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Dual Mode Solar Power for IoT based Smart Farming System

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Abstract: The agricultural sector's upheaval is experiencing a momentous surge, bolstered by urbanization and the proliferation of Internet of Things (IoT) technology. The use of modern information and communication technologies has led to increased efficiency in smart farming, resulting in improved productivity and plant quality with minimal human intervention. This paper introduces a smart farming system based on the Internet of Things (IoT) and powered by a dual-mode solar system, fitted with agriculture sensors for data collection from plants, including parameters like soil moisture, temperature, and pH levels. The data is transmitted to the IoT cloud for analysis and display on two IoT platforms, ThingSpeak and mobile Blynk application. A dual-mode solar power integrated in the system, together with an irrigation unit capable of watering the plants automatically or manually, enables seamless switching from solar to wired power in the event of inadequate solar energy. The objective of this initiative is to equip farmers with an affordable smart farming system using renewable energy. This enables them to monitor crop data in real-time and conduct comprehensive analyses to efficiently use water resources. This paper presents a resilient model of the IoT-based smart farming system.

Keywords: *Solar power, Smart Farming System, IoT*

1. Introduction

The exponential growth of the world's population and the subsequent increase in demand for food has made agriculture to become one of the most prominent industries. The advancements in technology have allowed the industry to evolve in order to meet the world's needs for food. Modern farming equipment and devices, developed with the integration of the Internet of Things (IoT), are designed to improve crop quality and production. In pursuit of sustainability, precision agriculture is being extensively adopted in the agricultural sector, with an increasing number of farms incorporating farming sensors to oversee crop quality and soil conditions, thus guaranteeing optimal utilization of resources like water consumption [1].

With the incorporation of sensors, farmers are now able to monitor crop conditions and allocate resources only when necessary, resulting in a boost in operational efficiency. An IoT-based smart farming architecture includes soil parameter sensors, a data collection and storage platform, a data visualization and interaction application, and analytical tools to further scrutinize the data. The advent of contemporary technology has facilitated the ability of farmers to monitor their crops remotely through smartphones, enabling them to run statistical predictions for both crops and livestock.

By incorporating IoT technology with sensors and an irrigation system, this project enables farmers to remotely gather real-time data on their plants. This can be done just from their smartphones so they can carry out in-depth analysis. The project's irrigation system is designed to automate plant watering, reducing the need for constant monitoring of soil moisture levels and enabling efficient utilization of water resources. Moreover, the utilization of solar energy enhances the system's mobility and promotes sustainability in the environment.

2. Method

The central focus of this project is on the implementation of IoT and the application of sensors to monitor and water the crops remotely. The sensor system of smart farming comprises three distinct types of sensors that gather data on three significant soil parameters. The attributes are soil moisture, temperature, and fertility. To automate plant watering, an irrigation unit comprising a water pump, relay switch and battery, has been integrated into the system. Temperature sensor to measure soil temperature. Moisture sensor to measure soil moisture level. Lastly, a pH probe sensor to determine soil pH levels to indicate its fertility. The NodeMCU WiFi microcontroller is the heart of the system, controlling the sensors, irrigation and wireless data transmission to IoT platforms through the internet. The dual-mode power feature comprises solar unit and wired power functions to power the primary system which includes the microcontroller interchangeably depending on the availability of solar energy.

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The smart farming system operates by having the sensors monitor the soil condition and transmit real-time data to the IoT cloud. Then, farmers can track and access the data gathered on IoT platforms through the ThingSpeak website or Blynk mobile application. The irrigation system operates on autonomous and non-autonomous modes.

1. Autonomous mode: When soil moisture level reaches the designated threshold, the algorithm will signal the irrigation system to water the plants automatically.
2. Non-autonomous mode: farmers can opt to manually initiate the water pump by pressing a dedicated button on the app.

This comprehensive system covers all essential aspects of the smart farming system as it operates sustainably with the efficient use of resources and is powered with renewable energy.

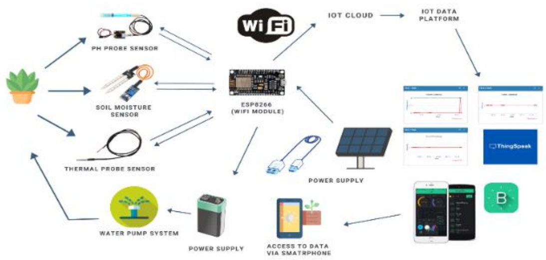

Fig. 1. Block diagram of IoT smart farming system

The block diagram of the smart farming system is shown in Figure 1, which provides an overview of how all the components are connected and operate together. The pH probe, soil moisture, and thermal probe sensors collect plant data, which is then gathered by the NodeMCU.

