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A Supervisory and Control System for Indoor Lettuce Farming

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Abstract: Despite the unpredicted weather conditions challenge ways of traditional farming, farmers still prefer traditional methods. This may be due to the challenge to interact with the existing technology to suit dynamic farming requirements. Therefore, this study evaluates the performance of a proposed feasible and user-friendly system in monitoring and controlling the variables that influence the growth of vegetables leading to optimal growth for indoor farming. The proposed system used various sensors to monitor temperature, humidity, and soil moisture; and to optimally control these parameters. Besides, a graphical user interface (GUI) was designed as a human machine interface so that users can set desired value for each parameter to suit a plant. The results show that the proposed system was able to accurately provide sufficient light that vegetables needed using a LED spectral lighting, and to control the temperature that was better than a typical outdoor traditional cultivation (i.e. with averaged total hourly cumulative errors per day of 11 and 16 ºC, respectively). Thus, this proposed system can minimize the effects from unpredictable weather to a farming by automatically monitoring and controlling parameters of temperature, humidity, soil moisture, and light with respective desired values that set by users via the GUI.

Keywords: Temperature, soil moisture, spectrum light, indoor farming

1. Introduction

The agriculture-based economy has undergone a significant transformation in the Malaysian economy where the agricultural sector has moved towards the status of an industrialized country rapidly. However, there are several challenges that threaten the ability to achieve this industrial status, namely the level of available technological advancements as well as the production efficiency. Malaysia has a tropical climate and monsoon seasons. With unpredictable weather conditions, it can affect the agricultural sector. Modern farming aims to improve crop production, quality, and efficiency. Based on the Ministry of Agriculture Malaysia (MoA) mission, the intention is to transform this agriculture sector into the modern sector and become more competitive as the world-leading food and agriculture sector [1]. To achieve this mission, the challenge is to increase crop production and quality to meet the growing demand for food. Based on The Food and Agriculture Organization of the UN (FAO) prediction, the global

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population will reach 9.2 billion by 2050. To keep the pace of this demand, food production must increase by 70 percent [2].

Apart from the increasing population, climate change also a big concern that can affect the agriculture sector. East Asia is expected to be one of the regions that will face more challenges from climate change compared to other regions [3]. By controlling the environmental conditions, the production of vegetables can be increased two to four-time faster compared to a typical outdoor and traditional cultivation. This is because a high precision computer control system can provide a desired temperature, humidity, light and CO_2 to vegetables [4][5].

Climate condition always playing an important role to grow the vegetable. Climate factors such as temperature, humidity, soil moisture, light, flood, rainfall and natural disaster cannot be controlled naturally. Since the 1980s, climatologists researched on climate change and predicted significant changes in global warming due to the increasing atmospheric concentration of carbon dioxide and it will affect the coming decades [6]. The Intergovernmental Panel on Climate Change (IPCC) report states that there was an increment of 0.85 °C from 1880 to 2012 on global land and ocean temperature. The IPCC also states that the period between 1983 and 2012 was the warmest in the past 800 years [7]. The unpredicted weather conditions challenge farmers to make correct decisions e.g. when to start farming, when to water the plant, and when to harvest. Some farmers still prefer traditional methods which are depending on experiences to monitor the conditions of farms and relying on the weather forecast to planning their farming activities [8]. This may be due to the difficulty to use the existing technology for small-scale farmers.

Starting in the 1970s, the revolution of the agriculture industry starts when United States (US) try to develop a fully control vegetable factory using only artificial light. The organization builds fully control vegetable cultivation environment by using electrical energy. Japan has started to involve in the vegetable factories in the second half of the 1970s mainly by Hitachi Ltd. and the Central Research Institution of Electric Power Industry and other electric power companies. The world's named Japan as the most active country for implementing technology in the agriculture industry [9]. The achievements of this development are the increase of cultivation spaces, the effective of light utilization and the reduction of production cost. Most of modern farming has been cultivated in such a controlled environment as a greenhouse and vegetable factory. In a vegetable factory, environmental factors are strictly controlled under the optimal condition, while in greenhouse these are controlled based on feedback as affected by the external climate condition [10]. A vegetable factory becomes more popular because it produces a more effective method to find the optimal conditions for a vegetable. The vegetable factory is developed for urban farming because it can be placed in any place regardless of the surrounding environment that can affect the growth. In a vegetable factory, environmental factors e.g. temperature, humidity, light, and CO_2 concentration can be strictly controlled based on desired set points. The optimal conditions of a vegetable can be identified by studying the effects of various conditions.

