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Internet of Things (IoTs) based hydroponic lettuce farming with solar panels

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***Abstract*— Every 1,000 kilograms of temperate lettuce produced by commercial hydroponic farming consumes 21.2 kW-Hr per crop approximately. The solar panel technologies have been considered as an alternative way to serve as a sustainable energy. However, a big problem of solar panel usage is their costliness. To get the most benefit of the solar panels, an IoT based transpiration leaf sensor has been presented as a main part for the solar panel based hydroponic system. Unlike the external factor based sensors such humidity sensors, temperature sensors, light intensity sensor, the internal factors based sensor like transpiration leaf sensor can detect and monitor the internal change of lettuce plant in real-time. According to the direct calculation, 30 set of solar panels with batteries (300 Watts and 100 A-Hr per set) would be used as the sustainable power supply for 800 square meters of a hydroponic farm. Absolutely, the cost of such the solar panels is 250% of hydroponic system cost. On the other side, the proposed IoT based technique can determine the suitable duty cycle in real-time. At the same area, the only 10 set of solar panels with batteries would be used when the proposed IoT based hydroponic system is considered.**

Keywords*— *Internet of Things/ IoT/Smart Farming/ Solar Panel/ Hydroponic/ Lettuce Farming/ Leaf Sensor

I. INTRODUCTION

Nowadays, hydroponic lettuce culture is very important for health food restaurants. The benefits of hydroponic are that the productivity is suitable for farm-to-table restaurants, salad bar based restaurants, and so on. For example, in Thailand, organic lettuce can cultivate in northern part of Thailand 8-10 month a year.

Profit of lettuce soilless outdoor (lettuce hydroponic outdoor) and lettuce soil culture is 58.20 Bath/sq. meters and 21.96 Bath/sq. meter respectively. The main reason of high productivity of hydroponic culture compared to lettuce soil culture is the nutrient circulation techniques. This circulation technique improves the root water potential of temperate lettuce. However, the circulation needs electric pumps that consume electric energy. Their electric cost is around 21.2 kW-Hr per 800 sq. meters approximately. In 2006, the estimated area of soilless lettuce culture is 67 ha (418.75 Rai) or 670,000 sq. meters. This consumes 17,587 kW-Hr per month for producing temperate hydroponic lettuce [1].

In 2016, the registered growers become 765 (400% increase). This means that the estimated area of soilless lettuce culture is around 2,680,000 sq. meters. The electric consumption reaches 70,350 kW-Hr per month [2].

The productivity of hydroponic lettuce farming is very important. However lettuce hydroponic growers face to the risk all the time. Recently, many researchers introduce IoT technologies based hydroponic system to improve the quality of temperate lettuce cultivation. In addition, the IoT based hydroponic system can reduce the production loss significantly.

In 2016, M. A. Triawan et. al studied Internet of Things communication by applying Cloud-based publish and subscribe method. Cloud IoT system development applied to the needs of the monitoring and controlling/settings the parameters of providing nutrient hydroponics NFT-based (Nutrient Film Technique) [3]. T. Wu et al. presented IoTtalk to provide a scalable and configurable software for hydroponic vegetable growers to easily and quickly add/remove/exchange the sensors and actuators, and program their interactions [4].

In 2017, S. Ruengittinun et. al presented the Internet of Things for Smart Hydroponic Farming Ecosystem (HFE). The system can help new growers who want to run hydroponic farm but do not have time to manage manually [5]. In addition, Manju. M et. al applied Internet of Things to access remotely the aquaponic system via wireless sensors. This would be able to identify and monitor the part of the system. The wireless sensor devices include temperature sensor, pH sensor, ammonia sensor, water level sensor and moisture sensor [6].

Recently, J. Chaiwongsai presented IoT based system to control and manage hydroponic cultivation for tropical area. The IoT based smart system can control humidity, temperature, water level, pH and EC. The system can control factors suitable for a various kind of vegetables in different nutrient solution tanks automatically by using Internet of Things (IoT) as wireless sensors [8].

In 2018, P. Pipitsunthonsan et. al presents a leaf sensor which was designed for stomatal transpiration detection. The sensor consists of a thermocouple, a humidity sensor and programmed microcontroller. The thermocouple measures temperature difference between the leaf and its surrounding atmosphere while relative humidity of the atmosphere was recorded [9].

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In 2017, P. N. Crisnapati presented the green energy conceopts used in the Hommons. The alternative energy source is the sun which was used by utilizing solar panels to convert into Electricity [7]. In addition, O. Chieochan et. al introduced a prototype of a smart Lingzhi mushroom farm. This system applied the solar cell to an irrigation system (fog and sprinkler pumps). The Watts usage of the proposed sprinkle and fog per day is 96 Watts (0.5 Hours/day) and 25.2 Watts (8 Hours/day) respectively. The solar panels are 2 modules of 40 Watts with 12 V Mono-crystaline. The battery is 45 Ah for store solar energy [10].

