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An IoT Controlled System for Plant Growth

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***Abstract*—This project aims to provide controllable environment for measuring and supporting plant growth by applying the Internet of Things technology and scientific experimental process together in order to improve farmers' performance of growing plants. Traditionally, farmers grow plants based on their experience and local knowledge from ancestors or friends without scientific methods. The plant production outputs depend largely on farm conditions such as air temperature, air humidity, light intensity, and soil moisture. Inappropriate farming conditions can lead to poor production output. It is necessary to measure, understand, and control farm conditions precisely in order to predict the performance of farming. We propose an IoT controlled system for plant growth in order to support these tasks. The system consists of two major components: (1) hardware consisting of air, light intensity and soil moisture sensors and actuators such as relay, motor gear dc, and water pump which are connected and controlled by microcontrollers. (2) management software consisting of dashboard for sensors data visualization and monitoring, and actuators control for adjusting farming conditions. The control could be operated manually or automatically using rule-based control based on the collected plant growth information in the system plant growth database. User can monitor and control air temperature, air humidity, light intensity, and soil moisture through our system user interface.**

Keywords—Internet of Things (IoT), Plant Growth, Smart Farm

I. INTRODUCTION

Traditionally, farmers grow plants based on their experience and local knowledge from ancestors or friends without scientific process and continuous process improvement. Farmers rely on suitable conditions which they know roughly in order to grow plants. In general, farm conditions such as air temperature, air humidity, light intensity, and soil moisture significantly affect that outputs of farming production. Farmers would like to have the most suitable farming conditions in order to generate the highest production output at the best quality.

Smart Farming has been introduced recently in order to help farmers improve farming conditions by applying modern technology such as the Internet of Things (IoT) into farming. In addition, IoT technology can make farmers' life easier in term of managing their farms conveniently through real-time monitoring of farms and remote control of equipment. Since the majority of Thai population are farmers, by using this system, farmers can achieve better production outputs and quantity. Smart farming has been widely adopted globally due to its ability to deliver precision and high throughput farming. However, currently in Thailand, smart farming has not been fully deployed due to the difficulty in the implementation. Thai farmers generally lack financial investment, technical knowledge and skills to setup and maintain the IoT devices and use them. Their technical knowledge and skills are key to harness the technology to support their career and hence help improve the country's productivity and gross domestic product (GDP). It would be beneficial and convenient if farmers could use the technology to the full potential to help them grow plants at lower cost through reduction in wasteful growing and labor and they could enjoy planting as a result. This work is introduced to provide easy-to-use environment for farmers to apply modern technology to their farm for controlling and monitoring the plant's environment in order to increase production. The system consists of sensors and actuators hardware and management software for monitoring and controlling farming environment. The hardware and software are conveniently provided as a black-box which removes all installation hassles away from the farmers so that they can focus on farming instead of technology.

II. BACKGROUND

A. Maintaining the Integrity of the Specifications

In [1], due to the maturity and the emergence of the Internet of Things technology, electronic and software systems were introduced and deployed in traditional farming in order to provide intelligence to the farming practice by allowing farmers to be able to monitor and control their farm environment. Smart farming technology was applied to several royal projects for controlling and monitoring the greenhouses' environment. The system comprise of a controller and a sensor system to control and monitor greenhouses' atmosphere. The sensor system can monitor temperature, light, air quality, humidity, soil quality. Farmers using this system would receive accurate information on their plant's environment, which can be used to manage their farm. Benefits of using this system includes increased production, increased quality of production, reduced human errors, accurate farm information to make better prediction, and real-time monitoring. However, farmers need Information Technology knowledge and skills in order to develop fully system that meet agriculturists' need and this process is a major obstacle for wide adoption of this technology among Thai farmers.

In [2], precision farming or smart farming has been adopt to a hops farm. The smart farming system consists of sensors as a monitoring module and controlling module for watering and fertilization tasks. Air temperature and humidity sensors

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has also been used to monitor temperature and humidity. Farmers grow hops as hydroponic plants and they can monitor and provide water and fertilizer simultaneously by using the system. Increased production, quality of production, real-time monitoring data, reduced operation costs, and accurate farm information are achieved when the monitored information is used to develop appropriate corresponding controlling system. However, this process takes a lot of time due to the collection and data analysis process for developing accurate control system.