There are many parameters that play important roles in growing vegetables and photosynthesis process e.g. temperature, humidity, soil moisture and CO_2. By controlling this parameter, the vegetable can grow healthier and produce better vegetables [11]. Soil moisture is referred to the amount of water per volume of land. Good water management can help the vegetable to increase the performance of nutrient absorption from the soil [11]. Next, vegetables need water in order to transport the nutrients and regulate their growth. The optimum percentage of relative humidity for vegetable development is between 55% to 70% [11]. Every vegetable has a suitable temperature for growth and development. When vegetables received unsuitable temperatures, the development process will be disturbed. Unsuitable temperature can damage the vegetable tissues, as it usually happens when the vegetable in the open air or night frost [11]. Lastly, light activates selectively different photoreceptors in different spectral regions, which induce highly overlapping genes indicating the presence of a shared signaling component [12]. In many developmental processes, e.g. seed germination, leaf size, leaf morphology, plant height, flowering and fruit growth, plant responses to various light effects occur [13]. Even though all visible light can promote photosynthesis, the 400 to 500nm, and 600 to 700nm regions are the most effective [11].

The Human Machine Interface (HMI) is the platform for humans to communicating with machines. HMI commonly used in the process industry because it can allow users to interact with machines, devices or systems [14]. HMI can provide a centralized monitoring and control system for different input and output parameters of the process [15]. HMI can provide a color graphical display to make it more attractive and user friendly. GUI and HMI are almost similar but not synonymous because GUI is frequently leverage for visualization capabilities within HMI. Besides that, HMI can be connected to any microcontroller such as Arduino, Raspberry Pi, Programmable Logic Control (PLC), and input or output sensor so the data can be display to the user for monitoring or controlling. HMI screens may be used for a single purpose, such as monitoring and tracking, or for more complex operations, such as switching off machines or increasing the output speed, depending on how they are implemented. HMI can provide interface to user that makes people who do not have engineering background to easily understand the machine applications and conditions.

The development of the vegetable sector in Malaysia has been increased year by year. Based on the 2018 statistic by the Department of Agriculture (DOA) Malaysia, lettuce ranked tenth on the highest hectare for 10 types of vegetables and cash crops. The production of lettuce in 2018 is 46,113.60 metric tons and the value of production is RM12 565 955.00 [16]. The lettuce harvest area was increased from 2552 hectare (2017) to 3325 hectares (2019) [17]. This shows that the production in lettuce keeps increasing by year because of the demand and it will be the same in the next coming years. The production of lettuce can be drastically increased if the technology was implemented. In Japan, lettuce is grown in vegetable factory technology. The largest vegetable factory in Japan produces 9 million lettuces per year and 25000 per day. The profit from using vegetable factory increasing steadily since 2009 [18]. This shows that technology is needed to improve the quantity and quality of production.

In the vegetable factory industry, it always about to grow plants under controlled conditions. Nowadays technology, Light Emitting Diodes (LED) are in the process of replacing these obsolete light sources. Light can be measured by its wavelength in the unit of nanometers (nm). A consistent red light that has 640nm wavelength is important for the creation of the photosynthetic apparatus in plants. The blue light that has 460nm also important to develop the formation of chlorophyll, photomorphogenesis, and stomata opening. A combination of red and blue light that range between 460nm to 640nm is favorable for plant growth [12]. The duration of LED light for lettuce is between 14 hours a day. Next, several studies have proved that the environment can give an effect on lettuce growth and the temperature is one of it. The fastest growth lettuce in a controlled environment was 25 ºC in day and night. There was no impact of varying day to night temperatures on the growth of lettuce when it changed due to light intensity [19]. Previous study shows that the minimum temperature for lettuce to growth is 10.8 ºC and the maximum can be reached at 29.7 ºC [19]. On the other hand, a suitable irrigation system for lettuce is drip irrigation because it more efficient compared to micro-sprinkler irrigation. The drip irrigation decreased the consumption of water in the soil, maintain proper moisture conditions for lettuce growth and yielding. This method is preferred because the water reached the soil directly in the root area and can make the leaves remain dry which reduces the percentage of the rotten wasted plant [20].

A supervision and control system that governs the growth of vegetables to lead to an optimum growth conditions are crucial to enhance the productivity of farming. Thus, the objectives of this study are to develop a HMI for monitoring and controlling system for a developed indoor lettuce farming prototype, and to evaluate the performance of the developed control and monitoring system in supervising and controlling the variables that govern the growth of vegetables that lead to optimum growth conditions.

