IoT-based fertigation system for agriculture

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ABSTRACT

Fertigation system has been widely used by farmers to automate some processes of crops productions. A conventional system requires workers to prepare a fertilizer mixture, before transferring it into a main storage tank to be mixed with water. Then, electrical conductivity (EC) of the mixture will be measured. The existing fertigation system still relies heavily on workers and is manually operated and prone to human error. Therefore, internet of things (IoT) based fertigation system has been developed to deliver the fertilizer mixture with consistent EC value automatically to the plants. The main system controller is designed using ESP32 development module. The operation of the system can be monitored using an IoT dashboard and farmers can also control the system remotely. Alert will be given to the farmers if the condition of the system or plant does not meet the predefined settings. The values of EC together with temperature and humidity sensors are recorded for further analysis. A testbed is set up to provide fertigation to 120 polybags eggplants. Using the proposed fertigation system, the eggplants have been harvested earlier, therefore reducing the fertilizer usage. The cost of this IoT based fertigation system is lower compared to existing commercial products.

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1. INTRODUCTION

Fertigation is the process of injecting fertilizer solutions with irrigation water into a dripping system installed into the growing area. Fertigation systems are made up of tanks that store fertilizer in liquid form, and one or more pumps that inject fertilizer into the irrigation system through a set of valves. A fertigation system can be set on timers to allow fertilizers to run through at set times. The system can also be controlled manually or applied to certain grow areas or agriculture plots.

Existing fertigation system requires workers to prepare two types of fertilizer solutions (type A and type B) before transferring them into the main fertilizer tank. In addition, the value of electrical conductivity (EC) needs to be measured manually using handheld meter, and the reading needs to be recorded manually. The process must be repeated every time the fertilizer mixtures are added into the main tank so that a specific and consistent value of EC can be obtained. The current fertigation system used in farms for crop production is operated manually with the help of an electrical timer. By this, a user must properly set input and output valves which are connected to the fertilizer tank or water tank through polyvinyl chloride (PVC) pipes. An electrical timer is pre-configured to allow the centrifugal pump to be turned on and off for specific time and interval each day, regardless of the weather conditions. This means that the pump is still operating even during a rainy day.

Moreover, farmers are unable to monitor the current value of EC, water level in the tank as well as operate the system remotely. In addition, temperature, humidity, light, and moisture sensors are not used to record weather condition to determine whether the system should operate as usual every day, stopped during rainy day or more fertilizer or water need to be injected into the dripping system when the weather is too hot. The proposed system aims to improve the conventional fertigation technique using an IoT based platform. System controlling and monitoring are performed using user interface provided through the IoT platform. Remote monitoring of sensors and controlling devices can also be done remotely via the internet. Furthermore, the end user will be notified if certain sensors value exceeds the threshold or when the system is offline.

The outline of this paper is as follows; section 2 provides the related works on fertigation system and the use of IoT in various intelligent systems for agriculture industries. The design and development of our proposed system is discussed in section 3. Section 4 provides the results produced by the IoT based fertigation system. Lastly, section 5 concludes our work.

2. RELATED WORK

Internet of things (IoT) [1], [2] connectivity system has been implemented in various applications, such as healthcare [3], industrial, logistics, utilities, and agriculture [4]–[9]. IoT allows monitoring and controlling any system remotely, either using smart phones or computers. With IoT, internet connection plays an important role in the system. With the internet, user from thousand miles away can remotely monitor the system through sensors or even real-time display of a camera [10], [11]. The use of IoT in agriculture can bring many benefits such as providing more efficient operation, improving worker safety, equipment monitoring, improving crops and weather forecasting. However, there are many challenges that need to be considered to deploy IoT technology in agriculture such as hardware and software, infrastructure, networking, and security challenges. Furthermore, [12] highlighted key technologies and methods that need to apply to achieve sustainable future agriculture. Technology such as wireless sensor network (WSN), IoT, communications, unmanned aerial vehicle (UAV), robots, machine learning, and vertical farming are suggested for smart agriculture.

Sensors also play a vital role in smart agriculture technology. Intelligent sensor techniques have achieved significant attention in agriculture [13]. Sensors such temperature, humidity, light intensity, water nutrient solution level, pH and EC value, carbon dioxide (CO_2) concentration are applied in agriculture to plan the several activities and missions properly by utilizing limited resources with minor human interference. Other types of sensors utilized in smart agriculture technology includes global positioning system (GPS), accelerometer as well as smart camera. Plant harvesting and related farming techniques adopted GPS technology to provide precise vehicle guidance system. For moving components and motors, accelerometer can be used to detect variations in movement and vibration inconsistencies. Therefore, the required maintenance and components replacement can be predicted. Smart camera technology has also been implemented for real-time and remote monitoring of agriculture sites as well as for pest detection.

