimum point for plant growth and yield as well as to increase efficiency [3].

Greenhouse technology itself has been used in fifty countries, China has optimized the use of plastic greenhouses, and Japan already possesses a total of 42,000 hectares of land shaded by plastic and glass to intensifying crop production. The advantages possessed by the greenhouse are:

- Plants can be planted outside the farming season,
- Any plant can be planted throughout the year,
- Protect plants against rainy seasons, storms, wind and frost,
- Higher yields with space optimization, for instance, planting vertically,
- More efficient consumption of irrigation,
- Reducing fertilizer waste,
- Control pests and diseases,
- Suitable for tissue culture plants,
- Increasing the level of carbon dioxide, which results in better photosynthesis,
- Promotes plant growth and fruit ripening,
- Reduce evapotranspiration,
- Filter out harmful UV rays,
- Planting of non-productive soil [4].

The greenhouse itself is rising due to increasing urbanization and a reduced amount of productive land. Greenhouses are generally constructed from plastic, glass, or fiberglass because they can transmit light and retain heat, which results in very high temperatures in the greenhouse, even though the temperature is an integral part of plant growth besides humidity [5].

To create an optimum environment for plant growth and maximum yield, effective ways to regulate temperature, ventilation, air humidity, soil moisture, nutrients, and carbon dioxide are needed. With developments in the field of information technology and the increasingly affordable price of computers, computers have become tools that can automate greenhouses [6].

Greenhouses are becoming more popular as a research site because researchers have control over developing a homogeneous environment so that plant growth will continuously be monitored and controlled compared to field research [7]. Research conducted in the greenhouse covers abiotic fields such as drought and salt tolerance [8], biotic fields such as resistance to pests and diseases [9], photosynthesis, and seedlings lifespan [10] and in recent years the plants analyzed in the greenhouse are generally plants that have a short growing and harvesting period, including tomatoes [11], [12], beans [11], corn [13], pepper [14], orchid [15] and roses [12].

Based on the shape of the roof, greenhouses can be classified under the following criteria:

- Spherical Dome
- Hyperbolic paraboloid
- Quonset
- Modified Quonset (Modified IARI model)
- Gothic Arch
- Mansard roof
- Evenspan
- Unevenspan

The shape of the greenhouse can be seen in Fig. 1, and the evenspan roof is the most commonly used in the greenhouse [16].

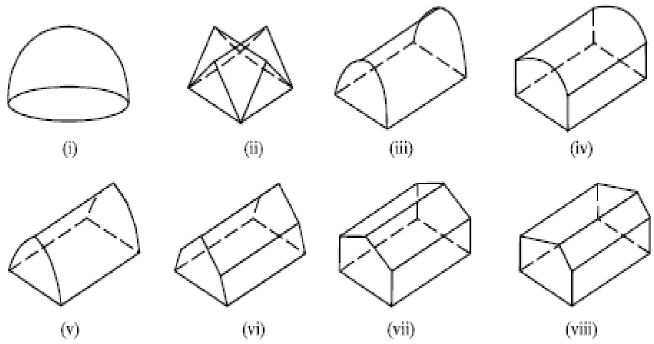

Fig. 1. Classification of greenhouses based on the shape of the roof [16]

II. Material and Methods

A. Monitoring

The meaning of monitoring is merely collecting data, but with the evolution of technology, monitoring develops into a system that works to collect data and produce information. Collected data will be verified through the analysis phase and stored in data storage. The results are stored in data storage and then arranged so that they can be used afterward [17].

The quality of a system can decreases if it is not monitored; monitoring is implemented to ensure that the system can run effectively. Monitoring that is designed and carried out correctly will provide the following benefits:

- Problems can be identified as soon as possible,
- Can produce reliable and accurate data for decision making,
- Save time and money [18].

Monitoring is widely utilized in many fields of study. In medicine, it can be used as heart rate monitoring [19], glucose levels [20], and patient data [21]. In the automotive field, it is used to learn the driver behavior pattern [22]. Some cases in agriculture also utilizes monitoring, such as to monitor microclimate [23], monitor soil moisture [24], and plant growth monitoring [25].

B. Process Control

Process control activities have first appeared in nature; natural process control occurs in living things; for example, heart rate, body temperature, and blood pressure. Artificial process control occurs because humans need a comfortable external environment to survive. This control can be achieved by determining variables, comparing them with the previously measured value, and creating an active system that can control these variables so that they are close to their original values [26].

An easy-to-use process control called Programmable Logic Controller (PLC) is a control device that has a microprocessor and works using internal memory that can receive instructions and functions for controlling tools and machines. This PLC is designed so that it can be utilized by technicians who may have limited computer knowledge [27]. The general conception of a PLC-based Process Control can be seen in Fig. 2.