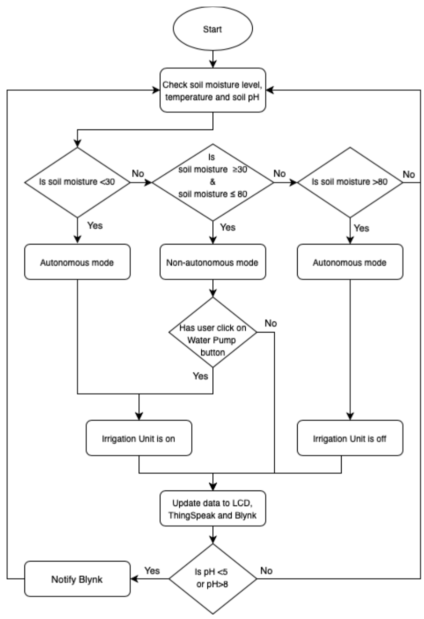

Fig. 2. The flowchart of smart farming system

The microcontroller effectively acquires data from the sensors to be transmitted to the IoT cloud, which is then conveyed to the two IoT data platforms. These platforms provide users a live data feed of their crops and facilitate further analysis by visualizing them in graphical format. When the soil moisture level falls below the predetermined threshold, the microcontroller will trigger the 9V battery-powered water pump to automatically start watering.

Figure 2 depicts the overview mechanism of the smart farming system. Initially, the system examines the soil moisture level. If it fails to meet the requisite level, the system enters autonomous mode. The irrigation unit is activated and the plant is watered.The soil moisture data is recorded to the IoT cloud. Once the soil moisture level is within optimal range, the system enters non-autonomous mode. Users can now manually control irrigation to their needs. Lastly, if the soil is overwatered, the system enters back to autonomous mode to turn the irrigation unit off. This blocks user manual control until the soil moisture level drops below threshold.

Figure 3 showcases the complete working smart farming system prototype. The LCD and solar panel are embedded on top of the case to display data of the soil attributes and harnessing solar energy respectively. The prototype of smart farming with the integrated water pump is shown in Figure 4.

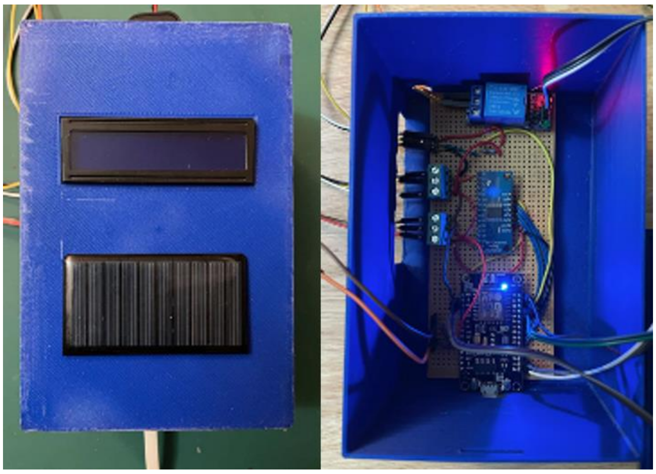

Fig. 3. Prototype of IoT smart farming system

Fig. 4. Prototype of smart farming system with the irrigation unit

To implement a more sustainable system, this project utilizes solar energy as an alternative power source. The dual-mode feature powers the microcontroller unit allowing the main system to operate with solar power. In instances where there is no sunlight, the main system can rely on wire-connected power. The solar power unit comprises three components to power up the prototype.

The solar power unit is shown in figure 5. It comprises a solar panel, a solar charger board and two Li-ion rechargeable batteries connected to the NodeMCU microcontroller. The red LED indicator on the charger board is signifying that the solar cell is charging the lithium batteries. The LED on the NodeMCU microcontroller lights up signifying it is powered up by the solar cell unit.

