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Intelligent Plant Care Hydroponic Box Using IoTtalk

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***Abstract*—This paper presents Intelligent Plant Care Hydroponic Box (IPCH-Box) that exercises environment driven control methods through an Internet-of-Things (IoT) management tool called IoTtalk. IoTtalk provides a scalable and configurable software for users to easily and quickly add/remove/exchange the sensors and actuators, and program their interactions. From the experimental measurement results of IPCH-Box, the developed environment driven control methods include LED lighting, water spray and water pump which can effectively lower the CO_2 concentration, the temperature and increase water level, respectively. Specifically, the time of CO_2 concentration reduction in IPCH-Box is 38.54% faster than that with the plant system without our mechanism.**

Keywords*—Air quality, hydroponic, intelligent plant care, LED lighting system, sensor.

I. Introduction

Sensor technology has been intensively applied to plant care systems. There exist two kinds of plant care systems. A large-scale plant care system can be a plant factory or a green house. On the other hand, a small-scale plant care system with the size of several square feet is typically installed in a green laboratory, an office or at home. Generally, a small-scale plant care system can be transformed from a large-scale system. Until now, except for data acquisition and plant growth status and environment condition monitoring, there still exist some challenges for the small-scale plant care system, including (1) how to quickly add/remove/exchange sensor devices and verify whether the plant-care system can work correctly; (2) how to effectively develop environment driven control methods with satisfactory air quality by light-emitting diodes (LED) lighting, water spray, and water pump affected by CO_2 as well as O_2, temperature, and water level, respectively. This paper presents small-scale intelligent plant care hydroponic box (IPCH-Box) that utilizes various sensors and actuators including temperature, humidity, CO_2, O_2, water level sensors, LEDs with three different wavelengths, water sprayer, and water pump. Environment data of the small-scale plant care system are collected from the sensors. The data are sent to a server called IoTtalk for analysis in order to monitor the environment condition and take care of the plants. Besides, IoTtalk can control the plant care system by instructing the actuators such as LED lighting and water pump according to user defined environment threshold values. The IoTtalk approach is proposed to easily and quickly manage sensors and actuators in IPCH-Box. Software for all devices in IoTtalk can be modularized. Therefore, the users can easily add/remove/exchange sensor devices to interact with actuators such as LED lighting and water spray with less development time. For example, we can flexibly add extra humility sensors to make more accurate monitoring of the developed system. With appropriate sensor and actuator setups, IPCH-Box can improve the air quality inside the plant-care box. Specifically, we compare CO_2 and O_2 concentrations inside the box: with the IPCH-Box's LED lighting and without the lighting. The experiments show that the IPCH-Box mechanism is feasible to reduce CO_2 concentration and improve O_2 concentration inside the box.

The remainder of this paper is organized as follows. Section II introduces the related works. Section III describes the IoT device management system called IoTtalk. Section IV demonstrates IPCH-Box. Section V presents environment driven control methods and air quality experimental results. Section VI concludes our work.

II. Related Works

In [1], a modern plant factory utilized micro-miniature size wireless temperature-humidity sensor to measure temperature-humidity distribution so as to help farmers to maintain suitable plant environment. In order to achieve low power consumption and low cost, Ijaz *et al.* [2] used ZigBee to build wireless sensor network and LED lighting rather than fluorescent lighting in the plant factory. A very large-scale plant factory [3] producing 5000 lettuces per day is equipped with the hybrid lighting control, robotic screening control of seedlings, ventilation control and data analysis systems. Lee *et al.* [4] used LEDs to establish the lighting system for low power consumption and low heat production and analyze effects of different light sources on hydroponic lettuce. A lighting circuit system [5] controls light sources between LED and sunlight according to intensity value of sunlight radiation to achieve energy saving. In [6], experiments were conducted to investigate plant growth performance under continuous light and pulse treatment, where the light source is a mix of blue and red at ratio of 16:4. A small-scale hydroponic plant care system called AeroGarden [7] has an LED system, automatic nutrient supply and watering system with control panel. A small-scale soil plowing called Rododo [8] provides users with customized service. These studies do not elaborate on how to easily and quickly add/remove/exchange sensors and actuators in the plant-care systems.

