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Implementation of smart monitoring system in vertical farming

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Abstract. The agriculture industry is facing labour shortage problem due to the difficulty to employ workers for “3D” (dangerous, dirty and difficult) jobs. This will reduce the number of labours needed and minimize the threats associated with the traditional agricultural system. Cyber-physical system (CPS) can provide farmers with a framework to remotely monitor and control the various factors that affect plant growth. The aim of this project is to implement CPS into a vertical farming system in which an Android-based remote monitoring and control (M&C) system is developed based on CPS for optimal production of the plantation system using Arduino ESP32 and sensors through the Internet. Experiments were carried to evaluate the practicality of implementing CPS in vertical farming process. Growth factors that were monitored and controlled in the experiments include ambient temperature, water temperature, humidity, pH level, light and carbon dioxide. In this study, an android application was developed and evaluated. The controlled parameters were display on the phone. The evaluation results shown that, the CPS system is practical to be used in plant growth monitoring (sensors and feedback system) and plant growth optimisation (sensors, feedback system and actuators). In addition, the automation of plant growth monitoring process can overcome the shortage of manpower in agriculture industry.

1. Introduction

Labour shortage is one of the main challenges faced in Malaysia agriculture industry [1]. Hence, a study was conducted to identify the solution to overcome labour shortage problem in agriculture industry by using technology. Naveen Balaji [2] introduced the application of IoT for crop monitoring by using components of Arduino microcontroller Atmega328, Soil Moisture sensor YL-69, temperature and humidity sensor DHT11, GSM module SIM800, WiFi Module ESP8266 (predecessor of today’s ESP32), MAX 232 and H.Arduino. This system used Industry 4.0 technology which include Cyber-Physical System and IoTs. However, it only monitored the conditions of the plant and factors affecting the growth of the plants. Besides, several components such as Arduino microcontroller, GSM and WiFi module ESP8266 used can be replaced by latest integrated WIFI module. Allafi and Iqbal

[3] designed a low cost web server by using ESP32 to monitor and collect data from photovoltaic power system. Information such as PV, battery current and voltage data sensed by sensors were inputs to ESP32 wireless system and saved in SD card, hence, transferred to the server via internet and can be saved into laptop or a cell phone. However, this is not a real time monitoring which gives the ability to view the data without downloading the data on site. Divya and Kumar [4] carried out comparative analysis between Android, Windows and Apple iOS and concluded that Android is the best operating system as Android provides open source for everyone to be able to create a program or install 3rd party application software. However, there are limitations that result malware attacks like spywares, Trojan horse, viruses and adware. Hashim et al. [5] performed a comparative study of different remote monitoring and control systems such as electronic device (Arduino), software development (eclipse), and system prototype internet protocol layer. The outcome of the study showed that remote control and monitoring system can be used to monitor plant. Torres-Sánchez [6] used Unmanned Aerial Vehicle (UAV) to monitor huge area of plantation. The UAV captured tree videos and transformed it to a 3-D geometrical data to identify tree size, soil properties, weed infestation and crop deficiencies etc. This concept of monitoring provided convenience, proven efficiency of 97% accuracy and time saving from monitoring the trees one by one by human vision. However, this requires more studies in order to design a UAV and 3-D geometrical data that requires huge investment. Okediran et al. [7] completed a survey by comparing and reviewing user interface toolkits and mobile operating systems from a perspective of developer and technological. The study concluded that most dominate of mobile operating system falls to Android. However, for software platforms (Java ME), it can be slow in speed and heavy to work with. Therefore, further improvement is required to overcome the existing problem. Jeyalakshmi and Radha [8] used digital image processing to identify nutrient deficiency symptoms in plants. Nutrients such as Nitrogen, Sulphur, Potassium, Calcium, Phosphorous, Magnesium, Phosphorous, Copper, Manganese, Boron, Iron, Molybdenum, Chloride and Zinc are needed for a plant growth. Offord, Meagher, and Zimmer [9] concluded that source of light and pH level in the soil are the factors that can affect the seedling growth. When low pH and high light is given, there will be maximum stem growth occurred in the seedling of Wollemia nobilis. However, different types and species of plants require different power of light and pH level. Further studies will be required to acquire suitable lighting and pH level for different plants. Tadesse, Nichols and Fisher [10] concluded that electrical conductivity (EC) can affect plants growth. When EC is higher, it promotes fruit ripening and increase dry matter content of the fruit. However, higher EC slows down plant growth and harvest. Pingping et al. [11] concluded that to have control systems that is autonomous in a greenhouse environment, factors such as temperature, light, humidity, carbon dioxide and nutrients must be monitored and controlled. Well controlled factors as aforementioned allow plants to grow well and achieved high quality, high economic return and high yield.

