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SMART INDOOR GREENHOUSE MONITORING SYSTEM USING INTERNET OF THINGS

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Abstract— Growing indoor plants is an intricate task that needs a lot of attention to ensure healthy houseplants besides producing a good amount of yield. Many parameters including soil moisture and environment parameters such as humidity, temperature and light intensity need to be monitored for the healthy growth of the plant, hence requires a lot of effort. However, with the advancement in the Internet of Things technology, monitoring these parameters can be done without human intervention. Therefore, this work proposed a solution that creates a favourable environment for the plant using an Internet of Things-based system by monitoring the soil moisture and environment parameters such as humidity, temperature, and light intensity where these data will be uploaded to the cloud server for monitoring purposes. Besides, considering the tight schedule of most users, the system is integrated with an automatic watering, cooling and lighting system which will operate based on the monitored data. In this work, a microcontroller unit (MCU) is used to control the systems and a UBIDOTS server is used to perform the data logging system. A testbed experiment has been conducted for four weeks, and the results show that the proposed system has high reliability. Besides, the results also show that the height of the plant is increasing during the four weeks duration, hence showing that the system is working effectively even without human intervention.

I. Introduction

Plants are very important to the planet and living things. Plants absorb carbon monoxide and release oxygen for humans and animals to breathe. Besides, plants are also an important source of food for living things. However, maintaining the crops requires high maintenance, especially with climate change. This has been highlighted by several researchers, where environmental conditions such as temperature [1-7], humidity [8][9] and light intensity [10] are the factors that affect the growth of the plants. In addition to this, soil moisture [10] also plays an important role in the growth of the plant. Therefore, proper monitoring of these highlighted parameters for immediate action is needed to keep the crops healthy.

Greenhouse farming has been widely developed to promote sustainable food supplies globally besides controlling the growth of crops [11][12]. The greenhouse is a structure with transparent material for the wall and roof [13] which used the radiation of the sun to warm the plants and the air inside the house. This allows plants to be grown throughout the year regardless of their seasoned time. However, the traditional greenhouse agriculture system is still using an expert gardener where his/her role is to manually observe and monitor the growth of the plants. Hence, this is not an effective approach, as continuous supervision is required to produce good yields [14]. Therefore, the authors in [14] emphasize the importance of developing a systematic monitoring system to ensure that the crops are free from any contaminants and fit for human consumption. In addition, a systematic monitoring system will be beneficial to those who live in a high-rise building and wish to do indoor gardening. With this systematic monitoring system, multiple inspections can be performed without human intervention. This can be done by using sensors to measure and monitor the important parameters including the temperature, humidity, air composition, illumination, etc to ensure the best environment for the plant is created to grow and produce good yield [13]. Besides, the development of the systematic monitoring system will lead to the development of a digital greenhouse system where watering the plant will be automatically done based on the soil dampness, hence reducing water consumption [15]. As reported in [15], the digital greenhouse can help to reduce water consumption by 40% compared to the traditional greenhouse concept.

Several researchers have focused on the development of smart gardening systems [4], [15-19]. For instance, in [4], the author developed a smart gardening automation system using a microcontroller unit (MCU) to control and actuate the humidity, temperature and soil moisture of the plant. Also, the system used the Blynk application where all the monitored parameters will be sent to the cloud via WiFi communication technology for monitoring purposes and to activate the meter in the home gardening. In [16], the authors used an Arduino Nano microcontroller to control the developed smart irrigation system. The system used G-rail and wheel motor to move the system along the garden to monitor the humidity, temperature, soil moisture, and CO_2 levels in each section of the garden. Also, a solar panel is used to power up the system. However, the system only allows the in-charge person to monitor the real-time data stored in the HTML web and does not integrate with an automation system.

In [18], the authors developed an irrigation monitoring system to monitor only the soil moisture to optimize the usage of water. The system used a node MCU to control the system. Also, a mobile application is used to store real-time soil moisture data where the gardener can monitor the condition of the soil moisture and can manually control the flow of the water to water the plant. A test-bed implementation has been conducted under several scenarios and the results show that it has high reliability. Meanwhile, in [19], an automatic watering system based on the condition of the soil moisture has been developed using an Arduino microcontroller. The system has been tested using solenoid valves and a pump to water the plant and the results show that the solenoid valve is more energy efficient than the pump.

However, the work in [18] and [19] only consider soil moisture as a parameter to indicate the amount of water needed to manually water the plant and to automatically water the plant, respectively. In this work, a smart indoor greenhouse monitoring system has been proposed leveraging the concept of the Internet of Things to monitor real-time data of the soil moisture and the environmental parameter including humidity, temperature and light intensity. Besides, the system is also designed to perform an automatic watering, cooling and lighting system based on real-time monitored data, hence reducing dependence on humans.