In Malaysia, fertigation method has been successfully demonstrated by Malaysian Agricultural Research and Development Institute (MARDI). This is a technique of cultivation to prevent soil borne disease that will affect plants. This technique avoids the usage of soil, instead cocopeat was used as replacement. Cocopeat does not hold water long enough compared to soil, hence frequent irrigation is needed. Mohd *et al*. [14] stated that by using fertigation technique, irrigation will be done when humidity of the cocopeat is low, providing just enough water for plant. Along with water, the plant will receive fertilizer too. An IoT system in agriculture industry is designed by [15] to monitor an automated fertigation system. The system consists of a web-based system, an automatic fertigation system and a communication network. The system uses data from SQLite database in a web-GUI to display parameters such as the status of water level, the flow condition of valves and pipes as well as the overall operation of automated fertigation system. This system is proposed for small-scale farming and helps farmers in managing fertigation systems using mobile devices. Kaidi *et al*. [16], proposed IoT application in agriculture production for rock melon farming. A monitoring and controlling system are developed using IoT for rock melon with additional user-friendly programmable farming routine human-machine interfacing (HMI).

A smart and automatic irrigation system for Indian agricultural and greenhouse is proposed in [17]. The system uses GSM technology to allow farmers to monitor the soil moisture, condition of water supply, water quality as well as the temperature and humidity at the agriculture field. An Arduino is used as the microcontroller in the system. Threshold sensor values are fixed for a particular crop and are programmed in the controller. Therefore, when the condition of the soil moisture is lower than the threshold value, the GSM automatically sends a message to the farmer and the motor will be turned on automatically. Zaman *et al*. [18], present the design of fully automated solar-powered irrigation and fertigation system. Two types of sensors, which are ultrasonic sensors and moisture sensors are used to detect the state of the tank and the soil moisture respectively. Similar to [17], the whole system is controlled with an Arduino microcontroller. In addition, a wireless monitoring system using Bluetooth technology with mobile application is designed using MIT Apps Inventor. The application allows users to monitor the status of the tank and farm remotely.

A compact and smart vertical garden system for urban agriculture is designed in [19]. This work also analyzed the growth performances of lettuce in the smart vertical garden system. There are two phases involved in this project which are the development of vertical garden system and the monitoring system for nutrient solution. A water nutrient system monitoring based on Arduino Uno is developed and implemented in the system to measure the pH and EC of the plant nutrient to ensure the quality of nutrient. The growth performances of different stacks of lettuce in the vertical garden system are observed and compared with a commercialized conventional hydroponic system. An automatic fertilizer mixer for fertigation system, which can be operated automatically or manually is developed in [20]. In this system, when one of the storage tanks runs low, a new batch of fertigation water is immediately prepared. The system prepares fertilizer solutions based on the EC value set by the users for each tank. The system is equipped with a mobile application that can be used to monitor and control the processes. The system required two different microcontrollers which are Arduino Mega and ESP8266, where the latter is utilized to create a Wi-Fi connection to operate an HMI software.

Compared to the existing works, we aim to provide an affordable IoT based fertigation system for end users. Therefore, an integrated controller is developed using low cost ESP32 microcontroller which can be interfaced with relays, sensors, and to the internet. Instead of using an Android-based application, an open source IoT platform is used in the system which allows end users to monitor the status of the system, sensor values and controlling the fertigation pump, solenoid valves as well as peristaltic pumps remotely via the Internet. A user-friendly dashboard is designed for these specific purposes. In addition, a scheduling can be set for the system to be operated automatically and notification can be provided to end user to ensure that the proposed system runs smoothly.

3. METHOD

This section presents the design of the IoT based fertigation system. The system block diagram consists of four different units which are interfaced to the main controller. The actual deployment at a test site is described in this section.

3.1. System design

Figure 1 shows the block diagram of the automated fertigation system. An ESP32 development board is used as the main controller of the system. ESP32 is the successor of ESP8266 and has new features such as built-in Wi-Fi and Bluetooth wireless capabilities as well as having dual core processor. A 30 pins version of this development board is used in the fertigation system. Wi-Fi based on 802.11 standard [21], [22] is used for the wireless connectivity between the main controller and a 4G modem router. Due to the short distance and line of sight scenario between the main controller and the modem router, Wi-Fi is the most suitable and low-cost technology compared to long range (LoRa) [23]–[25]. The modem router is used to provide Internet connectivity to the fertigation system so that it can communicate with an IoT platform.

The ESP32 board can be programmed in different programming environments such as Arduino integrated development environment (IDE), expressif IoT development framework (IDF), JavaScript and micropython. We used Arduino IDE to program the ESP32 as many libraries for the sensor modules are available. The main controller and sensor units are powered using 5 V source, which can be obtained by using step down module to convert from 12 V to a 5 V source. EC, temperature, and humidity sensors are connected to the main controller via analog-to-digital (ADC) channels using designated pins. For detecting the water level in the main fertigation tank, non-contact liquid level sensors are used.