In [3], a smartphone application has been applied to smart farming for monitoring and controlling agriculturists' farm. Farmers can easily monitor air temperature and control water and fertilizer of their farm via smartphone application. This allows farmers to conveniently make decisions about their farm anywhere and anytime. This system helps reduce labor and operation costs, reduce usage and learning difficulty, provide remote monitoring and controlling of real-time data, and increase quality and quantity of production. However, farmers require knowledge and skills in the area of robotics and Information Technology.

In [4], precision agriculture or precision farming is adopted for soil preparation. The system comprises of soil mapping and GPS (Global Positioning System). Soil mapping is a process for collecting soil data such as nutrients and type of soil in order to classify the quality of the soil. The collected data are stored in a database and downloaded to position tractors which use GPS technology to determine position. The tractors use soil data to recommend fertilizer suitable to the soil quality of the farm. This system provides convenient information on the surveyed fields using GPS, measured soil characteristics to the farmers in order to increase quantity and quality of production, provide accurate farm information and accurate field evaluation. However, in order for this system to be fully functional, plentiful soil data for a lot of coverage areas are necessary to develop the system.

In [5], the latest usage of IoT technologies for precision farming have been adopt in many area of farmland. Embedded sensors for soil monitoring, with this it is convenient to measure moisture in the soil and also provided accurate amount of water in soil. It allows remote monitoring and controlling water pump. Moreover, the system can set alert and alarm conditions according to temperature, humidity, and other farm conditions. These systems have many benefits for farmers such as real-time monitoring and controlling and reduced operation costs. To get all of these systems work properly, however, the initial costs may be high.

In [6], automatic temperature controlled system was introduced for greenhouse system. This system consists of Sonoff for smart wireless switch and temperature sensor system. When greenhouse temperature is high, then the sprinklers will start working to control temperature in the greenhouse. This can be controlled via Wi-Fi/3G/4G smartphone or tablet and also automatic mode. It is convenient to control temperature anywhere and anytime, on the other hand, Internet connection is required in order to control temperature.

III. Methodology

In order to control plant growth, we have to first understand plant growth process so that we can determine the process and environment, which are most suitable to the plant growth.

In order to understand plant growth process, a number of sensors are used to measure environmental variables related to plant growth. It is well known that there are a lot of factors that affect plant growth. Two most influential factors are light and water because plants use light and water for photosynthesis. Accordingly, we plan to use sensors that can measure the amount of light and water in the system. The sensors include air temperature sensor, air humidity sensor, light intensity sensor, and soil moisture sensor. These sensors will measure environmental data and send the measured data to a control center for further analysis using multivariate data analysis technique, and find the most effective model for plant growth.

Once the most effective model for plant growth is identified, the model could be compared with a current growing plant. The gap between the best model and the current environmental variable will be used to determine how to adjust the environment variable. For example, if the system determines that more light is needed, the system will send a signal to instruct the roof control system to retract the roof in order to let more light move into our plant growing environment.

Fig.1 shows the hardware architecture of our system. The hardware architecture consists of two major parts which are monitoring/sensing and controlling. In terms of sensing, we measure air temperature and humidity, light intensity and soil moisture which are common features considered for plant growing process.

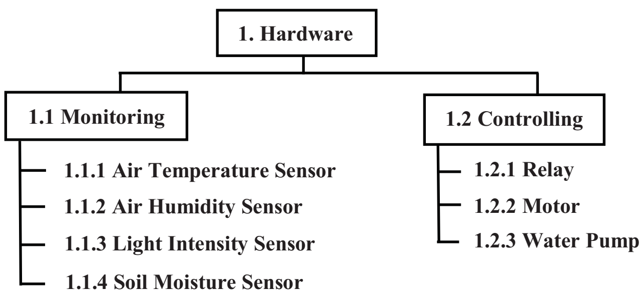

Fig.1. Hardware architecture

The measured data from the sensors will be sent to and stored in a database so that our data management software can analyze the data and give recommendation to the user of the system. Our database is designed to support two features of the system: (1) scientific study of plant growth and (2) recommendation system for plant growth. For the scientific study of plant growth feature, the data collection of measured environment and the associated growth (height) of the plant once a day are collected. The data are then analyzed using standard multivariate data analysis to understand the effect of each environment value (air temperature, air humidity, light intensity, and soil moisture) to the growth of plants. The result of the multivariate data analysis will be used to determine the best environment for plant growth.