III. The IoTtalk Device Mangement System

In IoTtalk, IoT devices consist of several input device features (IDFs) and output device features (ODFs) [9]. An IDF is typically a sensor and ODF is an actuator. For example, in IPCH-Box, a CO_2 sensor is an IDF and an LED is an ODF. The IoTtalk server is installed in a laptop, where all IoT devices connect to this laptop through Wi-Fi connection. Fig. 1 illustrates the IoTtalk architecture (Fig. 1(a)) that consists of five modules. The *Creation*, *Configuration and Management* (CCM; see Fig. 1(b)) systematically categorizes the features of

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the IoT devices, manages the functions to automatically configure connectivity of IDFs and ODFs, and stores all related information in the *Database* (DB; see Fig. 1(c)). The *Communication SubModule* (CSM; see Fig. 1(d)) provides HTTP based RESTful APIs [10] for the *Device Application* (DA; see Fig. 1(g)) to deliver/retrieve the IDF/ODF information. When an IoT device connects/disconnects to/from IoTtalk, the DA instructs the CSM through RESTful APIs to change the device status in IoTtalk. The *Execution SubModule* (ESM; see Fig. 1(e)) is responsible for executing network applications of the connected IDFs and ODFs. The network applications are modularized and can be reused for new applications. The GUI in Fig. 1(f) provides a friendly web-based user interface to quickly establish connections and meaningful interactions among the IoT devices. Through the GUI, a user instructs the CCM to execute desired tasks to create or set up device features, functions, and connection configurations. The ESM, the CSM, the CCM, the GUI and the DB modules reside in the network side are called the IoTtalk server. The server can be typically installed in a laptop, a desktop, or the cloud as a virtual machine.

The DA shown in Fig. 1(g) is responsible for connecting IoT devices to the IoTtalk server, which is installed in an MCU board (e.g., Arduino Yun [11]) or a mobile device (e.g., a smartphone). It consists of two software components. The *Device Application to the Network* (DAN; see Fig. 1(h)) communicates with the IoTtalk server for registration and data exchange through Wi-Fi. The DA is a Python program run on Linino AR 9331. The *IoT Device Application* (IDA; see Fig. 1(i)) is an Arduino program executed on ATmega32u4 [12]. The IDA connects to the DA through the *Device Application to IoT device* (DAI; see Fig. 1(j)). For Arduino Yun, the IDA and the DAI communicates through the Bridge in Fig. 1(k).

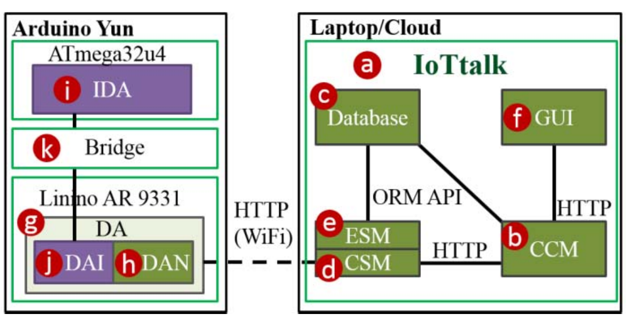

Fig. 1. The IoTtalk architecture.