The fertigation unit consists of a 0.5 horsepower water pump and several solenoid valves. Separate 240 V and 12 V power supplies are required to operate the water pump and solenoid valves respectively. Both water pump and solenoid valves are controlled by electronic relays which are connected to the main controller. The relays are used mainly to turn on/off the solenoid valves and the water pump. The water pump can be controlled during the fertilizer mixing procedure so that the required EC value of the fertilizer mixture can be obtained. It is also used to pump the fertilizer mixture and water to the plots through piping line and micro drip. Whereas the solenoid valves are used to control the opening of inlet and outlet points for the main fertigation tank.

The fertilizer unit or fertilizer injector is used to control the quantity of fertilizer liquid entering the main tank. Solenoid valves are used to turn on diaphragm pumps to transfer fertilizer solution into the main tank. In this work, Cayenne is used as the IoT platform. Cayenne is a drag-and-drop IoT platform which enables users to quickly prototype and share their connected IoT solutions. Cayenne MQTT Arduino library is utilized to work with ESP32 development board which provides the functions to connect to the IoT platform.

A dashboard is created using Cayenne to allow users to monitor various sensor values as well as the condition of the valves whether in on or off condition. Several custom widgets are available and used to design a user-friendly dashboard. In addition, widgets are also used to create virtual buttons which are responsible to trigger the corresponding electronic relays so that water pump or diaphragm pump as well as solenoid valves can be operated.

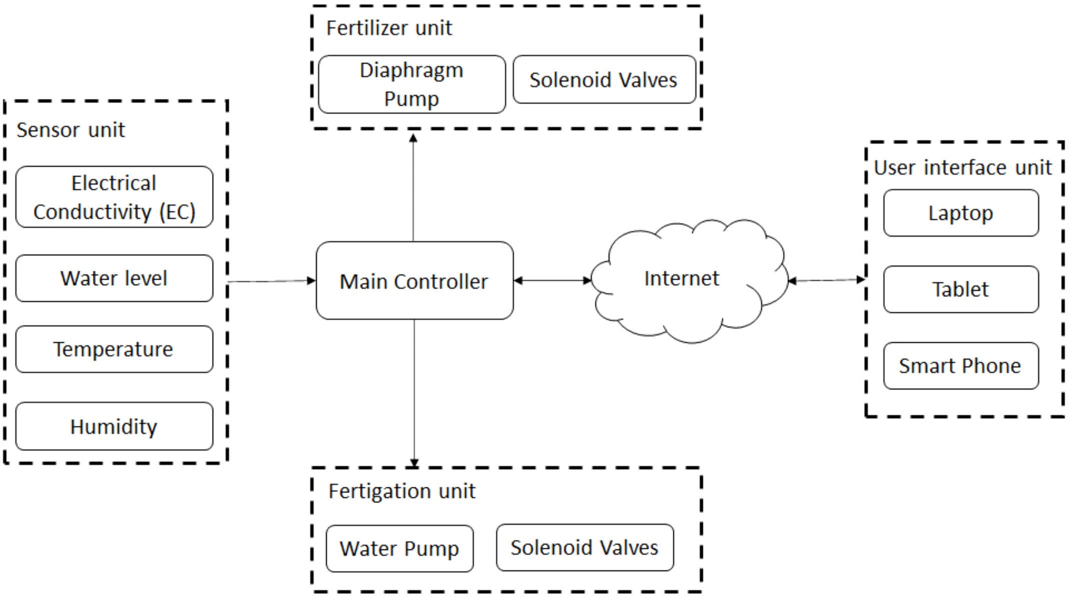

Figure 1. System block diagram

3.2. System deployment

During research and development stage, several prototypes of the IoT-based fertigation system have been designed. Figure 2(a) the prototype of the proposed IoT-based fertigation system while Figure 2(b) shows the functional system being deployed in a small-scale plot as proof of concept. In the first deployment, the system was used to provide fertigation to 120 polybags eggplants. We deployed the system prototype in an unused satellite receiver ground station site at University Teknikal Malaysia Melaka (UTeM).

(a) (b)

Figure 2. IoT-based fertigation system; (a) prototype and (b) actual site

4. RESULTS AND DISCUSSION

In this section, we discuss the IoT platform used by the system. A user-friendly dashboard was designed for monitoring and controlling the IoT based fertigation system. Functionalities of the proposed system are described and sample outputs of the fertigation system are provided to highlight it advantages.