Once the best environment for plant growth is found. The data will be stored and the objective model for any farmer who use this system. The measured environmental variables from the farmer's farm will be compared against the objective model for each time and day of growth. A recommendation will be provided to the farmer based on the comparison results. The farmer will be able to obtain real-time condition of the farm through our provided dashboard (Fig.3). The farmer can use this information to manually adjust the environment based on the system's recommendation. In addition, the system provides an automated system, which control the amount of light and humidity of the farm based on rule-based instruction set, through the use of controllable roof and water sprinkler.

The overall architecture of the software of this system is shown in Fig.2. It consists of the front-end data and system management software application including monitoring module and controlling module. The back-end system software takes care of low level control for microcontrollers sending and receiving data and control instructions from the front-end software, database system, sensors and actuators.

In order to demonstrate our system protocol, we design our experiment around two types of plants, which are Sunflower Sprout and Morning Glory Sprout.

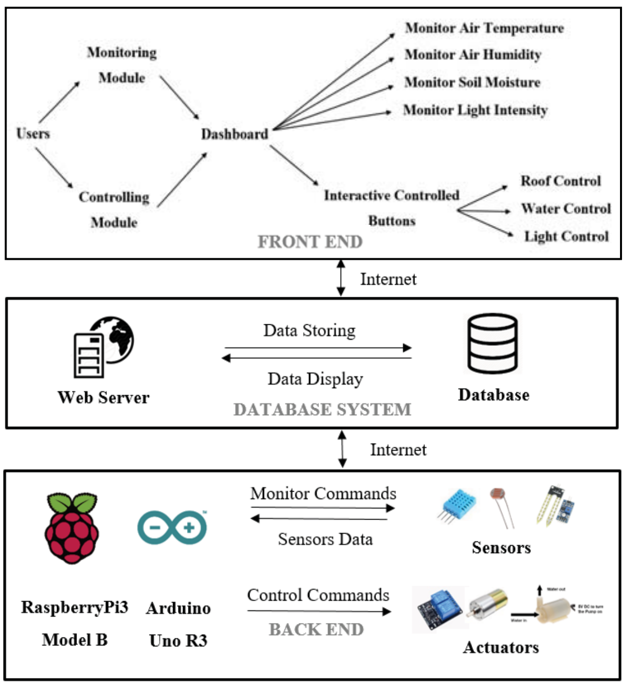

Fig. 2. Overall design of the system's software architecture

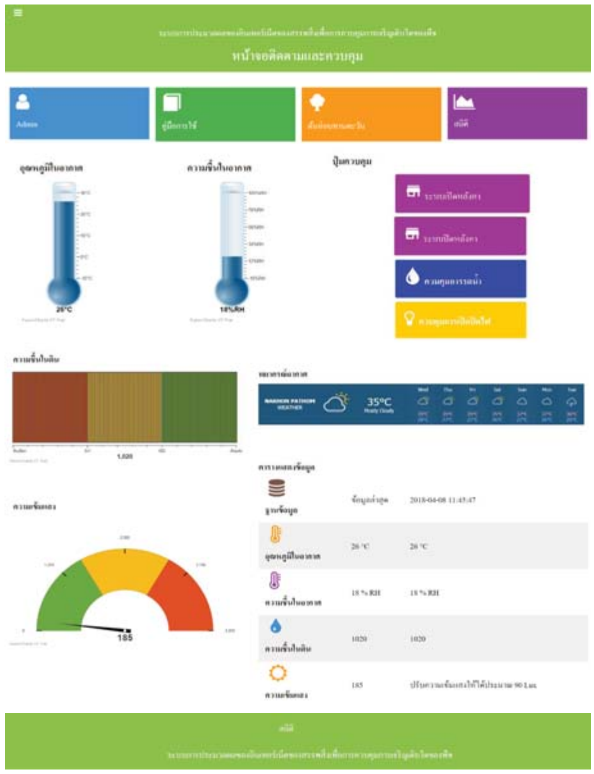

Fig.3. Overall design of the system's dashboard

IV. IMPLEMENTATION

According to Fig.2 and Fig.4, the system consists of both hardware and software. The implementation therefore mainly consists of hardware implementation and software implementation.

A. *Hardware Implementation*

The hardware components consist of sensors and actuators components interfacing with each other through the use of microcontrollers. Fig.4 shows how these components are connected together.