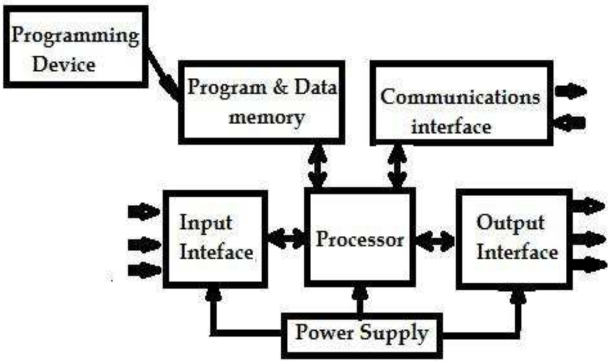

Fig. 2. PLC Based Process Control [27]

C. Automation

Automation is a domain in the subject area of engineering that integrates information technology and control systems to improve energy efficiency, improve production processes, worker safety, reduce product damage to increase production and quality. Automation is the relationship between information and control systems to ease the coordination and control of operating systems [28].

In the past three decades, automation technology has proceeded in tandem with information technology, computer networks, communications, and electronics. Automation is part of an industrial process that calls for continuous external regulation. This industrial process is separated into three types, as follows:

1) Localized Process. Processes that are in a small physical environment with components connected close together. For instance, in one room or on the same floor.

2) Distributed Process. The process that connects between localized processes is in a significant physical environment. Generally, connect systems that are in separate rooms or different floors [29].

3) Embedded Systems: An embedded system is a mechanical-electrical system created to perform specific tasks. This system was built using hardware and software precisely prepared to achieve predetermined requirements. An embedded system will have a processing unit in the shape of a microprocessor or microcontroller that will bridge the connection between the sensor and the actuator [30]. By using embedded systems, users will focus on building the design flow and looking for the right iteration to improve system performance, more easily understand the problems associated with hardware and software design and not dwell on technical issues such as soldering and etching PCB boards [31]. In 2018 a researcher built an embedded system consisting of two primary parts, where the first part is used to read data from sensors, classify data in real-time and send the results to the server. The second part of this system is used to visualize data through web-based applications that can be accessed using a web browser [32]. At present, there are two types of embedded systems often employed, namely the Arduino UNO microcontroller and the Raspberry Pi System-on-Chip (SOC). Both are widely used for hobby and research activities, and there are even some industries that use it because of the low price and a quite powerful function [33].

III. Results and Discussions

A. Sensors

To detect using a microcontroller, it takes a sensor that serves as an artificial five senses, the form of electronic components that serves as input and output. By using sensors, a microcontroller can detect what is occurring in the surrounding environment [34].

1) Temperature Sensor: One popular temperature sensor is the LM35, an analog type sensor with an output value in the form of voltage so that to be read in the form of Celsius conversion is needed from voltage to Celsius. This sensor is a low-cost sensor with a temperature detection range between -55 - 150^{o}C [35]. Not only used in greenhouses, but LM35 sensors are also utilized to detect temperatures in the copra drying chamber to obtain high-quality copra. Its function is to heat the room at night and control the fan during the day [36].

2) Temperature and Humidity Sensor: Various sensors can detect temperature and humidity, including DHT11 and DHT22. These sensors are components that have a digital output value; thus, they can be used immediately. DHT11 is used by Wang and Chi [37] to detect temperature and humidity that this sensor has anti-interference features, ease of integration, high level of accuracy, low electricity usage, and small size. Whereas the DHT22 sensor has been used by Islam et al. [38] to develop a wireless humidity monitor with good accuracy results and with an average rate of data retrieval errors by 2%.

3) Soil Moisture Sensor: Unlike the temperature and humidity sensors, there are two ways to have a soil moisture sensor; the first is to buy it at an electronics store, the second is to build it by hand. M S Kumar et al. [39] explain the method of making low-cost soil moisture sensors using two copper bars with a certain distance to detect soil electrical resistance. The data obtained in the form of analog data and an Arduino UNO can be paired with six sensors at once. The sensor design can be seen in Fig. 3.

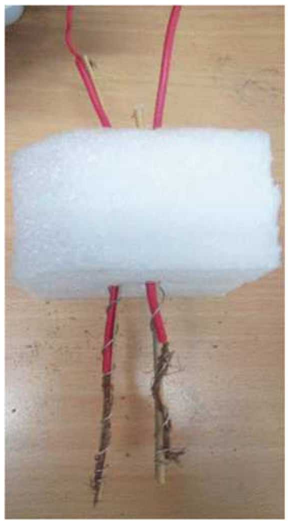

Fig. 3. Homemade Soil Moisture Sensor [39]

Ardiansah et al. [24] have also used a soil moisture sensor and Arduino Mega to create a drip irrigation system on lettuce plants, a problem that occurs is the appearance of rust on the sensor surface due to oxidation. This causes the automation system to work improperly because the sensor must be routinely cleaned.