In summary, studies have shown that, Internet of Things (IoTs) technology and Android based application software were widely used in various areas but there is little evident of application of Cyber-Physical System in vertical farming. Literature review outcomes has indicated that, Cyber-physical system (CPS) which is one of the key system in 4^{th} industrial revolution can provide remote monitoring of the plants. With this technology, dependency of workers in plantation can be reduced by relying on quantitative data from sensors and remote monitoring system that consists of threshold based algorithm. The objective of this project is to construct a Cyber-physical system and conduct experiments to study the feasibility of replacing workers in vertical farming.

2. Methodology

Based on the literature review, a remote monitoring and control for vertical farming using aeroponics system was developed. Method of growing plants using aeroponics is able enhance the plants' growth with no infection of pests, weeds and algae [12]. Figure 1 illustrates the framework for remote monitoring & control system.

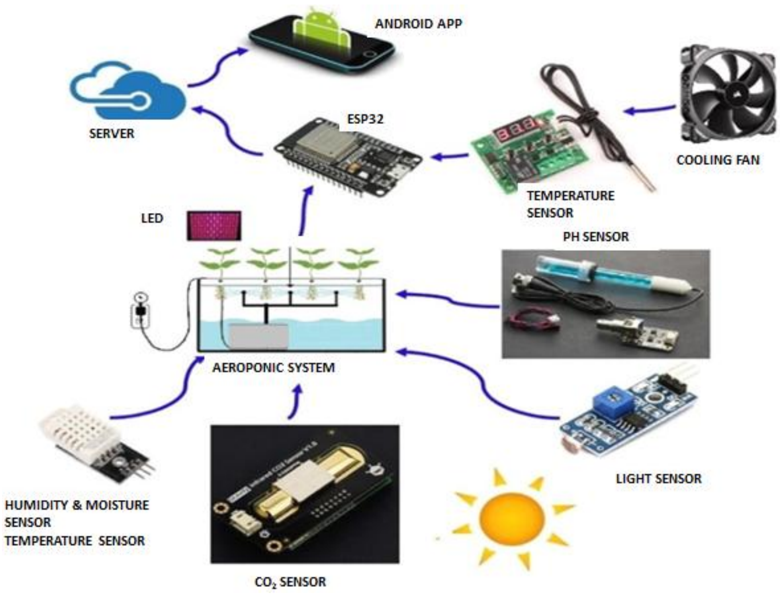

Figure 1. Illustration of concept framework for remote monitoring and control system.

Factors that affect plants growth such as light intensity, carbon dioxide (CO2) level, pH level, ambient temperature and humidity were monitored by various sensors and the data from sensors were analysed by Arduino ESP32 controller. The controllers (solenoid for CO_2 and Pumps for pH) were then triggered on the mobile app though internet. Once the "On Solenoid" is triggered, CO_2 are pumped into the system until the "Off Solenoid" function is triggered to stop the flow. While for pH level pump, once the "Pump pH up" is triggered, pH solution is pumped for 2 seconds and then stopped. This is to prevent solution from over pump which could harm the plants. Once the power is on, LED will be at OFF mode. The system will first sense if there is any sufficient light given to the plant by the measurement of LDR sensor. Amount of light can be adjusted manually on LDR sensor. If there is sufficient sunlight, LED remains off. However, if there is not enough sunlight, the system can be triggered on mobile app and the system will automatically switch off when there is enough sunlight. Water pump will be on for 9 seconds and off for another 9 seconds while UV light will be on for 5 seconds and off for 20 seconds. For practical use, it is advisable to ON UV light for 15 minutes/week. UV light does not need to be ON persistently as too much of UV light will eliminate beneficial bacteria that convert waste to plants' nutrients. There were two temperature sensors being used. One temperature sensor is premade that comes with manual setting, monitor and relay to trigger external controllers. This sensor is used to display ambient temperature reading on the machine. It has the function of auto-triggering (cooling off mode with fan) at the pre-set threshold value. Block diagram of the remote monitoring and control system is shown in figure 2.