2. Materials and Methods

2.1 System Design and Architecture

This section explains the whole process used to develop the supervisory and control for the developed indoor farming prototype. The prototype used DHT11 for temperature and humidity sensing, FC-28 for soil moisture sensing, Arduino Uno Ethernet Shield as microcontroller, LED spectral light for sunlight replacement, water pump for water control, a DC fan for the temperature control, and DS3231 clock module for performing actuator at a specific time as that illustrated in Figure 1. Arduino Uno was the primary component that communicated with the FC-28 and DHT11 sensors and displayed the reading on HMI so that the user can monitor the environmental conditions of the prototype. The FC-28 sensor used capacitance to measure the water content of soil by measuring the dielectric permittivity of the soil. In dry condition, the sensor gave an analog value from 0 to 300; in humid soil analog value was from 300 to 700; and if the sensor was in water, the analog value ranged 700 to 950. The water pump was triggered when the soil moisture was below 30% DHT11 used a capacitive humidity sensor and a thermistor to measure the humidity and temperature of surrounding air. The measurement range for DHT11 sensor is 20 to 90% for relative humidity and the accuracy ± 5% RH, 0 to 50 ºC for temperature and the accuracy is ± 2 ºC. The threshold value for temperature is set to 30 ºC. If the DHT11 sensor detects temperature equal or more than 30 ºC, the fan would be automatically turn on to reduce the temperature inside the prototype by air exchange.

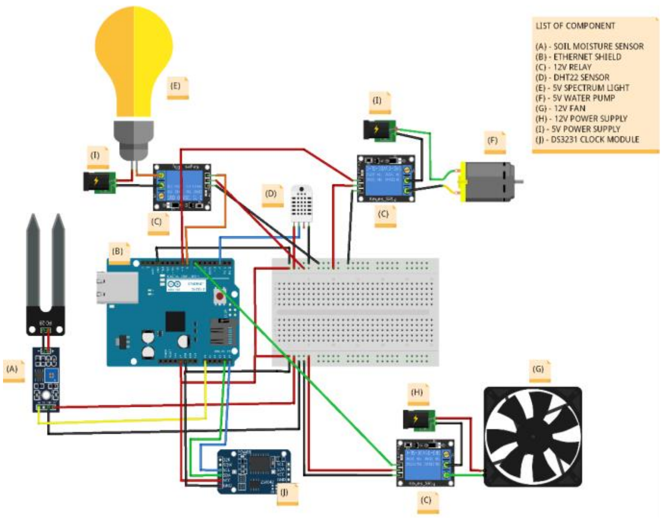


Fig. 1 - The block diagram of the proposed prototype

Figure 2 depicts the proposed layout of the prototype. The main task of this system was to help farmers to monitor their farm more effectively by controlling the farming conditions according to desired parameters. The recorded data that showed on HMI can be used as references to improve the quality and quantity of future production. Ethernet shield and RJ45 cable were used to communicate Arduino Uno with HMI on the laptop. Arduino Uno Ethernet shield was used to capture the data from the sensor to trigger the actuator and display to HMI. Spectrum light was set to turn on for 14 hours using the DS3231 clock module. All the sensors, spectrum light, DS3231, and water pump were powered by 5V that supplied from the Arduino Uno, while the fan used an external 12V power supply. All the data were display on HMI so the user can monitor the parameter without manually check it on a prototype.

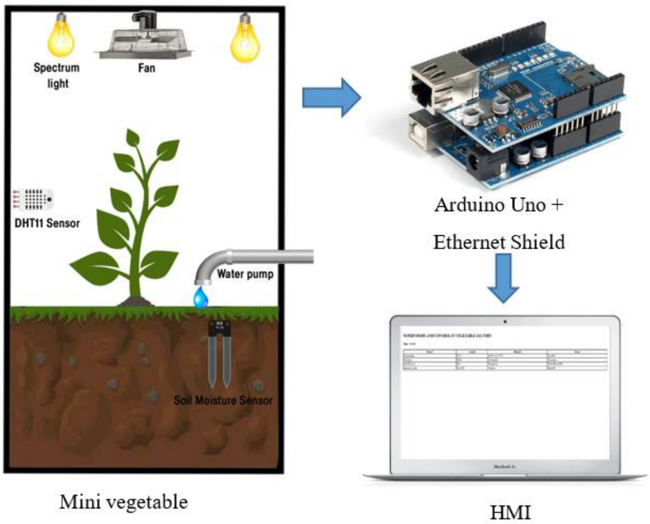


Fig. 2 - Layout of the proposed prototype

2.2 Human Machine Interface

The proposed HMI allows users to key-in their desired values of each parameter. HTML language was used to develop the webpage-based GUI. To open the developed GUI webpage (Figure 3), users can use an internet browser (e.g. Internet Explorer) and then type the IP address that set from the initializing the connection. The Arduino Uno communicated with the webserver so that the data from sensors and actuators were transmitted to the web server and lastly illustrated on the GUI. The last column is the action that automatically taken by the prototype to minimize the difference between the actual and the desired values of the parameters.