IV. The Intelligent Plant Care Hydroponic Box (IPCH-Box) Architecture

A small-scale prototype of Intelligent Plant Care Hydroponic Box (IPCH-Box) is shown in Fig. 2. The system architecture in Fig. 3 includes a sensing system, a data processing system, and a response system. The sensing system controls IDFs or sensors such as temperature, humidity, CO_2, O_2, water level, and timer. The response system controls ODFs or actuators such as LED, water spray, water pump, and nutrient supply. Both the sensing system and the response system are integrated on an Arduino Yun board that is responsible for environment data acquisition and execution of the instructions sent from the data processing system. The data processing system including IoTtalk plant-care intelligence and the dashboard with threshold management is responsible for executing environment driven control functions according to user-defined thresholds. The environment data collected by Arduino Yun and the environment thresholds provided by the threshold management are transferred to IoTtalk plant-care intelligence, which instruct the actuators to take actions in the response system. Meanwhile, the environment data are delivered to the dashboard for data recording and displaying. Arduino Yun communicates with IoTtalk in the laptop through Wi-Fi. Both IoTtalk and the dashboard may reside at the same laptop and interact with each other through HTTP.

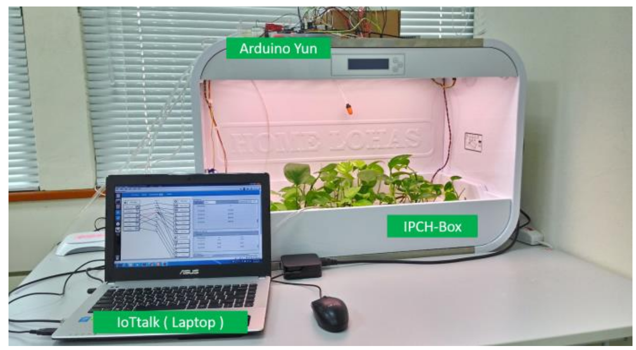

Fig. 2. A prototype of IPCH-Box.

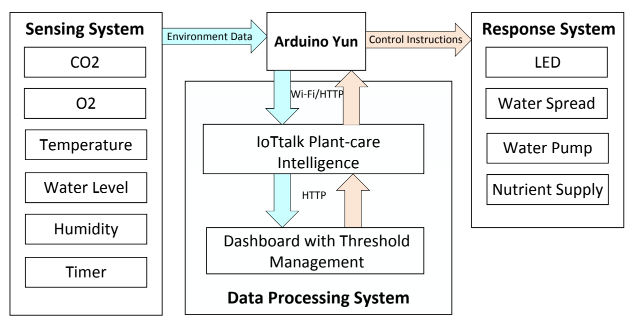

Fig. 3. The functional block diagram of IPCH-Box.

The software programs for sensors and actuators are modularized in IoTtalk as device features for the IPCH-Box model. The IPCH-Box's sensing and the response systems are illustrated in the IoTtalk GUI as two icons in Fig. 4(A) and Fig. 4(B), respectively. In the GUI, IDFs and ODFs are connected at seven join circles in Fig. 4(D)~(J). Each join circle implements the desired IoTtalk plant-care intelligence for the corresponding IDF-ODF connection. The sensing system in Fig. 4(A) sends sensor data to the dashboard in Fig. 4(C) for display through the connections in Fig. 4(D), (E), (H), (I), and (J). Threshold value managed by the dashboard with threshold management can be modified dynamically to fit different types of environment and plants according to the user's decision. After the processing of the IoTtalk plant-care intelligence, the corresponding control instructions are issued to the response system to perform environment driven controls, which will be described in Section V. With the web-based GUI, the user can modify the intelligent control logic in IPCH-Box by directly changing connections for different sensors and actuators and revising the control codes in a straight way. Besides, with the connections in Fig. 4, one sensor can affect more than one actuator and one actuator can also be controlled by several sensors.