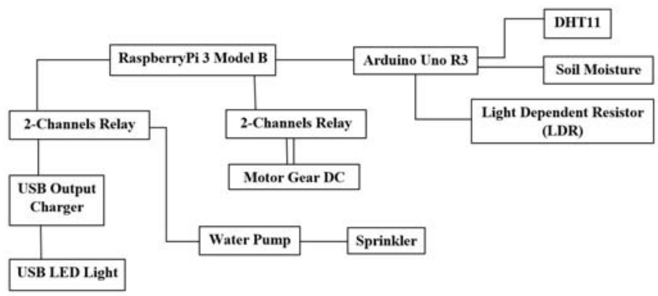

Fig.4. Overall implementation of the system's hardware architecture

For sensor components, there are a lot of sensors in the market that we can use. we select the sensors based on performance, cost and availability of the sensors in our country, which have to be suitable for monitoring plant's environment in the field. For example, Table 1 represents the specifications of air temperature and humidity sensors we considered. We select DHT11 sensor [7] to measure the air temperature and humidity. We use the same principle to choose other sensors. The soil moisture is measured using YL-69 soil moisture sensor [8]. The light intensity of the system is measured through the Light Dependent Resistor (LDR) by GL5516 [9].

Actuators used in controlling system consist of 2-channels relay, USB LED light, dc motor gear, and water pump (5v). We select actuators using the same principle as the sensors. The 2-channels relay acts as an electrical switch (for turning a device on or off) for controlling dc motor gear, water pump, and USB LED light. Dc Motor gear is used to control retractable roof system. The water pump is used to provide water to the sprinkler. We use USB LED Light for LED light, Gear Motor DC 12v 10 rpm for motor [10], DC Pump 5V for motor pump [11] and Mini Sprinkler Raindrop, MAXI-120 for sprinkler [12].

RaspberryPi3 Model B [13] and Arduino Uno R3 [14] are used together to systematically control the entire system which consists of many hardware components such as sensors and actuators.

TABLE 1. DIFFERENT TYPE OF AIR TEMPERATURE AND AIR HUMIDITY SENSORS [15, 16]

Specifications	DHT11	DHT22
Power Consumption	3V to 5V	3.3V to 6V
Humidity Operating Range	20 - 80%RH	0 – 100%RH
Temperature Range	0 - 50 °C	-40 – 80 °C
Cost	50 Baht	150 Baht

C. Software Implementation

The software is implemented based on the designed shown in Fig.3. The software implemented for the hardware back-end is based on the programming language and specification of each specific hardware based on RaspberryPi3 and Arduino Uno R3 platforms. The front-end software is implemented as a web-based application. Standard web technology platform and packages consisting of Apache Web Server, HTML, PHP, CSS, Javascript and Python are used. The database server is implemented using MySQL Server interfacing through phpMyAdmin installed on Apache Web Server.

V. EXPERIMENT

The experiment can be divided into three major parts: sensor calibration for relating the measured data from the sensors to the real world, scientific experiment for understanding plant growth, and engineering experiment for controlling the actuators.

A. Sensor Calibration

In order to make use of sensors data, the reliability and accuracy of the measured data from the sensors compare to the real world must be determined. Different sensors may report measured data differently due to the different characteristics of the sensor hardware (e.g., circuits and detector materials). We have to be confident when using data from the sensors. To ensure that the sensor is reliable, the same set of sensors must be able to produce the same data for the same real world environment at any time. Different circumstances such as improper installation or any interference can cause fluctuated data. Therefore, calibration process is conducted to minimise errors of the measurement and allow us to relate the measured data to the real world value (e.g. by comparing the measured data from the sensors to the measured data from standard scientific laboratory). The calibration curves shown in Fig. 5 and 6 represent relationship between sensor output (y-axis) and measured parameter (x-axis).

We perform calibration for each sensor. For the calibration of the DHT11 sensor, scientific digital thermometer and hygrometer are used to calibrate air temperature and humidity sensor. The testing was conducted by placing DHT11 sensor and standard scientific measurement devices together in the same environment and record both data for plotting a calibration curve.