II. The architecture of the IoT-based Smart Indoor Greenhouse Monitoring System

The architecture of the IoT-based smart indoor greenhouse monitoring system is composed of three main parts which are monitoring (i.e. yellow box), data logging (i.e. red box) and automation (i.e. green box) as shown in Figure 1. These three main parts are controlled by a microcontroller unit (MCU) node. The WiFi communication technology is used to perform the data transmission to the cloud server. Figure 2 shows the circuit diagram of the IoT-based smart indoor greenhouse monitoring system.

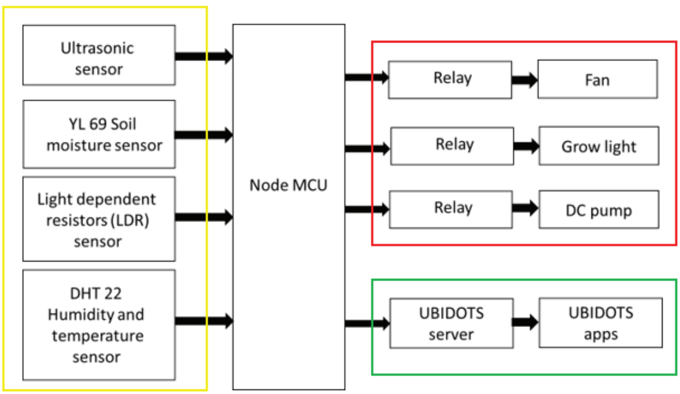

Figure 1: The architecture of the developed IoT-based smart indoor greenhouse monitoring system

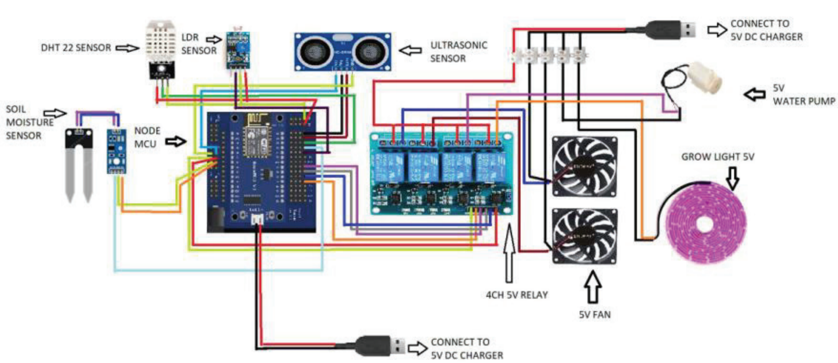

Figure 2: Circuit diagram of the IoT-based smart indoor greenhouse monitoring system

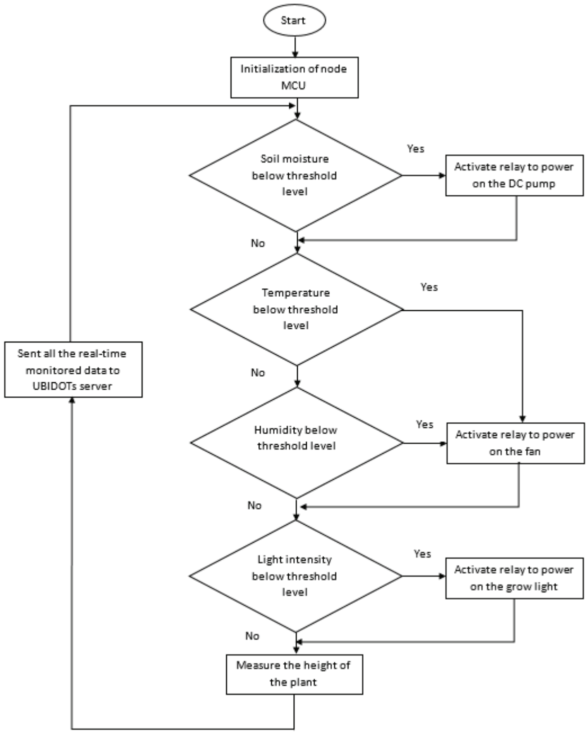

Figure 3: The flow system of the IoT-based smart indoor greenhouse system

In the monitoring part, the system will measure five main parameters which are the level of soil moisture (i.e. YL 69 sensors), the environmental parameters including the humidity and temperature (i.e. DHT 22 sensor), the level of light intensity (i.e. LDR sensor), and the height of the plants (i.e. ultrasonic sensor). It is worth noting that, the aim of monitoring the height of the plants is to measure the growth of the plants from time to time.