According to the related works, Internet of Things based smart farming can be classified into two groups: external factor based sensors and internal factor based sensors. To develop the sustainable smart farming, this paper would apply the internal factor sensor like transpiration sensor to detect the transpiration status of plant leaf. When the transpiration status is known the suitable duty cycle can be easily calculation to control electric pump in the nutrient container of hydroponic system.

II. Method

This section explains the basic concept of solar panel applications for hydroponic system. According to the previous works, there are two papers mentioned the solar panel application for smart farming. However, the details of calculation are not included for farming concept. In our experience, the solar panel applications would be success when plant understanding is included in the design. Otherwise the installation cost of solar panel module would be very expensive than hydroponic system.

The total power of electric pumps for producing 1,000 kg of temperate lettuce is about 21,600 Watts per day. To cover the total power for producing 1,000 kg, we need 15 modules of solar panel and battery with 300 Watts and 120 Ah, respectively. This is calculated in case of the sunlight is in average condition (6 Hr in every days). Unfortunately, in practical, it is impossible to get sunlight in the average condition. In addition, the solar panel in fix angle would be not getting the maximum power. So we need to include more 100% of solar panel (15 modules of solar panels and batteries) to make sure that the power be enough for the hydroponic system when the sunlight is under average condition. Thus the 30 sets of solar panels and batteries would be suitable for serving the 800 square meters of hydroponic farming.

Figure 1 shows the concept of controlling electric pump to reduce the electric power consumption of hydroponic system. The real-time transpiration of lettuce leaf would be monitored using infrared temperature sensor module. The difference of leaf temperature and ambient temperature is calculate to be an input of duty cycle determination. The electric pumps of hydroponic system would be turned on when the difference of leaf temperature and ambient temperature is close to zero. Thus the period of duty cycle can be automatic adjustable in suitable condition. Basically, the external factor based sensor like light intensity sensor might be able to control duty cycle as well. But the light intensity sensor cannot sense the internal change from the plant leaf.

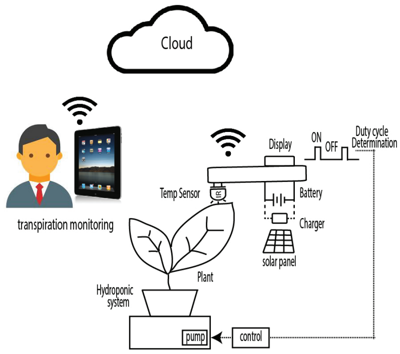

Fig. 1. The concept of controlling electric pump based on IoT leaf sensor

III. The Proposed System

The concept of controlling electric pumps for hydroponic system from section II can be realized as the prototype of infrared temperature sensor as shown in Figure 2. There are four components: ESP8266 NodeMcu, Light sensor, IR temperature sensor and OLED 0.96 inch display. The function of ESP8266 NodeMcu is the controller that can be able to communicate light sensor and infrared temperature with hydroponic growers or experts via cloud platform. This paper uses www.thingspeak.com as a cloud platform. The IR temperature sensor is designed to be a leaf sensor. Basically, the output of IR temperature sensor is leaf temperature and ambient temperature. To determine the transpiration status, the difference of leaf temperature and ambient temperature would be calculated by the controller. In addition, light intensity sensor would be act as an external factor based sensor to compare the response between the internal change and environmental change. The concept of transpiration monitor in real-time can be applied in many kinds of vegetable or fruits.

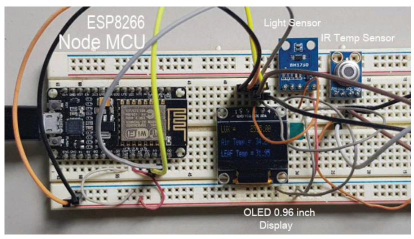

Fig. 2. Prototype of infrared temperature sensor module and light intensity sensor based on Internet of Things

The prototype of hydroponic system with solar panel module is shown in Figure 3. The basic operation of the hydroponic system is that the electric pump will circulate the nutrient solution along with the PVC tube and then turn back to the container again. However if the electric pump is controlled by the suitable duty cycle, the power consumption of electric pump would be significantly reduced. Moreover the operators or growers can be able to monitor the transpiration of lettuce leaf in real-time. When the internal change of the lettuce plant is not maintain perfectly, the growers can address the problem as soon as possible.

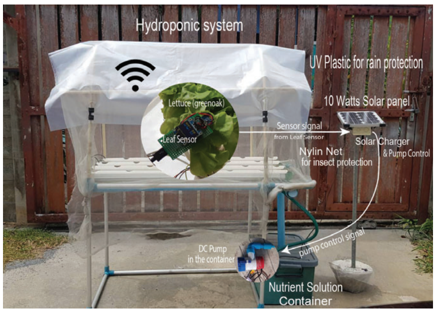

Fig. 3. The prototype of hydroponic system with solar panel module

Fig. 4. The prototype of hydroponic system with solar panel module

For farming application, the solar panel can be installed as a roof top installation as shown in Figure 4. The hardware and software lists are shown in Table I and II respectively.