YL-69 soil moisture sensor is calibrated by measuring the relationship between the humidity data from the sensor and the humidity data from scientific hygrometer at different humidity stages of the air and the soil. In order to do this, we first dried the soil to have 0 reading for sensor by putting the soil in an oven at 180 °C for 3.30 hours and then measure the humidity of the soil by the sensor. Then, the soil is added 10 grams of water and measure the humidity of the soil by the sensor in multiple rounds. The weight percentage of water content in soil (x-axis) is plotted against with measure humidity by the sensor data (y-axis) shown in Fig. 5

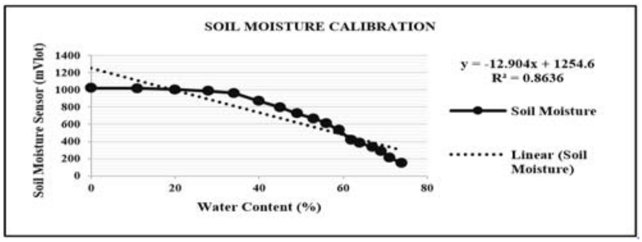

Fig.5. Soil Moisture Calibration Curve

The calibration of the light intensity sensor is a bit tricky because the standard light intensity device measures light intensity as the amount of lux but the GL5516 sensor measures light intensity as LDR value, which has to be later on converted to lux. The calibration process was operated by putting LDR and light meter together in the same system, record both data, and plot a graph showing the relationship between the data from both devices.

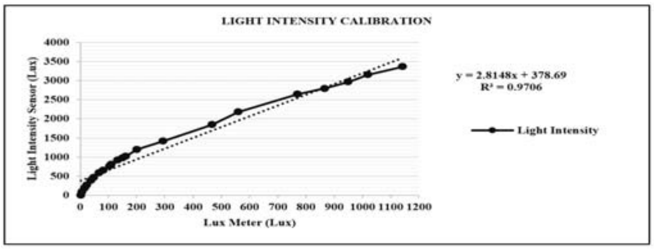

Fig.6. Light Intensity Calibration Curve

B. Scientific Experimental Setup

In order to study the factors that affect plant growth, experiments with varying environmental values were setup. Table 2 shows an example of the experimental setup for light intensity in order to study how light affect the growth of plants.

TABLE 2. DIFFERENT TYPES OF VARIABLES IN EXPERIMENT

Types of Variables		
Independent	**Dependent**	**Controlled**
Amount of Light Intensity;1.26, 14, and 42 μmol m^{-2} s^{-1}	Height of Plant in centimetres (cm)	Pots Size, Type of Soil, Types of Plants, and Amount of water

In order to start the growth process of the plants, the plant seeds must be initialised as follows:

- For Sunflower Sprout, Sunflower Sprout seeds are put into water for 8 hours, and then incubated inside a piece of wet fabric for 12 hours.
- For Morning Glory Sprout, Morning Glory Sprout seeds are put into water for 24 hours, and then incubated by a piece of wet fabric for 20 hours.
- White LED light bulbs are prepared for different light intensity (1.26, 14, and 42 μmol m^{-2} s^{-1})

After Sunflower Sprout and Morning Glory Sprout seeds are incubated, ten seeds of each are planted in each pot using the following procedure:

- Pour soil in the pot so that the soil level is 1 inch deep
- Dig 10 holes for each pot
- Place one seed of plant per hole
- Label each plant from 1 - 10
- Cover the seed with soil
- Water the plant according to the experimental design
- Repeat these steps for all pots
- Label the pots according to its light intensity and types of plants

We measure the output of each experiment by measuring the height of plants in centimetres (cm). Before measuring height of plants (we make sure that the plants are straighten out) which is the distance from the haulm of the plant at the surface of soil to the highest haulm. The measurement is conducted for 7 days.

C. Engineering Control

Once all devices are installed, connected and configured as a system. The system is tested to ensure that all functionalities proposed in the system design can work properly.

VI. Experimental Results and System Testing

This section comprises of scientific experimental results for both plants (sunflower and morning glory sprout) and system testing for functionality.

A. Experimental Results

Fig.7 shows the effect of light intensity on the growth of sunflower and morning glory sprout.

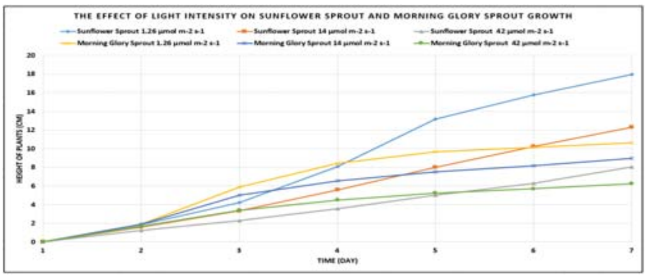

Fig.7. The Effect of Light Intensity on Sunflower Sprout and Morning Glory Sprout Growth

Due to the space limitation, similar experiments to study the relationship between air humidity and soil moisture were conducted but not shown here.