SENSOR	ACTUAL	DESIRED	ACTION
TEMPERATURE INSIDE	32°C	11°C to 30°C	FAN ON
HUMIDITY	60%RH	MORE THAN 35%RH	-
SOIL MOISTURE	20%	30%	WATERPUMP ON
SPECTRUM LIGHT	TIME= 10:36	ON 7AM TO 9PM	LIGHT ON

Fig. 3 - The design of the proposed webpage-based GUI for HMI. (Note: RH = relative humidity)

2.3 Overall Process

Figure 4 explains the overall process of the proposed system. The proposed system was started by initializing all the inputs and outputs (i.e. DHT11 and FC-28 are the input; and water pump, spectrum light and fan are the output). After that, it initialized the real-time clock module and the connection between Arduino Uno Ethernet shields and a laptop computer to display the data from Arduino to the HMI. DHT11 sensor was used to measure temperature and humidity inside the mini vegetable factory prototype, and the fan would be turned on if the measured temperature exceeded 30 ºC. FC-28 sensor was placed inside the soil to measure the level moisture of soil, and water pump would be turned on if the measured moisture was below than 30%. The duration of spectrum light was 14 hours and it would be automatically turned on or off because the real-time clock module was used to trigger relay at a specific time. All the data from inputs and outputs would be displayed on the HMI so the user can monitor the parameter in real time.

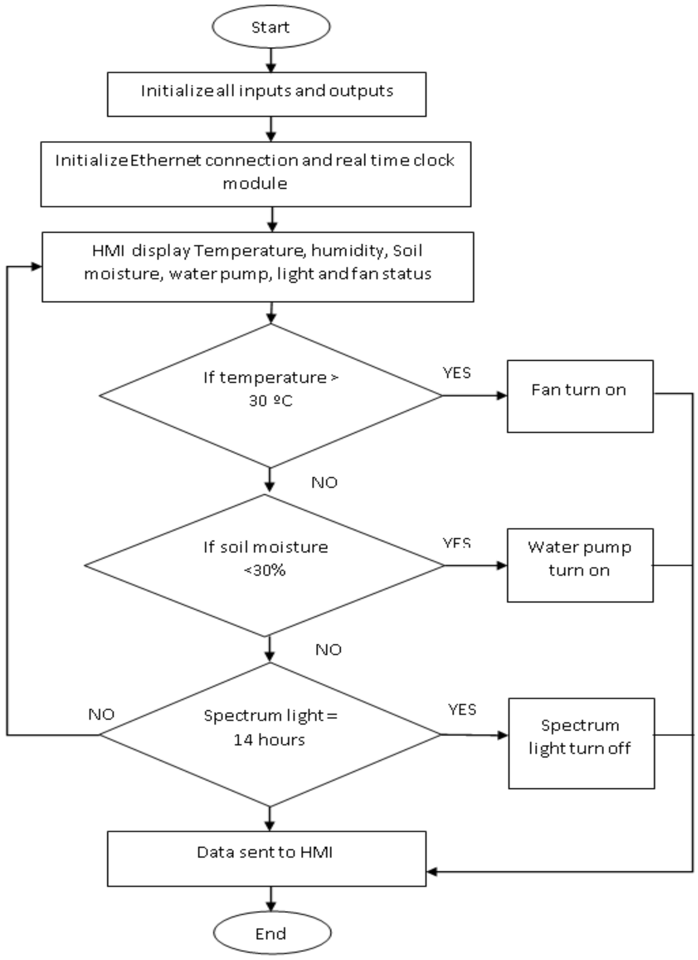


Fig. 4 - The overall process of the proposed system

2.4 Performance Evaluation

The proposed system was compared with a conventional farming method. For the conventional farming method, a plant pot was placed outdoor. The conditions e.g. light source would depend on natural sunlight and environment. There was not irrigation system in the conventional farming method, but we manually water it each day. In this study, the test plant was lettuce. The seed was sown in a pot (10 x 7 x 6.5cm, 25 seed per pot) containing a mix of soil (coco peat and organic). The soil used was 70% of coco peat soil and 30% of organic soil and then mix both soils. After filling the soil inside the plant pot, mist the top of the soil until the soil moist and place the lettuce seed inside the soil in the depth of 0.5cm to 1cm. For the light source, this system replaces sunlight with a LED array light. This LED array light contained four blue (i.e. from 420 to 500nm) and 10 red (i.e. 620nm to 750nm) LEDs. The light would be turned on for 14 hours (i.e. from 7.00 am to 9.00 pm) daily by using the DS3231 real-time clock module. For irrigation of this system, we used a drip irrigation system. The outlet of the water pump diameter pipe was 8mm and the drip was 5mm.

To evaluate the performance of the system, the data from DHT11 and FC-28 sensors were recorded. The data from DHT11 sensors was to evaluate the temperature control performance, while the data from FC-28 sensors was to observe how long it took soil to dry. The temperature and soil performance were observed for 3 days. For temperature control, the data was compared with the temperature by using traditional method. For conventional farming method, no data recorded for soil performance. The soil condition has been checked manually by using bare hand and water if the soil dry and it normally took 1 to 2 days for soil to be dried. With the system, the soil performance was recorded to evaluate how long it took the soil to dry and start watering again.