In the data logging part, all of the monitored real-time data including the soil moisture, the humidity, temperature and light intensity of the environment together with the height of the plants will be sent to the cloud server, i.e. UBIDOTS [20][21] every one-minute intervals via WiFi communication technology for monitoring, storage and analysis purposes. Moreover, all the stored data can be viewed via the UBIDOTS web user interface or the dashboard. This is essential for the user to monitor the condition and the growth of the plant.

Meanwhile, for the automation part, the system will power on and off the water pump, the grow light and the fan which is embedded in the system based on the real-time monitored data. For instance, the pump system will be powered on when the monitored level of soil moisture is low (i.e. < 75%) [25], the fan will be powered on when the temperature of the environment is high (i.e. > 24ºC) [22][23] or the humidity of the environment is low (i.e. <85%) [24] while the grow light will be powered on when the light intensity of the environment is low (i.e. < 2690 lx) [22]. Figure 3 illustrates the working flow of the developed system. It is worth noting that, the ultrasonic sensor is used in this system to measure the height of the plant.

III. Development of the IoT-based Smart Indoor Greenhouse System

A complete proposed model of the developed IoT-based smart indoor greenhouse monitoring system is shown in Figure 4. It is worth noting that, the structure of the prototype is fabricated using the PVC pipe. Meanwhile, we used transparent plastic to cover the structure to control the environment inside the greenhouse.

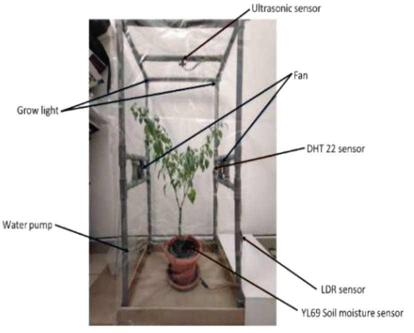

Figure 4: A complete prototype model of the IoT-based smart indoor greenhouse system

In this model, an ultrasonic sensor is placed in the middle of the roof to measure the height of the monitored plant. The temperature and humidity sensor, the DHT 22 is placed at the side of the greenhouse structure to measure the temperature and humidity of the environment. The LDR sensor is placed at the side of the structure of the model to measure the light intensity of the environment. Meanwhile, the soil moisture sensor is placed on the soil to measure the level of the soil moisture.

For automation purposes, a pump with a tube is placed on the soil to water the plant while the grow light is placed along the top side of the roof to increase the amount of light intensity if necessary. Also, two fans that function as an inlet and outlet for airflow are placed at the sides of the greenhouse structure.

IV. Results and Discussion

To evaluate the functionality and the performance of the developed IoT-based smart indoor greenhouse monitoring system in terms of its reliability, a testbed experiment has been conducted for 4 weeks duration. Note that, we considered a chilli plant with organic soil for the test-bed experiment. The chilli plant is considered relevant to the greenhouse setting as it benefits from the controlled environment, which enables temperature regulation, extends growing seasons, protects against pests and diseases, and enhances yield and quality. Recall that, in this work, the monitored data will be sent to the UBIDOTS server every one-minute interval for monitoring and analysis purposes. Figure 5 shows the overview of the developed UBIDOTS dashboard of the developed system.

Figure 5: Overview of the UBIDOTS dashboard of the developed IoT-based smart indoor greenhouse system

To ensure the functionality and reliability of the system, we evaluate the average height of the plant for each week for a 4-week duration. The result indicates that the height of the plant is increasing by 2 cm over the 4-week duration as shown in Figure 6. This shows that the developed system is functioning effectively even without human intervention.

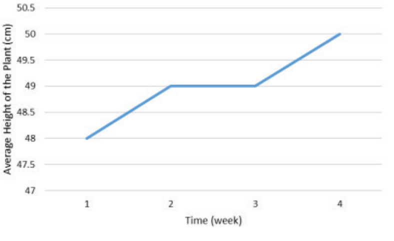

Figure 6: Average height of the plant for a 4-week duration under test-bed experiment

As mentioned earlier, the system is tested for a 4-week duration and each of the monitored parameters will be updated to the UBIDOTs server every one-minute interval. As the trend of the results is similar for each day over the 4-week duration, therefore, most of the results that we present in this section are based on the results of the 1-hour duration.

Table 1 shows the status of the soil moisture and the LDR sensor during the 1-hour duration (i.e. nighttime). The results show that the status of the soil moisture sensor is '0' for the 1-hour duration which indicates that the soil is damp. This shows that the water pump is functioning efficiently. Also, based on the observation for the 4-week duration, the pump will be powered on every morning each day to water the plant as shown in Figure 7, hence the status of the soil moisture sensor is '0' as in Table 1. However, the number of watering plants may differ based on the amount of the soil and the type of the plant.

