Design and Implementation of IoT System for Aeroponic Chamber Temperature Monitoring

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Abstract— **Urban farming lifestyle has gained traction in recent years as society started to pay more attention to the quality of the product being consumed. Aeroponic is one of the urban farming techniques which employs air as the growing medium. Aeroponic allows a significant reduction in water usage with increased productivity as compared to hydroponic or conventional farming. However, optimum aeroponic farming requires precise control of the cultivation environment. This work presents a design and implementation of a lab-scale aeroponic system that employs the Internet of Things (IoT) for online and automated monitoring capability. An aeroponic system that consists of a growth chamber and a root chamber was built for 6 vegetable plants. The root chamber was designed as a closed and dark space resembling that of the soil. The temperature in this chamber was carefully monitored by using the DHT-11 sensor connected to the internet through the Wemos-D1-mini integrated microprocessor and Wifi module. Actuators, i.e. a Peltier cell, fans, and mist makers were placed to control the temperature and to supply nutrients to the roots. Considering the ideal growth environment for the plant, the required temperature was in the range of 25-30°C with a humidity level above 60%. The chamber was placed indoor with a certain exposure to sunlight where the recorded temperature variation was from *29-32.9°C*. Application of a simplified temperature control system with 2 set points at 25°C and 29°C successfully decreased the root chamber temperature to an average of 28.8°C, ideal for vegetable plant growth.**

Keywords— aeroponic, internet of things, online and automated monitoring, control system

I. INTRODUCTION

For the last couple of decades, a significant increase in global health consciousness has driven the changes in food industries [1, 2]. Public awareness of the quality of foods such as nutrition and safety has increased. In conventional agriculture, pesticides and various chemical substances have been used. This has damaged not only human health but also the environment. Nutritious and safe food is commonly attributed to organic foods. Therefore, the demand for organic foods has grown rapidly since the last decade [3, 4].

Organic farming has first been developed within the soil. However, soil-based agriculture has also negative impacts on the environment such as soil degradation and nutrient pollution. This pushed researches to develop urban farming methods. One of the promising methods is aeroponic that uses the air as a farming media instead of the soil.

In aeroponics, the plants are never submerged in the water. The nutrients from the water solutions are delivered to the plants by spraying the water to their lower stem and roots. The main advantage of this technique is that the plant will grow healthier because the disease that may spread from plant to plant can be prevented. However, there still exists a problem in aeroponic, i.e. any failure of the nutrient distribution (including water) can lead to the rapid death of the plants. Therefore, to prevent the failure in aeroponic farming, indicators, i.e. humidity and temperature, that are crucial for the cultivation environment must be carefully and continuously monitored and controlled [5]. There are some previous reports on the implementation of aeroponic systems. An aeroponic system was built for a seed-potato development [6]. This system was capable of monitoring the root chamber temperature and humidity onsite. Humidity was created by using mistmaker and fan which was controlled by a timer without any feedback from any sensors. Another system was developed with the capability to monitor the parameters in real time and online [7, 8].

In this paper, the implementation of temperature control through a closed-loop feedback system in a lab-scale container is reported. This paper also proposes the use of the Internet of Things (IoT) for real-time and online monitoring as well as real-time and online control (activation/deactivation) capabilities to agriculture [9]-[11]. The nutrient distribution was carried out by employing the ultrasonic mist maker. The root chamber temperature control system was built by using a sensor and actuator system that is controlled and connected to the Internet by an integrated microcontroller and Wi-fi module. Effective control of temperature and humidity using a sensor-actuator system is reported in this paper. The system has successfully achieved an average temperature and humidity well within the target range. The capability of online and real-time monitoring of temperature, humidity, and light intensity was also demonstrated.

The rest of the paper is organized as follows. Section II covers the design and implementation of the proposed IoT system for aeroponic. In Section III, the experimental results

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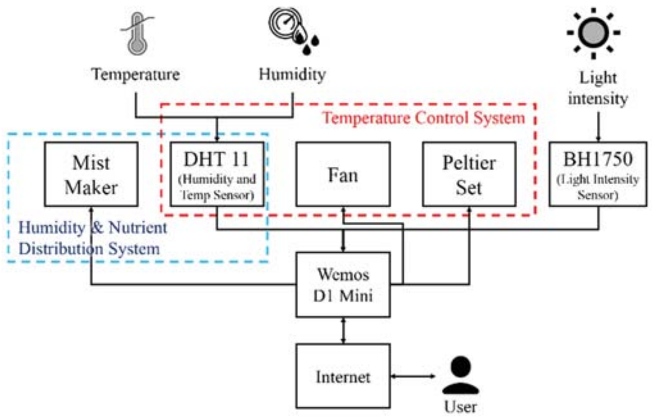


Fig. 1 Aeroponic System Schematic

are presented. Measurement results of key parameters, i.e. root chamber temperature and are also discussed in Section III. Conclusions are provided in Section IV.