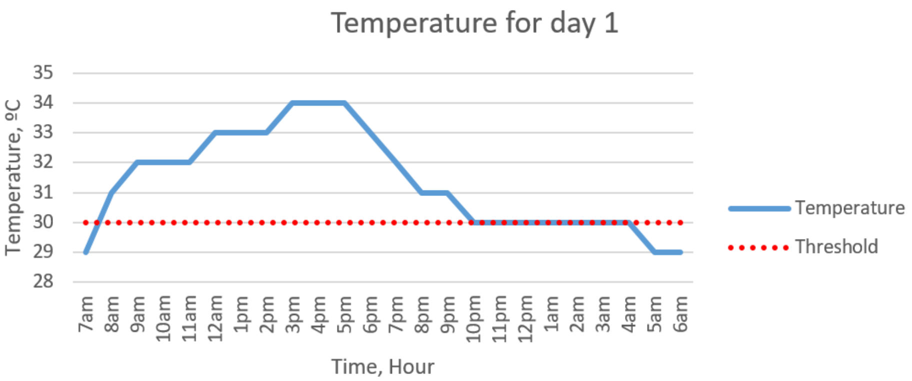
3. Results and Discussion

3.1 Temperature Control

Figure 5 illustrates that the range of temperature during the day and night were between 28 to 34 ºC and 30 to 33 ºC, respectively, for the conventional farming method in the outdoor for three days. This indicates that the natural temperature range was between 28 to 34 ºC. The threshold was the maximum temperature (i.e. 30 ºC) that needed by vegetable. If the temperature exceeded the threshold value, the temperature was not suitable for vegetable to grow optimally. Thus, a desired temperature should be below the threshold indicator. For day 1, the seed received 10 hours of optimum temperature that needed by seed to germinate. For day 2 and 3, the seed received 9 and 6 hours of optimum temperature, respectively. Table 1 shows a comparison between the proposed system and without the proposed system for three different days. The average temperature of the farming method without the proposed system was deviated more from the desired temperature (i.e. 30 ºC), compared to than that used the proposed system. Without the proposed system, the average temperature was 1.33 ºC to 2.5 ºC higher than the desired temperature that the seeds needed to germinate. With the proposed system, on the other hand, the average temperature was only higher 0.04 to 0.50 ºC than the desired temperature. Next, the total hourly cumulative error per day was significantly reduced when the proposed system was applied, i.e. from 14-20 ºC to 10-12 ºC. The total hourly cumulative error per day was computed by summing up the error in each hour per day. The error existed when the temperature was more than the desired temperature i.e. 30 ºC.

Table 1 - Descriptive statistics of the measured temperature and error percentage by using the proposed system and that without proposed system

	Without the proposed system			With the proposed system		
	Day 1	**Day 2**	**Day 3**	**Day 1**	**Day 2**	**Day 3**
Temperature range (ºC)	29 - 34	28 - 34	30 - 35	28 - 33	27 – 33	28 - 32
Average Temperature (ºC)	31.33	31.29	32.50	30.50	30.21	30.04
Standard deviation (ºC)	1.62	1.69	1.66	1.44	2.14	1.20
Total hourly cumulative error per day (ºC)	14	14	20	11	12	10



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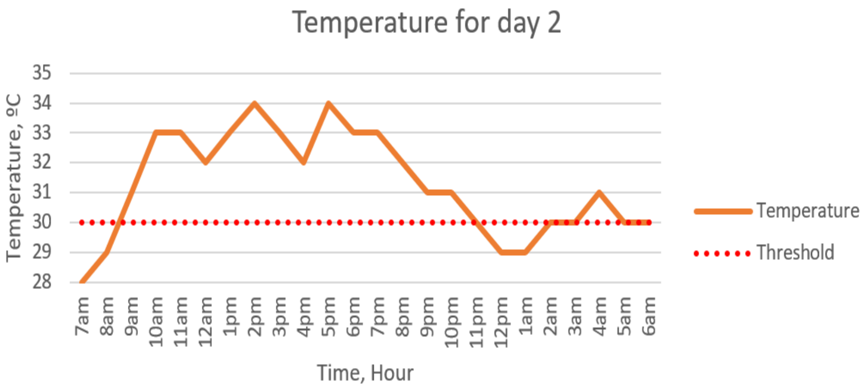