B. *Wireless Connection*

Internet of Things (IoT) generally uses wireless technology in its application; there are three short-range technologies used in IoT namely Bluetooth and Zigbee, while for long distances, it is generally used Wi-Fi technology. These technologies have differences in power consumption, transmission distance and interference from other signals. All of this wireless technology can be used in greenhouses by first bringing into account the field conditions [40].

1) Bluetooth: The work carried out by Hong and Hsieh [41] has produced a wireless irrigation system for lettuce plants using a Bluetooth module type RN41 that has a transmission distance of 100 meters. This written report found that controlled plants had better results in plant height, the number of leaves, wet weight, and dry weight, as well as saving water and electricity up to 40% compared to uncontrolled plants.

2) Zigbee: ZigBee hardware is a technology that implements a Low-Rate Wireless Personal Area Network (LR-WPAN) system that can communicate safely and reliably. Developed for control in the fields of industry, health, agriculture, and home automation. ZigBee consists of three types of devices, namely Coordinator, Router, and End Device, and is supported by three topologies namely Star, Cluster Tree and Mesh [42]. The transmission distance of ZigBee devices in a greenhouse is within the range of 30 meters, and this distance can be reduced due to air humidity, the presence of obstructions between devices, the environment, the direction of the antenna and interference from other signals that are in the same frequency range either from other ZigBee devices or other wireless devices [43].

3) Wi-Fi Network:. Brinkhoff and Hornbuckle [44] said that the advantage of utilizing a wireless connection is that the distance of the signal can reach more than 1 km with minimal weather conditions influence, the principal note is the strength of the wireless signal depends on the distance between the access point and its height from the ground level. Wi-Fi has a broader bandwidth and is the most widely used connection in electronic hardware devices, making it possible to integrate it with other hardware such as wireless cameras, smartphones, and PCs, as seen in Fig. 4.

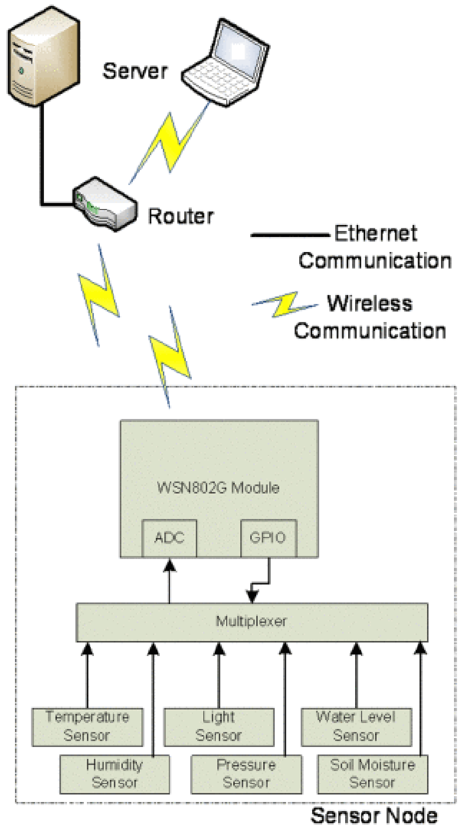

Fig. 4. The General Design of a Wi-Fi Based Microcontroller [45]

C. *Monitoring Using Arduino UNO*

Arduino is an open-source licensed development board that can facilitate anyone who wants to construct electronic devices despite having minimal knowledge. Arduino can be programmed using the Arduino IDE; compiled programs can be directly uploaded to the Arduino system using a USB cable, after which Arduino can run independently [33], [46].

Arduino has been widely applied in agricultural activities, including monitoring plant growth, regulating irrigation, area monitoring, measure water quality, and pest monitoring. As well, the data acquired by Arduino can be stored in a database for use during the next planting season [47].

The system proposed by Hammami [48] uses Arduino UNO and DHT11 sensors to acquire temperature and humidity data and transmit it to the ThinkSpeak web service that is accessed using the Application Programmable Interface (API) via an internet connection provided by the Mobile Wi-Fi Router but has not implemented a notification system in the event of an anomaly.