II. DESIGN AND IMPLEMENTATION

A. System in General

The aeroponic system in this work consists of two separate chambers. The chamber on the upper side is called the growth chamber where the stem, leaves, or fruits grows. This site is exposed to light. The chamber on the lower side is called the root chamber. The root chamber contains the roots hanging upside-down in the air. It is sealed from light to provide an environment similar to that of the soil. This system employed mist maker for the distribution of water and nutrient in the form of mist. The root chamber temperature and light intensity are monitored online, continuously. Some actuators are placed to control the temperature to realize an ideal condition for plant growth, i.e. water spinach (*Ipomea Reptans*).

The overall schematic is presented in Fig. 1. The aeroponic system consists of a temperature control subsystem (red dashed block), a humidity & nutrient distribution subsystem (blue dashed box), and a light intensity sensor. These subsystems and light sensors were connected to Wemos D1 Mini microcontroller which has an integrated Wi-Fi module. The connection established by Wemos D1 Mini allowed the parameters, i.e. temperature, humidity, and light intensity, to be monitored in real-time via the internet.

The perspective and the top view of the aeroponic system design can be seen in Fig. 2a and Fig. 2b, respectively. Fig. 2c and Fig. 2d show the picture of a finished aeroponic chamber. Based on Fig. 2, it can be seen that the system consists of two separate chambers, i.e. the growth and the root chamber. The plants are to be placed in the six available netpots such that the upper side of the plants (stem and leaves) is in the growth chamber while the lower part of the plants (roots) is in the root chamber. The growth chamber was designed for the plants to be exposed by the sunlight. The root chamber was designed as a closed and dark space resembling that of the soil.

For cooling of temperatures, a Peltier cell that is attached to a water block was placed on the backside of the container as can be seen in Fig. 2b. The water block was used to help decrease the root chamber temperature by letting water flow through the cool side of the Peltier cell. The Peltier cell was

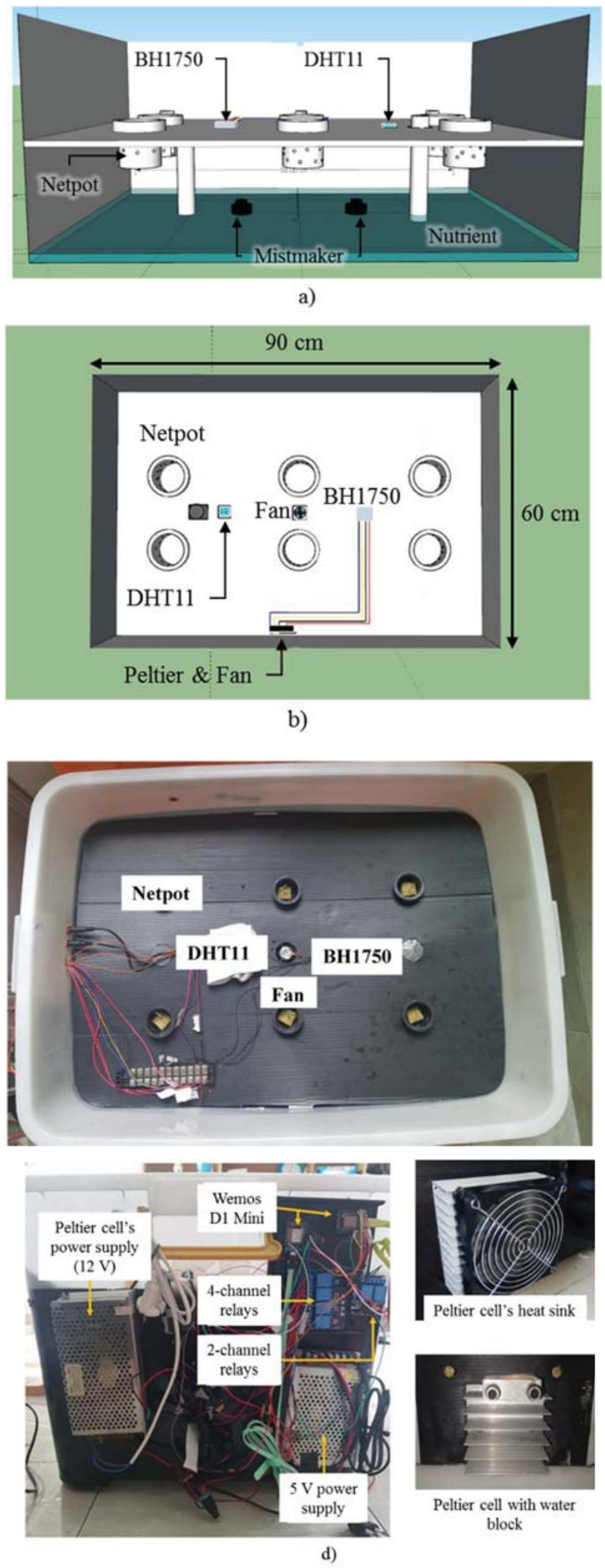
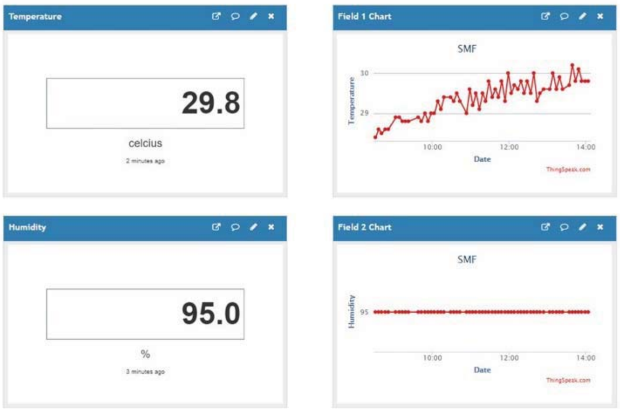