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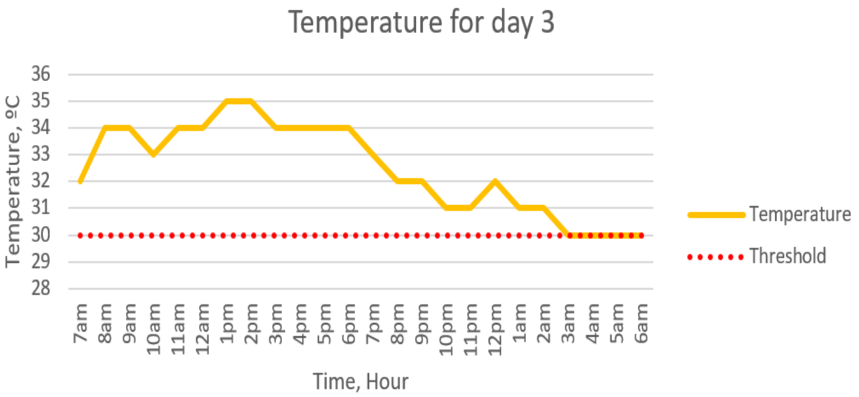
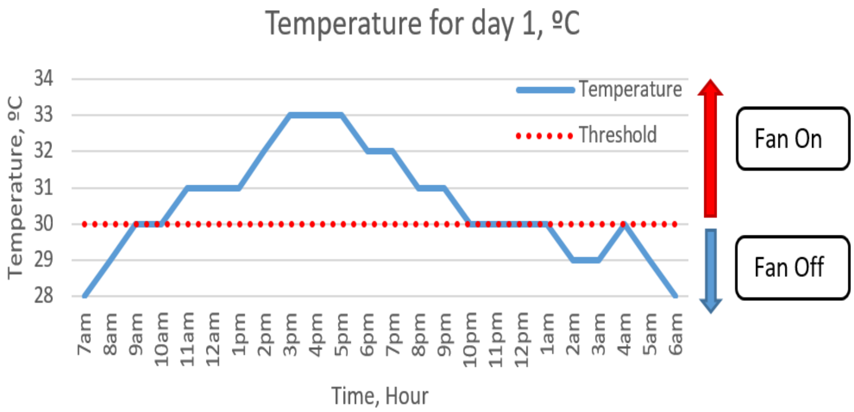


(c)

Fig. 5 - The measured temperature of the conventional farming method for the three days

Figure 6 shows the temperature that measured inside the prototype with the proposed system for three days. By inspection, the proposed system minimized the difference between the measured and the desired temperature compared to that without the proposed system (i.e. Figure 5). To grow a lettuce, the minimum temperature is 10.8 ºC and the maximum can be reached at 29.7ºC. For this system, the desired value set to 30 ºC because the sensor resolution is equal to 1. The fan was turned on when the measured temperature was more than the desired (a.k.a. threshold) value. Figure 6 also illustrates that the prototype can sustain 12 to 15 hours a day below the threshold value. The proposed system was able to maintain an optimum temperature for 13, 12, and 15 hours in day 1, 2, and 3, respectively. However, the measured temperature exceeded the desired value from 11 am to 10 pm. This could be due to the surrounding temperature that was high during daytime and the heat exchange mechanism by means of a fan was unable to reduce the temperature below the ambient temperature. Nevertheless, a better performance was obtained compared to that without the proposed system. Alternative that may improve the performance is using Proportional controller that was reported outperform to Logic controller and can maintain the desired temperature [22].



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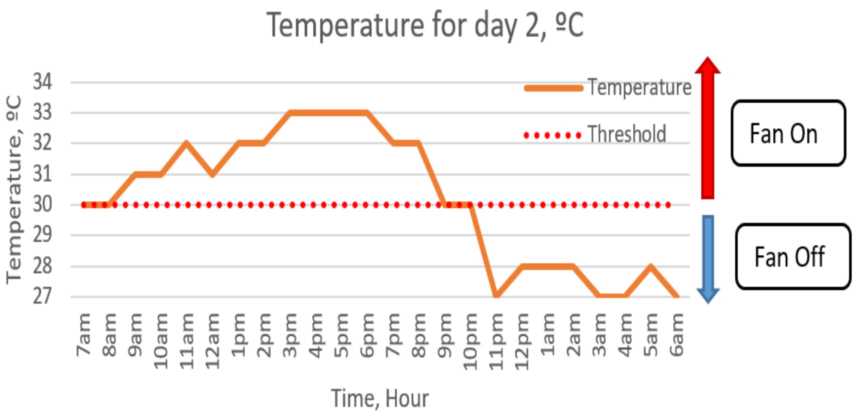