Android-based application software was developed by using MIT App Inventor. The graphic user interface (GUI) display sensors reading. An alert message will be sent to the plantation owner when the sensor reading exceeded the pre-set thresholds. At every collected data from sensors such as light that the foliage plants require 14 to 16 hours while flowering plants require 12 to 16 hours of light per day [13], the light sensor will sense if there is sunlight at the plants. If there is no sunlight within the number of suggested hours needed by plants, Arduino ESP32 will activate light (Board Red Blue) given by specialised designed LED. The concept of this algorithm with different setting of thresholds will be set at every sensor. It was found that every plant required different threshold of each sensing factors to optimize a plant growth. In this project, general setting for most plants in Malaysia are used. Different types of plant, grow at different levels of nutrient strength. General vegetables served in a dish by a lot of restaurants requires pH level of 5.5 to 6.5 while Electrical Conductivity (EC) of 1.0 to 1.6 mS/cm. Information received from sensors will be sent to an Android mobile operating system through wireless network system (Internet). User will be able to monitor information regarding to the factors that affect a plant growth and control it. An algorithms used to control plantation's affecting factors can be set autonomous. For e.g. if the user defines pH level to be set at 7.0, the system will re-set the pH level to 7.0 by automatically insert pH-up or pH-down solution. Besides, manual setting is also allowed. The users can perform manual pH level setting by using the newly designed mobile application software.

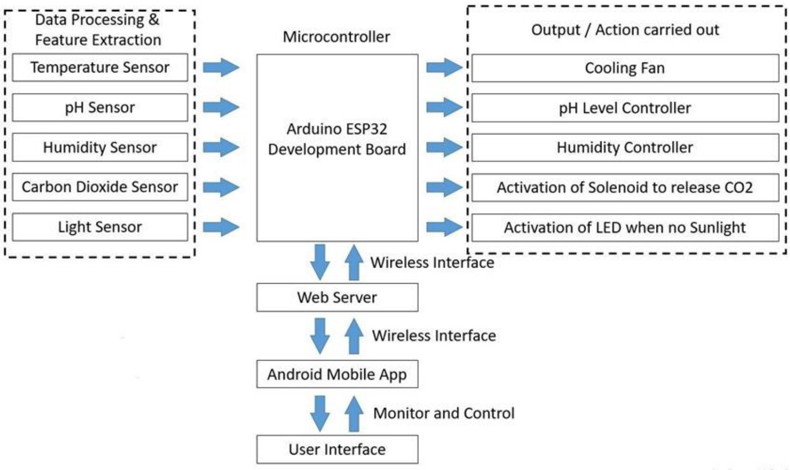

Figure 2. Block diagram of remote monitoring and control system.

The sensors used to retrieve the data were installed at the system as shown in Figure 3. An extra temperature sensor module was installed to auto trigger the small Direct Current (DC) fan. If the fan is not strong enough to reach the desired temperature and humidity, the system can trigger bigger DC fan through mobile application.