Fig. 2 a) The perspective and b) the top view of the aeroponic system design. c) The implemented aeroponic system with d) some key components such as Wemos D1 Mini, relays, power supplies, and a set of Peltier's cell.

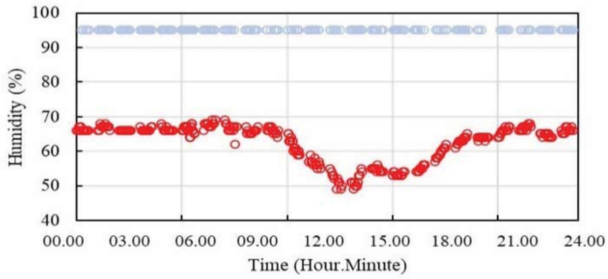
also equipped with a fan that is installed inside the chamber to better control the spread of cool air. Another fan was used outside of the chamber to blow the heat out of the hot side of



a)

b)

Fig. 3 a) real-time, online monitoring of temperature and humidity in the Thingspeak webserver, and b) the QR codes which contain the hyperlink to control all the actuators.



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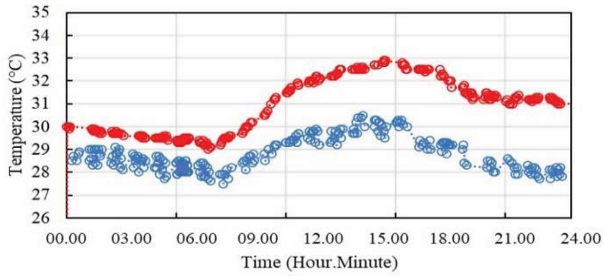

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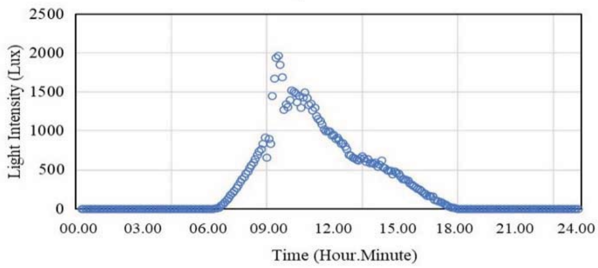

c)

Fig. 4 a) Humidity in a controlled (blue marks) and uncontrolled environment (red marks), b) temperature in a controlled (blue marks) and uncontrolled environment (red marks), and c) light intensity

mist maker was set to be active and inactive for five minutes the Peltier cell. The system was built in a 90 cm x 60 cm x 40 cm container with 6 net pots holes for the water spinach.

B. Monitoring

The sensors are responsible for getting temperature, humidity, and light intensity data. The sensor installed for light intensity was BH1750 and it shows the intensity of light in lux. This reading indicates the amount of light received by the plants. The temperature and humidity data were taken using DHT11. Data validation was performed by comparing the DHT11 sensor to a commercially available temperature and humidity measurement product (HTC-1). At 30°C and 69% humidity, it was found that the temperature and humidity differed by ~1% and ~5%, respectively, which are well in the accuracy range of the commercial product. The temperature and humidity measured by the DHT11 are transmitted to a webserver (Thingspeak) through the Wemos D1 Mini that has an integrated Wi-Fi module, i.e. ESP8266.