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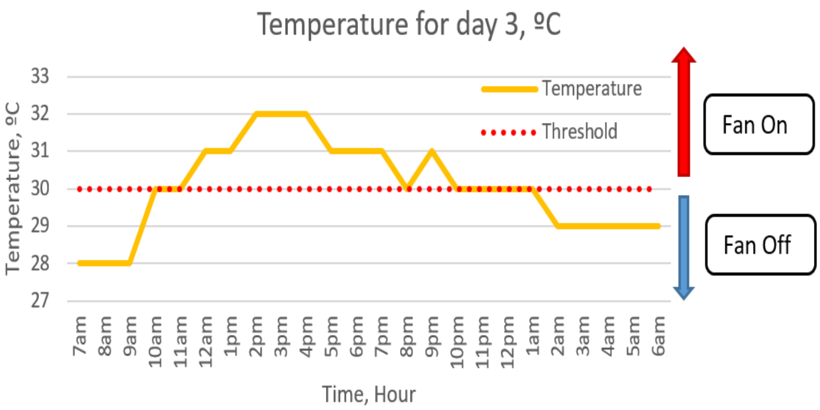
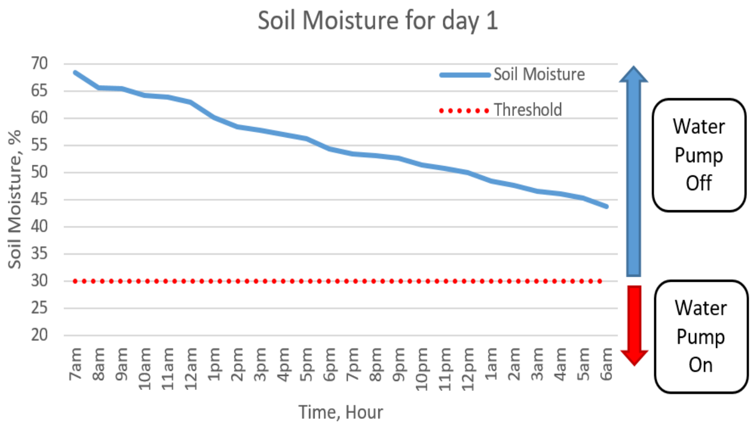


(c)

Fig. 6 - The measured temperature of the farming method with the proposed system for the three days

3.2 Soil Moisture Control

Figure 7 shows the measured soil moisture by FC-28 sensor for the prototype with the proposed system for three days. Soil took more than 32 hours to reduce its moisture to the 30%. On the first day, soil moisture was start from 0%. When the sensor detected the soil moisture was below the threshold, a water pump was activated to watering the soil until the measured soil moisture was more than 30%. From the experiment, the soil moisture would be around 68% when the water pump was activated and deactivated once. For the first day, the water pump was activated to supply water into soil because the reading was below the threshold and deactivated when the reading at 68.33%. For the first day, it took 32 hours before then next cycle of watering. The water pump was activated at 3 pm on day 2 and lastly, the water pump was activated at 1 am on day 3. With this system, we can accurately monitor the soil moisture condition with optimal moisture level. The threshold value can be set accordingly to avoid water overflow inside soil compared with the conventional farming method. This is because the system can display specific amount of water inside the soil and only start watering if the soil moisture was below the desired level.



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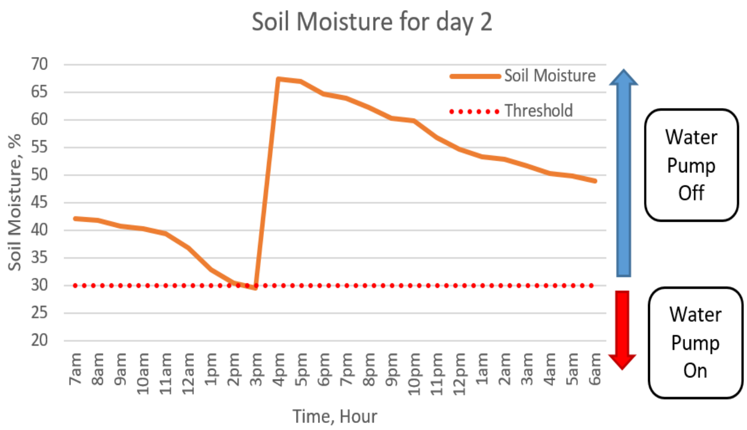

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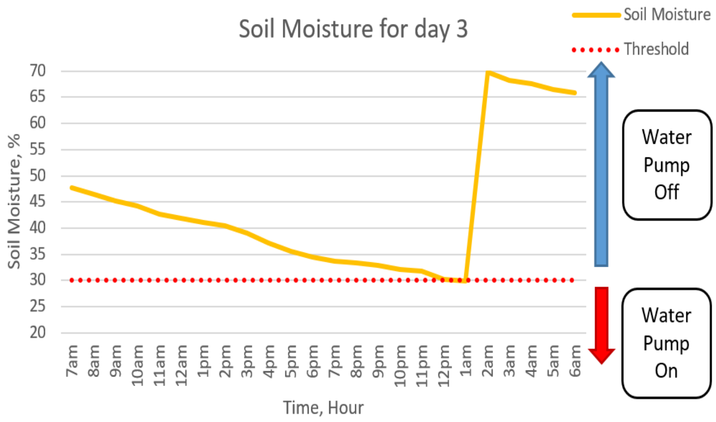

(c)