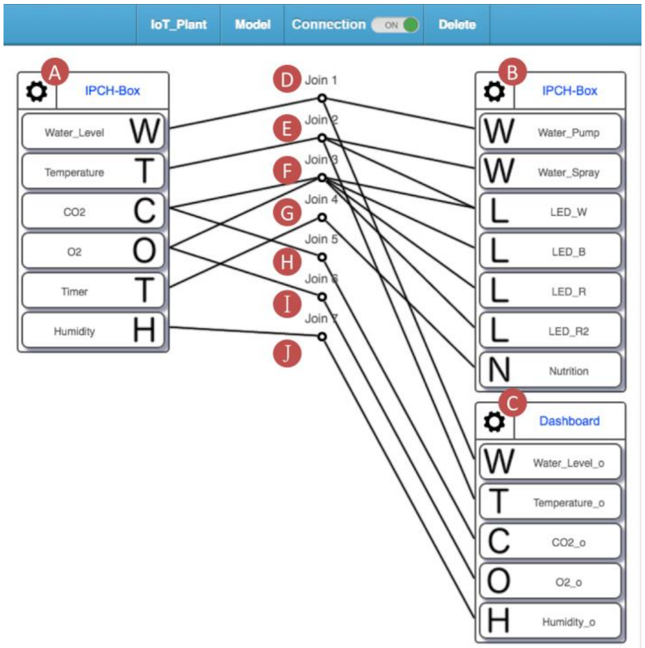

Fig. 4. The IPCH-Box Configuration in IoTtalk.

V. Environment Driven Control Methods and Experimental Results

The current version of IPCH-Box provides three environment-driven control methods including LED lighting, water pump, water spray and one timer-trigger control method for nutrient support. The above control methods are fulfilled by IoTtalk plant-care intelligence and the threshold management functions executed at the join circles in Fig. 4(D)~(G). The join control logic in IoTtalk plant-care intelligence will check each threshold value from the dashboard and generate control instructions to the response system.

1. LED Lighting

The LED ODFs include 6 red, 2 blue, and 8 white light sources which are the most essential components in this system. The LEDs are controlled by both the O_2 sensor and the CO_2 sensor according to the join control logic in Fig. 4(F). The white light sources are turned on in IPCH-Box's normal operation. The white light sources are turned off when one of the three conditions is met: (1) CO_2 concentration is higher than 1000 ppm, (2) O_2 concentration is lower than 18%, and (3) the temperature is higher than the user-defined threshold value. When the CO_2 concentration is higher than the acceptable standard level by 1000 ppm or the O_2 concentration is lower than 18%, which violate the standard levels [13, 14], the red and blue light sources will be turned on and fused into the purple light source to efficiently consume CO_2 and produce O_2 in the photosynthesis process.

2. Water Pump and Spray

A water level sensor is responsible for detecting the water level in the sink. Whenever the water level is lower than the user-defined threshold, the pump starts to draw water into IPCH-Box until the water level is higher than the standard value. The intelligent control logic is implemented in Fig. 4(D). When a temperature sensor senses that the temperature is higher than a threshold value, IoTtalk triggers the function in the join circle in Fig. 4(E) to spray water on plant leaves to lower the temperature.

3. Nutrient Supply

Nutrient supply follows a user-defined time period to trigger a pump that draws nutrient into the sink in IPCH-Box. The time to supply nutrient is set by a software timer which is modularized as a feature in Fig. 4(A). The control logic is executed at Fig. 4(G).

To verify the proposed IPCH-Box functions, the following experiments test the presented environment driven control methods. Two cases for the CO_2 concentration reduction and O_2 improvement experiments are considered. Case 1 is the baseline plant system model, which disables the IPCH-Box's LED lighting. Case 2 enables IPCH-Box's lighting control function. In both cases, a few Pothos are placed in the sink with full water. A fixed quantities of baking soda (0.6 gm $\pm$ 0.1 gm) and vinegar are used to produce about the same CO_2 quantity for both cases. Inside the IPCH-Box in Case 1, the maximum CO_2 production approaches around 1358 ppm in Fig. 5. In Case 2, the maximum CO_2 concentration is around 1220 ppm. The maximum CO_2 reduction in Case 2 is less than that in Case 1 by 138 ppm. Most importantly, compared with Case 1, the time of CO2 concentration reduction arriving at around 1000 ppm is 38.54% faster than that without LED lighting inside IPCH-Box.