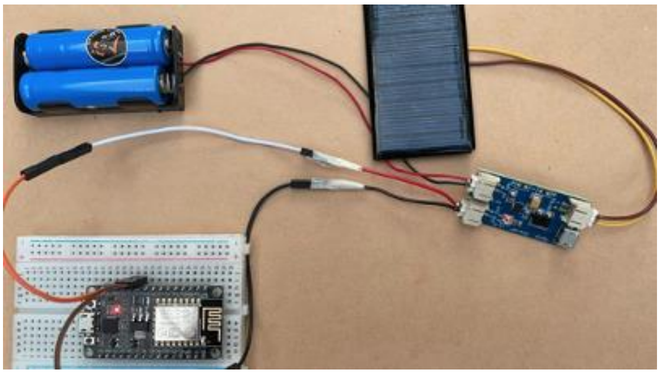

Fig. 5. The smart farming solar power unit

Calculating the NodeMCU average power consumption (*In reference to the datasheet of NodeMCU Lolin V3 ESP8266*):

$$3.3V * 100mA = 330mW$$

Based on this, the smart farming system requires about 0.33W to power up the microcontroller. After additional calculations with the assumption that the solar panel receives full sunlight throughout the day, it has been ascertained that the solar cell is capable of powering both the microcontroller and the system.

A Solar Charging Battery Capacity Estimator was utilized to assess the solar power unit's capacity to energize the system. The simulator was configured to run a five-day scenario, which assumed the system would be entirely powered by the solar power unit. The outcome of the simulation revealed that the NodeMCU could sustain operation for approximately one day with only the solar power unit. Consequently, the system prototype was engineered so that it can be powered interchangeably with either solar power or a wired power supply. In this regard, during the daytime, the solar power unit can energize the prototype and simultaneously charge the lithium batteries. In the absence of sunlight, the prototype is then powered by the lithium batteries and the MicroUSB cable.

3. Results

Several experiments were conducted to test the system prototype to collect data of plants for over a week, which was subsequently updated and displayed on the ThingSpeak. The collected data was then analyzed and visualized using graphs, after which the results were exported to Excel sheets.

To ensure accurate sensor readings, the sensor positions were analyzed prior to the data collection process. In order to determine the optimal location for implanting the sensors, several parameters are set. Initially, a soil moisture sensor was inserted into the soil to assess the soil water retention capacity with respect to distance. Next, 200 ml of water was poured into the soil and the soil moisture measurements were recorded at one-centimeter intervals originating from the epicenter of the water source.

According to Figure 6, the graph depicts soil moisture readings at 100% within the first 5 centimeters from the center of the water source. To maintain precision in moisture readings and uniform watering of the soil, the sensor is implanted at a distance greater than 5 cm from the center.

Figure 7 presents the data on soil moisture as a function of time, which was gathered over the course of a week by the plant sensors and subsequently logged onto the ThingSpeak IoT platform.

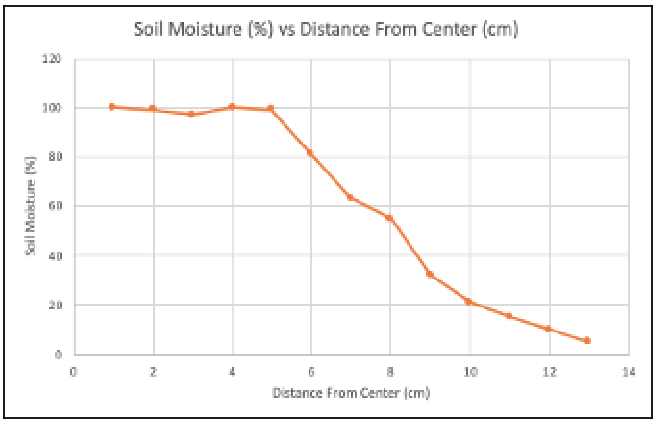

Fig. 6. Graph of Soil Moisture (%) vs Distance (cm)

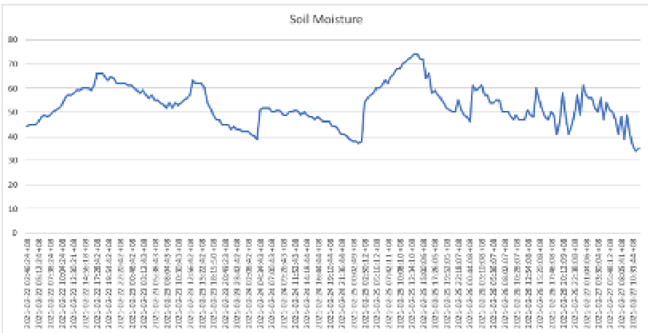

Fig. 7. Graph of Soil Moisture versus Time

Next, the second experiment is conducted to collect soil moisture data. The readings are recorded every hour for over a week then calculated and presented in percentage.