Fig. 7 - The measured soil moisture by FC-28 sensor

3.3 Lighting Control

For the performance of LED spectrum light control, the duration of the light in turn on condition was 14 hours, from 7 am to 9 pm each day. The duration can be adjusted according to the type of vegetable. This spectrum light contained two different wavelengths for red and blue, respectively. The color of spectrum light is important because it can affect plant growth. The blue light (i.e. 460nm) is important to develop the formation of chlorophyll, stomata opening and photomorphogenesis. The red light (i.e. 640nm) is vital to create photosynthetic in vegetables. The favorable light is a combination of red and blue light that has ranged between 460nm to 640nm. The performance of the spectrum light was accurate because the spectrum light was working based on the desired time. There is no delay when the light changing the state because the DS3231 real-time clock module was used in this system.

3.4 Seed Germinate

The preparation of seeds and soils was the same with the conventional farming method. The plant pot placed inside the prototype with the proposed system to control environment parameters of temperature, soil moisture, and lighting. The temperature range inside the vegetable factory was between 29 ºC to 34 ºC. For soil moisture, if the early reading of the sensor more than 60%, it would take 32 hours for the next watering cycle. In general, the proposed system was unable to germinate lettuce seeds successfully. This could be due to the mean temperature was from 30.04 ºC to 30.5 ºC while lettuce needs temperature from 10.8 to 29.7 ºC. This system was unable to maintain the optimum temperature for hours. The temperature treatment of more than 30 ºC might cause the effect of inhibitory on germination. The inhibitory effect causes the seed to produce ethylene during the germination period [21]. Nevertheless, the proposed system (Figure 8) can provide better environment conditions compare to the conventional farming method.

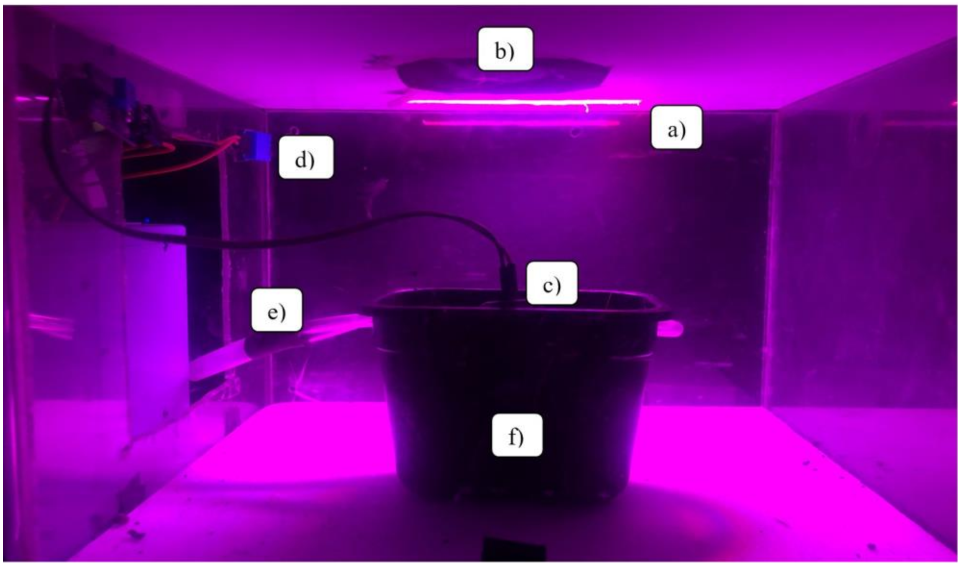

Fig. 8 - The prototype with the proposed system for indoor farming: (a) LED lighting; (b) fan; (c) moisure sensor; (d) temperature sensor; (e) watering pipe; and (f) planting pot

4. Conclusion

The proposed supervisory and control system for this prototype was successfully developed to control and monitor the temperature, soil moisture, and lighting duration for indoor farming. Results show that the proposed system provided better environmental conditions compared to conventional farming method. A Human Machine Interface (HMI) was developed to monitor and control the system in developing the prototype. The HMI can communicate with the Arduino ethernet shield and it successfully displayed all the parameters that regulate the growth of vegetables automatically according to the desired values. The proposed system was able to collect the measured temperature and soil moisture values for the purpose of evaluating the performance of this prototype and comparing it with the conventional farming method. The proposed system provides a longer optimum temperature duration that needed by vegetables and has lower averaged total hourly cumulative errors per day compared to the conventional farming method, i.e. 11 and 16 ºC, respectively. Besides that, the proposed system can display the soil moisture reading and watering automatically if the soil moisture was lower than the desired value. By using this system, environmental conditions can be automatically controlled and easier to be monitored by farmers. Since this proposed system can minimize the impact from unpredictable weather, the proposed system is promising to bring positive impact to the agricultural sector by providing better conditions for growing vegetables.

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