IV. EXPERIMANETS AND RESULTS

To evaluate the basic concept of the proposed method, the IoT based leaf sensor module would be tested with the greenoak lettuce. Firstly, the experiments are set up as shown in Figure 5. There are three parts: a tested greenoak, IoT based sensor module and labtop for monitoring the transpiration status and light intensity status via wifi communication. The difference of leaf temperature and air temperature of greenoak lettuce in realtime is shown in Figure 6. Basically, it depends on which type of lettuce planting in the hydroponic system. In case of greenoak lettuce, the normal light intensity (40000 lux – 80000 lux), the off period of dc pump can be achieved around 3-5 minutes and the on period of dc pump can be achieved around 1-2 minutes. Thus the solar panel unit does not need to supply the electric power all the time. The installation cost of solar panel unit is significant reduced.

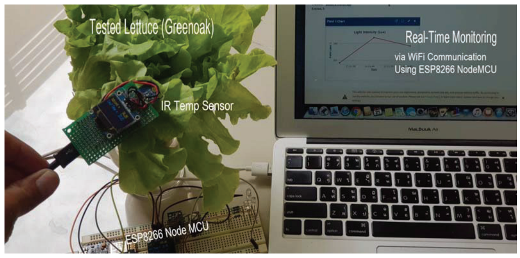

Fig. 5. Experimental set up for transpiration and light intensity monitoring

The situation of turning off electric pump is at 12:05. The difference of leaf temperature and ambient temperature is between -7 and -10. This is mean that the transpiration status is in the good condition. The leaf stomata are still open in the transpiration. At 12:10, the leaf stomata gradually start to go up (close to zero). The duty cycle of this condition would be turn on 1 minute and turn off 5 minute.

According to the conventional method, the external factor like light intensity (LUX) sensor have been widely used to adjust the duty cycle of controlling dc pump for hydroponic system. Figure 7 shows the monitoring of light intensity (LUX). This experiment shows that the external factor based sensor cannot use for controlling electric pumps. The light intensity sensors like the any kinds of external factor sensors such as humidity sensor, water level sensor, and temperature sensor and so on.

However, the efficiency of the proposed controlling method depends on the plant healthy as well. When the proposed system is used to the hydroponic system with stressed problem, the off period of duty cycle is close to zero. It is because transpiration period of lettuce is too short for turning off the dc pump.

TABLE I. HARDWARE COMPONENTS

Hardware	**Details**	
Controller	ESP8266	Arduino controller with WiFi communication feature
Light Sensor	BH1750	Light sensor for measuring light intensity (Lux)

Hardware	Details	
Solar panel	10 wattage	DC supply for sensors and controllers
12 Vdc charger	19,200 mA	DC supply for sensors and controller

TABLE II. SOFTWARE LISTS

Software	Details
Arduino IDE	Programing ESP8266 Node MCU to deal with sensor
Cloud platform	https://Thingspeak.com

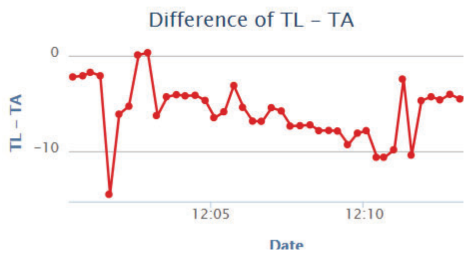

Fig. 6. Experimental result: difference of leaf temperature $T_L - T_A$

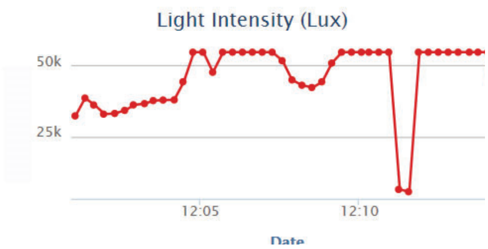

Fig. 7. Experimental result: monitoring light intensity (LUX)

V. CONCLUSION

The sustainable green power is very important for future life of human. This paper presents the integration of solar panel applications and the Internet of Things (IoTs) applications to reduce the installation cost of solar panel for hydroponic smart farms. To realize the research objective, the transpiration principle is the main concept of internet of things based leaf sensor. The obvious benefits of the IoT is that the communication between plants and grower is possible in real-time. In addition, the WiFi based controller can control the electric pumps in the smart for optimal control. According to the experimental results, the power consumption of the hydroponic lettuce farming with the proposed leaf sensor based control is significantly reduced by 67%. This means that the installation cost of solar panel would be only 33% compared to the conventional design (without leaf sensor technique) of solar panel.

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