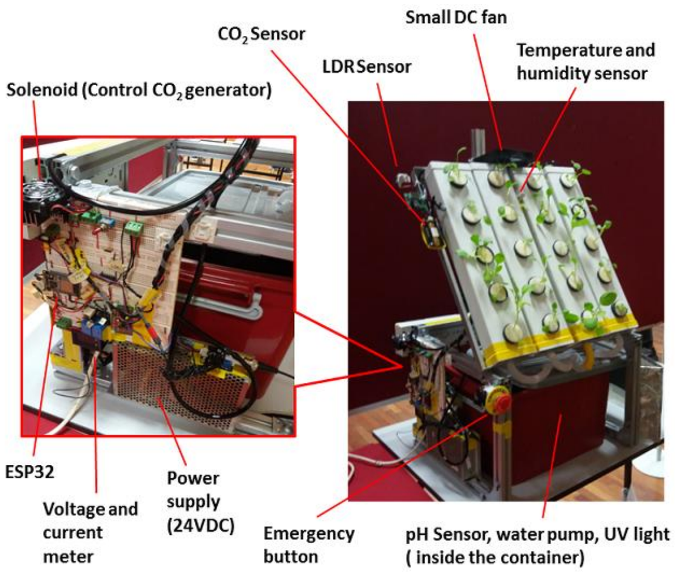

Figure 3. Main sensors used in the system.

3. Results and discussion

An evaluation experiments were conducted to study the practicality of applying CPS system in vertical farming (Figure 3). Two experiments were conducted to compare the plants growth without and with monitoring system. In the plants growth experiment with monitoring system, a remote monitoring and control system was developed to monitors factors that affect plants growth. For both experiments, the plants were placed at indoor but close to the window. The plants will expose to the sun light during day time.

CO_2 level, ambient temperature and humidity fluctuating over time but pH level decreased without applying the monitoring system. Whereas, experiment result for the plant growth with monitoring system, showed that CO_2 level, ambient temperature and humidity were maintained at the desired rate. When the system was used to carry out the monitoring of the plant growth only without user interface from early morning to midnight, the results show that CO_2 concentration and humidity varied significantly from 2109 ppm to 3580 ppm, and 85%-51%, respectively with changes of environment, while pH level and temperature fluctuated slightly, the environment became more acidic over time with the pH level changes from around 6.6 to 6.2 when the temperature fluctuates between 24- 32 °C during the day. The growing factors were then controlled and monitored at the desired level, in which the threshold of CO_2 was set at a minimum level of 2600 ppm, temperature below 28 °C, and pH level the range of 6.5 to 7.0.

There was tip burns observed on the leaves of the plants. It was found that low transition of nutrients to the plant was the root cause of tip burn. A fan was installed to reduce the surface temperature of the leaves and increases the speed of photosynthesis and LED was added to allow the leaves absorb more light.

There were algae observed in the water and the surrounding of the plants. Algae can be harmful as they produce harmful toxic to the plants. In addition, algae will compete with plants by absorbing nutrients, oxygen and carbon dioxide. There are few method to over this problem such as using cinnamon boil with water then spray on medium surface of the plant to prevent algae grow or providing shade and cover to prevent the contact of sunlight to the water. The method used to solve the problem was providing shade and cover to prevent the contact of sunlight to the water and therefor prevent the growth of algae.

The CPS system is able to reduce the use of human resources to maintain and optimise the plant growth process by performing remote monitoring of plant growth using various sensors. The temperature sensors can be used to monitor plant ambient temperature and water temperature. Humidity sensor can be applied to monitor air humidity. pH sensor is used to monitor pH level of the fluid in the container. LDR sensor is used to detect the lighting on the plant, CO_2 sensor can be used to detect the carbon dioxide level at surrounding of the plant. Although the growing factors are similar but the pre-set thresholds depend on the type of plant being monitored. Besides, this system is also able to optimise the plant growth factors by changing ambient temperature and air humidity by using electric fans; regulate pH level and CO_2 level; supply additional light to the plant by using LEDs. In addition, the system also can eliminate the growth of algae which is harmful to the plant.

4. Conclusion

The study outcome indicated that, introducing CPS system in vertical farming is able to carry out remote monitoring of the plants growth An android-based remote monitoring and control system for plantation system was developed based on based on current CPS technology. The evaluation result shown that, the newly developed CPS system was able to reduce manpower to monitor and control the plants growths factors such as light, humidity, temperature, pH level and volume of CO_2. In addition, the newly developed CPS system can also be used to eliminate the growth of algae that can affect plant growth. Therefore, it is practical to apply CPS system to optimize the plants' growing rate and improve the plants' quality in vertical farming.

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