Other systems proposed by Taru and Karwankar [49] are water quality detection systems using Arduino UNO connected to the DS18S20 sensor to monitor water temperature, pH sensors to measure water acidity, and turbidity sensors to assess water clarity and web-based panel monitors built with LabView applications. The architecture is shown in Fig. 5.

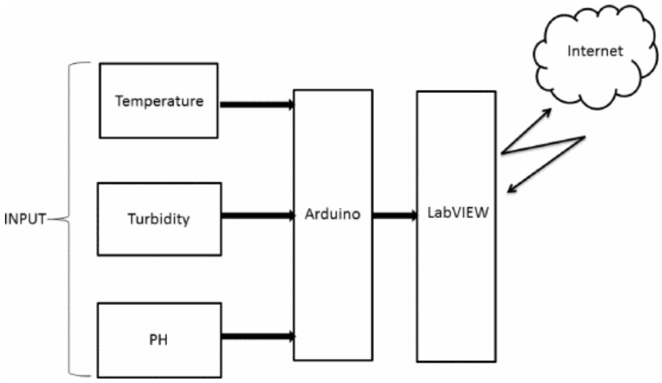

Fig. 5. Water Quality Monitoring Architecture [49]

Osman S O et al. [50] also built a similar water quality detection system by adding an Electrical Conductivity (EC) sensor to detect conductivity in water; the smaller the conductivity, the higher the purity of water. The system is implemented with LED and Buzzer components to provide visual notifications when the water quality is outside the safe range. Arduino can also be used as a weather station using Arduino Mega2560 because it holds more storage memory and abundant input and output [51]. The instrument has built excellent performance and can store extensive environmental data. The proposed design uses six sensors, and it can be seen in Fig. 6.

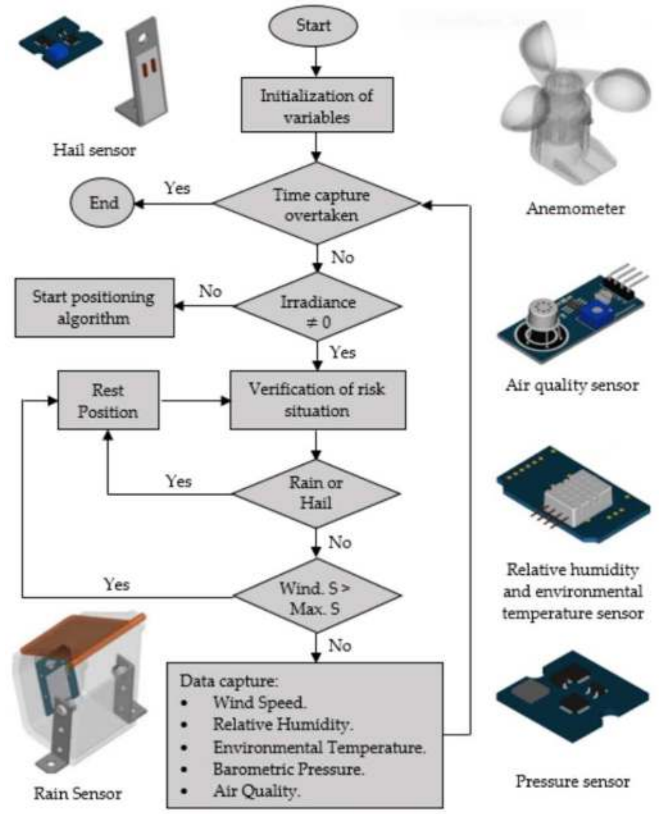

Fig. 6. Arduino Weather Station Sensor and Logic [51]

In addition to monitoring climate conditions or plant growth, Arduino can also be applied to control pests. Mankin et al. [52] have examined the response of buzzer signals to reduce the population of the Diaphorina citri pest in citrus plants. The buzzer signal is employed to attract male D. citri by imitating the frequency of the female D. citri wing flap. He wrote that this system was suitable for making short to medium duration traps.

The works of Samseemoung et al. [53] discussed how Arduino could be employed to monitor and control pests and diseases in coconut plantations. The tool that is built can spray pesticides with different variable levels on the hood of trees that are at the height of 5-9 meters. The aim of building this tool is to prevent worker pesticide poisoning.

An RFID based system has also been developed to analyze the movement of pesticide spray vehicles in orchid plantations. This RFID system is used to register the amount of pesticide given and the routes traveled by vehicles; the data are displayed in real-time so that it can help operators improve efficiency. Operators can also find out the position and direction of the vehicle [54]. The device design can be seen in Fig. 7.