B. System Testing

Our system consists of the monitoring module and controlling module. The monitoring module was tested by calibration. The controlling module was tested for the functionalities proposed in Section III. Table 3 shows that the system could perform the proposed functions correctly.

TABLE 3. FUNCTIONALITIES TEST

Operations Performed	Functions		
	Monitor	Control	
		Interactive	Rule-based
Air Temperature	✔		
Air Humidity	✔		
Light Intensity	✔		
Soil Moisture	✔		
Roof		✔	
Water		✔	
Light		✔	✔

VII. Discussion

For scientific experiment, Fig.7 represents how light intensity affect Sunflower Sprout and Morning Glory Sprout growth. For light intensity at 1.26 μmol μmol m^{-2} s^{-1}or 90 lux, Sunflower sprout had significant growth rate from 4.23 cm to 8.08 cm on day 4, while morning glory sprout had considerable growth rate from 1.9 cm to 5.87 on day 3. This level of light intensity is the most effective light intensity for both plants since the highest growth rate is observed for this light intensity throughout the period. Light intensity at 42 μmol m^{-2} s^{-1} (3000 Lux) produces lowest growth rate for both plants. We can observe that sunflower sprout and morning glory sprout grew effectively in low light intensity level environment.

We look for the most suitable planting conditions using multivariate data analysis, which is a statistical method to study correlation of multiple variables. We aim to study the effect of the experiments by controlling the independent variables as inputs, which will result in dependent parameters that are observed after conducting the experiments. The collected data can be represented as a graph or table, and then Cronbach's alpha (α) can be applied to calculate the relationship between variables. If Cronbach's alpha is greater than or equal to 0.7, the higher the interrelation between the variables. Otherwise, there is less correlation. [17]

After performing experiments for light intensity, air humidity and soil moisture, we perform standard scientific multivariate data analysis [18] to find the relationship among the input parameters (air temperature, air humidify, soil moisture and light intensity) and the height of the plants.

For functionalities test (Table 3), the system can perform both monitoring and controlling modules. For the monitoring part, the system can monitor air temperature and humidity, light intensity, and soil moisture simultaneously on dashboard. The measured environmental variables are used to determine the best condition for growing plants. Once the best model is found, the system will use the best model as the objective for future plant growth. Subsequent users can use this model to receive recommendation on the plant growth based on their measured environmental variables. The users can control the system manually or let the system control environmental variables automatically by executing the recommended actions. The system allows users to control roof, light, and water by themselves. Rule-based Control, on the other hand, users allow the system to automatic control light based on present rules of the system.

Our work provides a lot of advantages for farmers in term of convenience and accuracy [19]. For convenience, farmers can view the status of their planting in real-time (air temperature and humidity, light intensity, and soil moisture) via Internet connection. They can make decision anywhere and anytime. In term of accuracy, the system can reduce human errors and operation costs such as labor cost.

VII. Conclusion

This paper demonstrates that the Internet of Things technology consisting of sensors and actuators can support planting or farming very well. This technology can be designed and packaged such that precision or smart farming can be easy and convenient for farmers or even people who would like to start planting by themselves. Farmers can monitor their farm conditions and adjust their plant's environment anywhere and anytime through the sensors and actuators used by this system. By applying IoT technology, farmers can increase production and quality of production because of appropriate and precise treatments to their farms. In addition, they can reduce operation costs due to automatic control to manipulate their plant's atmosphere. This system can also have significant impact to people who are interested in farming because of the convenience and quick learning curve. They can gain more knowledge to manipulate their plants by using technology. Therefore, technology that supports farming has lots of benefits for farmers and plant lovers.

However, a major limitation of this system is that the system requires calibration to be able to provide accurate real world measurement and accurate recommendation, especially, if the user of this system uses different hardware from the system used by this system. As shown in Section V, the IoT sensors that we used do not provide measured environmental data as same as standard scientific measurement tool. A complete package of this system with improved quality of sensors must be obtained together in order to deal with this limitation.

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