Table 1: The real-time monitored status of the soil moisture and the LDR sensors

Time (PM)	Status Soil/LDR	Time (PM)	Status Soil/LDR	Time (PM)	Status Soil/LDR	Time (PM)	Status Soil/LDR	Time (PM)	Status Soil/LDR	Time (am)	Status Soil/LDR
8.00	0/1	8.11	0/1	8.22	0/1	8.34	0/1	8.45	0/1	8.56	0/1
8.01	0/1	8.12	0/1	8.23	0/1	8.35	0/1	8.46	0/1	8.57	0/1
8.02	0/1	8.13	0/1	8.24	0/1	8.36	0/1	8.47	0/1	8.58	0/1
8.03	0/1	8.14	0/1	8.25	0/1	8.37	0/1	8.48	0/1	8.59	0/1
8.04	0/1	8.15	0/1	8.26	0/1	8.38	0/1	8.49	0/1	9.00	0/1
8.05	0/1	8.16	0/1	8.27	0/1	8.39	0/1	8.5	0/1		
8.06	0/1	8.17	0/1	8.28	0/1	8.4	0/1	8.51	0/1		
8.07	0/1	8.18	0/1	8.29	0/1	8.41	0/1	8.52	0/1		
8.08	0/1	8.19	0/1	8.3	0/1	8.42	0/1	8.53	0/1		
8.09	0/1	8.2	0/1	8.32	0/1	8.43	0/1	8.54	0/1		
8.10	0/1	8.21	0/1	8.33	0/1	8.44	0/1	8.55	0/1		

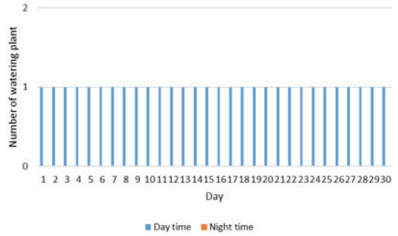

Figure 7: Number of watering the plant for a 4-week duration under test-bed experiment

It is also worth noting that, the results in Table 1 also show the LDR status is '1' during the 1-hour duration. This is because the plant is located inside a room. Therefore, during the night time, the light intensity is below the threshold value, hence triggering the LDR sensor to be '1' and the grow light to power on. In addition to this, Figure 7 and Figure 8 show the monitored data of the humidity and the temperature of the environment for the 1-hour duration (i.e. nighttime). Note that, these data are updated to the cloud every one-minute interval. The results show that the percentage humidity of the environment is 99.9% while the temperature is between 27.7°C and 28°C as indicated in Figure 8 and Figure 9, respectively. It is worth noting that, during this duration, the fan is powered off as both data are below the threshold value.

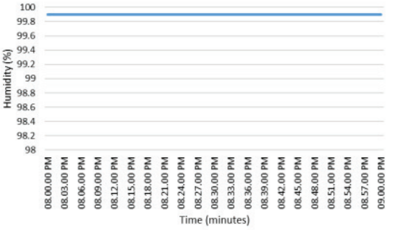

Figure 8: The real-time monitored humidity level for a one-hour duration

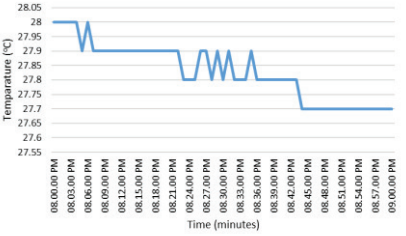

Figure 9: The real-time monitored temperature data for a one-hour duration

V. Conclusion

In this work, an IoT-based smart indoor greenhouse monitoring system has been proposed to monitor the important parameters which are soil moisture, and environmental parameters including temperature, humidity and light intensity. Based on the four monitored parameters, the system will trigger the relays to control the function of the water pump, fan and grow light to ensure the monitored data does not exceed the threshold values of the soil moisture, temperature and humidity and the light intensity, respectively. In addition to this, all the monitored data will be updated to the cloud for monitoring purposes. A test-bed experiment has been conducted for a 4-week duration without any human intervention, to show the effectiveness and the reliability of the system. The results show that the system has high reliability in updating the monitored data to the cloud every one-minute interval. Besides, the results also show that, during the 4-week duration, the automation system (i.e. water pump, fan and grow light) is working effectively based on the monitored data. Also, the height of the plant is measured during the experiment and the results show that the height of the plant is increasing by 2 cm. This shows that the proposed indoor greenhouse system is scalable and applicable to households and can also be extended for agricultural purposes.

VI. Acknowledgement

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