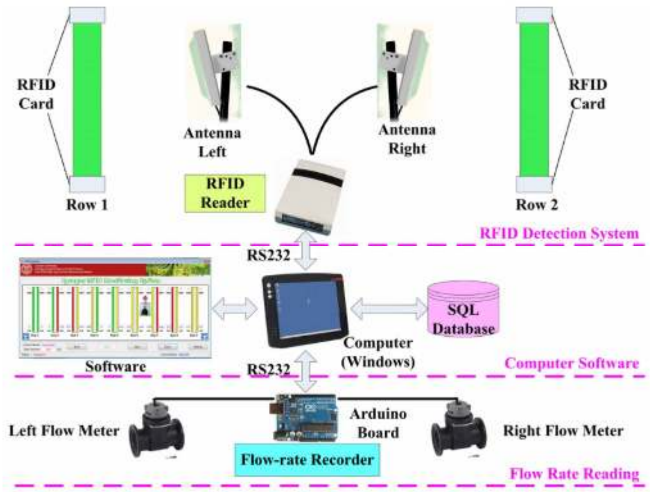

Fig. 7. Design of RFID-based Monitoring System [54]

D. *Precision Farming*

Precision farming is an advance in agricultural management by optimizing the utilization of the latest technology to monitor and streamline the agricultural production process. It is a cycle of observation and data acquisition process, followed by interpretation and evaluation of data obtained so that decisions can be taken [55].

Precision farming is a system that helps farmers manage crop variables and climate conditions in the land to increase profits, yields, harvest quality and minimize costs. In Germany, precision farming has a significant effect on farmers who have less than 5 years of farming experience, because, eventually, the economic value of precision farming is higher than the costs incurred. These farmers are mostly young and highly educated [56].

E. *Internet of Thing (IoT) in Greenhouse*

The Internet of Things can be practiced in agriculture as a real-time monitoring system for agricultural production and agricultural equipment, automation by conducting real-time analysis, data processing, information presentation, and then making decisions based on the results obtained without the need for human intervention [57].

A group of researchers in Japan has developed a platform called IOTomato that can detect temperature conditions, humidity, soil moisture and light for greenhouses planted with tomatoes. The acquired data are then transferred wirelessly using the ZigBee module to a server and stored in the cloud. Information acquired is also sent to the user's smartphone via the LINE bot service [58].

There are several steps to constructing an Internet of Things greenhouse system (Fig. 8):

- Choose sensors that are able to collect greenhouse parameters in either analogue or digital format,
- Sensor data acquisition using a microcontroller,
- Data is transmitted to the server and then processed,
- The server stores processed data to the IoT Cloud,
- Data from the acquisition is compared with the acknowledgment data, and if the conditions are not met, action will be required,
- Users can monitor the condition of the greenhouse using connected internet equipment [59].

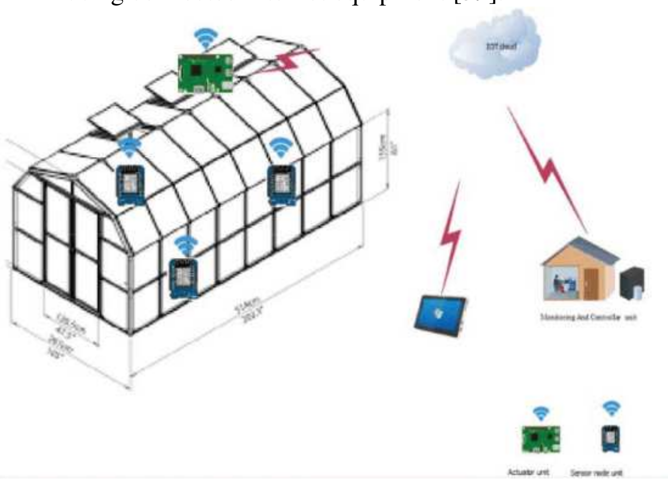

Fig. 8. Internet of Things Greenhouse Design [59]

IV. CONCLUSIONS

The Internet of Things has become a popular subject in the fields of computers, engineering, and agriculture for the last few years. Ease of accessing information technology, cheaper internet connections, and abundant hardware are essential details in the development of it. It has become an option for small, medium and large-scale agriculture to create better agricultural output. Internet of Things in agriculture can be instanced as a combination of protected cultivation in a greenhouse, sensors to detect parameters in a greenhouse, a microcontroller as a data acquisition system, a server as a data processing system, and cloud as a data storage. The characteristics of this model can be adopted by farmers who desire to develop precision farming. Although the Internet of Things has become a phenomenon and has been applied in various fields, there are still some obstacles that need to be considered, such as high initial costs, varied field conditions, complex installations and lack of apprehension of technology. These factors need to be considered before developing IoT in agriculture so that IoT can be used in the long term and work optimally.

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