4.1. IoT platform

Figure 3 shows the dashboard for the system. It consists of three main sections for sensor monitoring, fertilizer mixing and fertilizer injection. We can create multiple dashboards for the system depending on the usage level. The basic dashboard contains information for monitoring purposes which is suitable for guest users. For advanced level, we allow user to perform both monitoring and controlling function on the system. Therefore, the user can monitor each sensor value and perform actions such as controlling the fertilizer injector section, solenoid valves, and the water pump. In addition, advanced users are allowed to set the alert and trigger according to the threshold value of the sensors.

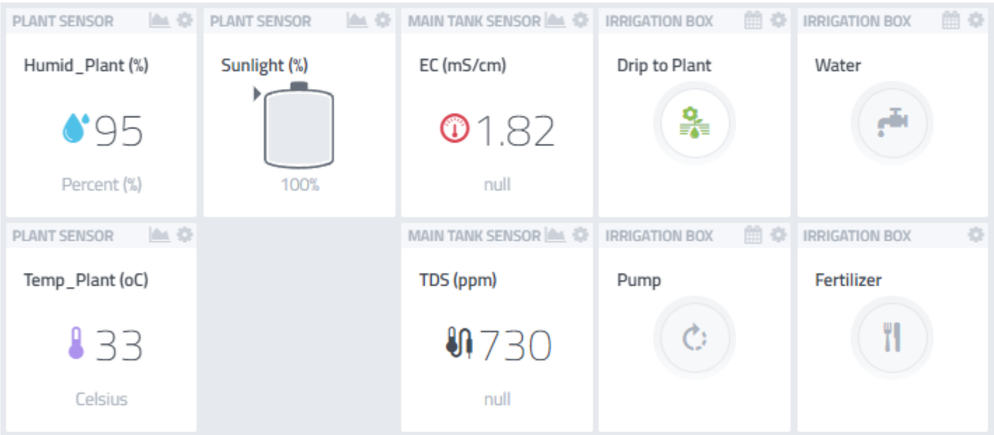

Figure 3. Dashboard for IoT-based fertigation system

Figure 4 shows a sample of temperature data recorded for a week in year 2022 at the deployment site. The maximum recorded temperature value was 35.94 degree Celsius which occurred in the afternoon. Whereas the minimum recorded temperature value was 22.36 degree Celsius recorded in early morning hours. During the same period, the maximum humidity as high as 100% was recorded during night-time to early morning. The minimum humidity value recorded in this week was 51.25% which occurred in the afternoon. Across this week, the temperature and humidity value show similar trends. The maximum and minimum temperature in each day exceeds 35 and 22 degrees Celsius respectively. Whereas the minimum humidity value exceeds 50% every day.

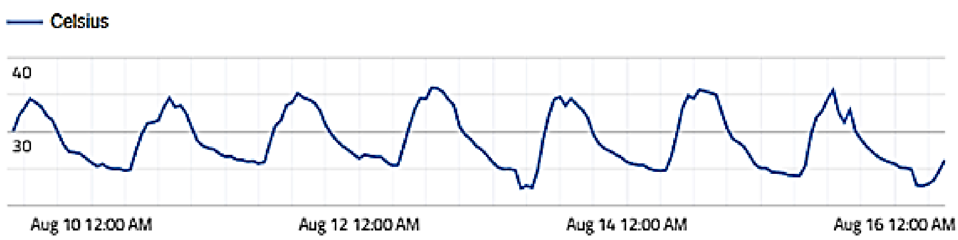

Figure 4. Temperature data

4.2. Agricultural output

The outcome of the proposed system is shown in Figure 5. Figure 5(a) shows matured eggplants ready to be harvested. Each polybag was labelled according to the number of rows and polybags in the planting plot. Therefore, we can record the eggplants' weight for each polybag. Figure 5(b) shows the harvested eggplant from the Satellite ground station site. During the season, the first harvest was obtained 42 days after planting the eggplants. Within 8 weeks, we managed to harvest approximately 98 kg of eggplants.

(a)

(b)

Figure 5. System output; (a) matured eggplants and (b) harvested eggplants

5. CONCLUSION

In this work, we have developed a prototype of fertigation system for smart agriculture based on IoT technology. The system allows automated fertilization and irrigation processes which can be controlled using an IoT platform. It allows farmers to control the system manually and automatically as well as adjusting the EC values for fertilizer mixture in the main tank and monitoring its liquid level. Furthermore, temperature and humidity sensors are implemented to measure the weather conditions so that pumping schedule can be arranged accordingly. The system has been deployed in a test plot consisting of 120 polybags of eggplant at Universiti Teknikal Malaysia Melaka. Results show that the system can function properly by delivering enough fertilizer to all polybags in the test site according to a predefined schedule. The proposed fertigation system allows the eggplants to be harvested earlier and managed to reduce the fertilizer usage.

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