The second experiment measures the O_2 concentration distribution, where an O_2 sensor records concentration data for both cases, respectively. As shown in Fig. 6, O_2 concentration values recorded in Case 2 are in the range between 18% and 20.5% and are always higher than that without using the IPCH-Box's LED lighting.

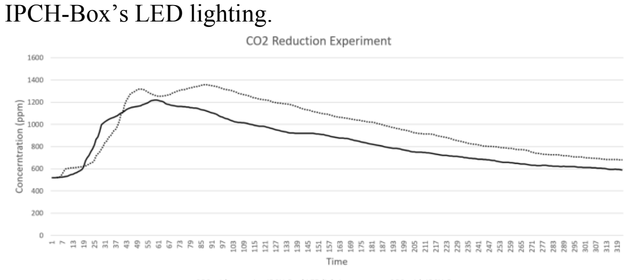

Fig. 5. Experiment of CO_2 reduction inside the IPCH-Box.

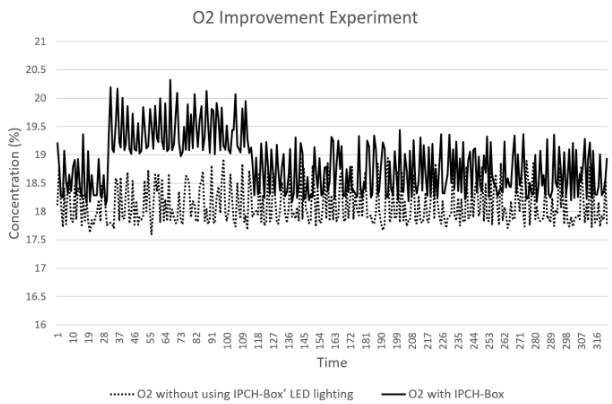

Fig. 6. Experiment of O_2 improvement inside the IPCH-Box.

In other words, the air quality of Case 2 is better than that of Case 1. Note that data in Figs. 5 and 6 are collected from the join circle in Fig. 4(F). It is expected that more IPCH-Boxes are used, the air quality of the indoor space can be improved.

VI. Conclusion

In this paper, we have presented and demonstrated IPCH-Box. IPCH-Box exploits the advantages of IoTtalk to provide a scalable and configurable infrastructure. We demonstrated the feasibility and the functionality of IPCH-Box with the experimental results. The differences among the presented IPCH-Box and other works are shown in Table I. The most important feature is that IPCH-Box integrates IoTtalk which offers users to easily and quickly add/remove/exchange sensors and actuators and provides environment driven control methods between sensors and actuators. In other words, IPCH-Box is capable of providing scalability and configurability compared to most existing small-scale plant-care systems with the same functionality. To our best knowledge, through IoTtalk, IPCH-Box is the first real work to modularize the sensing-response functions for plant care systems. In the near future, we will scale up the number of IPCH-Boxes and conduct monitoring of the plant growth.

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TABEL I: Comparisons with Other Plant Care Systems

	Kameoka [1]	Ijaz [2]	Sugano [3]	AeroGarden [7]	Rododo [8]	IPCH-Box
Type	Factory	Factory	Factory	Home	Home	Laboratory
Hydroponic / soil plowing	Soil plowing	Hydroponic	Hydroponic	Hydroponic	Soil plowing	Hydroponic
IoT Device Management System	No	No	No	No	No	Yes (IoTtalk)
CO_2 Sensor	Yes	Yes	Yes	No	No	Yes
O_2 Sensor	No	No	No	No	No	Yes
LED Lighting	Yes	Yes	Yes	Yes	Yes	Yes
Temperature	Yes	Yes	Yes	No	Yes	Yes
Humidity	Yes	Yes	Yes	No	Yes	Yes