The Wemos D1 Mini is a Wi-Fi module-integrated microcontroller. The Wi-Fi module enabled communication with the ThingSpeak platform through the Internet. The connection was carried out by inserting the Application Programming Interface (API) Key to the Wemos D1 Mini. The data transmitted from the Wemos D1 Mini was tabulated, recorded, and graphically displayed by the Thisngspeak platform. This data was used in online and real-time parameter monitoring, while the data received from the ThingSpeak was used for actuator control.

C. Controlling

Four kinds of actuators were employed in this system: mist maker, Peltier cell, fan, and water pump. The humidity is manipulated by the mist maker. The nutrient-rich-water was ultrasonically turned into mist. The mist occupied the root chamber and finally attached to the roots. Since it is ultimately important for the root chamber to be humid, the each. A fan was used to distribute the mist inside the chamber so that the roots can get an even amount of nutrients. The water for the mist maker was supplied by a water pump. The fan and the water pump were controlled simultaneously with the mist maker. For controlling the temperature, a Peltier cell and a fan were employed. The Peltier cell was set to turn on when the temperature in the root chamber is above 29°C and to turn off if the temperature in the root chamber is below 25°C. The water for the water block was supplied by the water pump.

III. Results and Discussion

A. Online monitoring and control

The system's online monitoring and control were first tested. Fig. 3a shows a screen capture of the temperature and humidity data in the Thingspeak webserver. Graphical representations were also provided. Fig. 3b shows sample QR codes that contain links to activate or deactivate all the actuators.

B. Root Chamber Humidity

Fig. 4 shows the humidity data for one day in a controlled (blue marks) and an uncontrolled environment (red marks). The uncontrolled humidity at the root chamber decreased down to 50% between 10 am to 3 pm.
This occurred during the noon where in Indonesia the sunlight is at maximum intensity. At this low humidity, the roots in the aeroponic system will quickly dry out.

The humidity in a controlled environment was successfully maintained at a constant value of 95%. The condition at the root chamber was full of mist this guaranteed an adequate condition for the roots.

C. Root Chamber Temperature

Fig. 4b shows the temperature data for one day in a controlled (blue marks) and an uncontrolled environment (red marks). The uncontrolled temperature variation at the root chamber was between 29.0 °C-32.9 °C. This is higher than the ideal temperature for plant growth, i.e. 20 °C-30 °C. The temperature in a controlled environment was successfully maintained at an average of 28.8 °C. Only ~7.1% of the data were over 30 °C. This result meets the requirement for plant growth.

D. Light Intensity

Fig. 4c shows the light intensity data for one day. The data correlates well with the sunlight condition in the test environment. This data shows the maximum light intensity at the test environment was about 2000 Lux which occurred between 9 am to 10 am.

E. Plant Evaluation

The system was tested by using 6 water spinach plants grown for 16 days. The plants were first placed in the aeroponic system when they were 7 days old. It can be seen in Fig. 5, the plant's length increased steadily which shows that the plant is growing in the system.

IV. Conclusions

An IoT System for Aeroponic Chamber Temperature Monitoring has been successfully designed and implemented. The system performed real-time, online monitoring of key parameters, i.e. humidity, temperature, and light intensity. Without any control, the root chamber temperature reached 32.9 °C. The control of root chamber temperature was properly carried out resulting in an average value of 28.8 °C which is well within the ideal plant growth temperature. The system was tested by using water spinach and results showed that the plants grew in the aeroponic chamber. In the future, the performance of the aeroponic system can be further improved the performance of this system by installing LED lamps.

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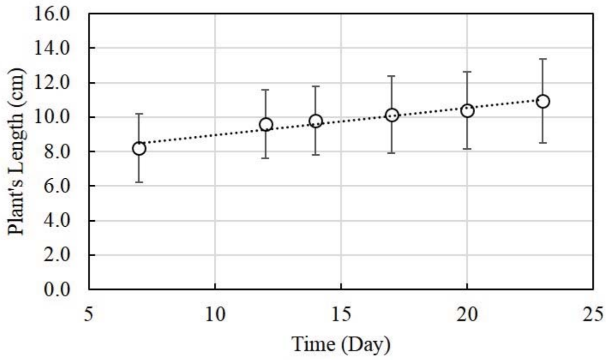

Fig. 5 The average length of plants. Error bars indicate the standard deviation.

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