From the graph, soil moisture level is consistently below 80% which signifies that the system did not overwater the soil and the moisture level is within the optimal moisture range. The trend of the graph shows a decrease in soil moisture over time, followed by a quick rise, indicating that the system waters the plant automatically when the moisture falls below the programmed threshold.The system's ability to monitor soil moisture and prevent under-watering was demonstrated by the soil moisture data being consistently maintained within the optimum range of no less than 33%.

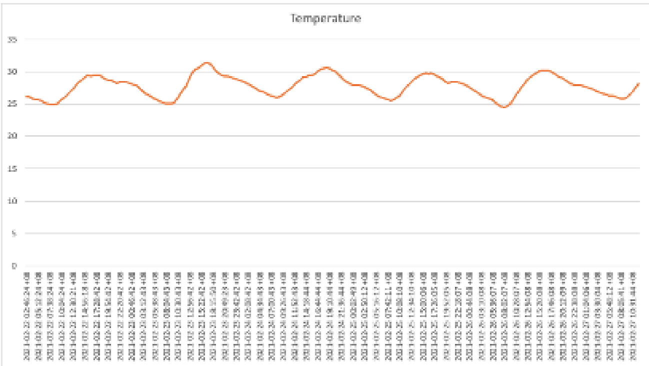

Fig. 8. Graph of Temperature versus Time

The third experiment is conducted to measure soil temperature over a week. The temperature of the soil where the plant was grown in Kuala Lumpur, Malaysia, in January, was recorded and graphed above. The experiment was conducted under partial shade, with sufficient sunlight exposure.

The graph displays a consistent pattern of soil temperature throughout the week, with temperatures peaking during the day and gradually decreasing as the sun sets. The highest temperature recorded during the day was 32℃, while the lowest temperature was 24℃. This indicates that the soil temperature range is within the optimal range for healthy plant growth and does not pose a threat of overheating or drying out.

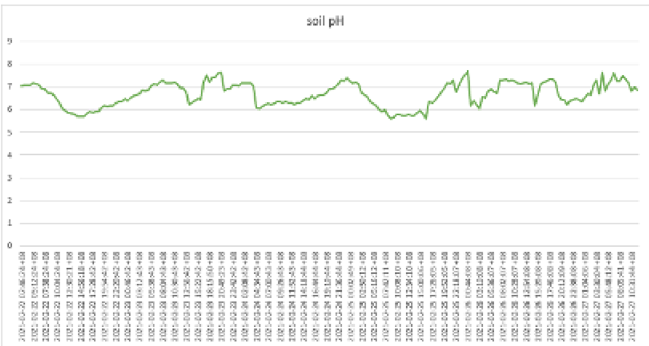

Fig. 9. Graph of Soil pH versus time

The fourth experiment was conducted to measure soil pH levels. The illustrated data in Figure 9 portrays the soil pH level readings over a week against time. Soil pH level, which is a significant parameter for soil fertility assessment, provides insights into the soil's nutrient availability.

The graph indicates that the soil pH level remains within 5.6 and 7.7, with minor fluctuations throughout the experiment. Based on research made, the ideal pH range for optimum plant growth is between 6 to 7. The collected data demonstrates that the soil pH level lies within this range. The soil is fertilized twice during the week, in accordance with the recommended guidelines, which contributes to significant changes in the pH values. However, slight deviations in the readings may be attributed to the pH sensor's sensitivity.

In order to assess the efficiency of the water-saving capabilities of the system, an additional experiment was conducted. This experiment used two identical plants placed in identical pots. This was done to compare the amount of water used to water the plants using two different systems for over five days in a controlled environment. The plants were placed under a shade exposed to rainwater. One set was watered by the smart farming system. The other set was watered manually twice a day at scheduled times using a watering can. Figure 10 illustrates a visual comparison of both plants. The experiment procedure is explained below:

<u>Smart Farming System</u>

(a) The smart farming algorithm is equipped with a counter that tracks the number of times the system waters the plant in every 24 hours.

(b) After 24 hours, the counter resets.

(c) The water pump is turned on to water the plant for 3 seconds each time.

(d) Throughout the 5 days, the same amount of water dispensed by the system (based on the counter value) is collected into a small bottle and the results are recorded.

<u>Scheduled Watering System</u>

(a) At every 8am and 5pm, the plant is watered manually for 3 seconds.

(b) The amount of water used to water the plant is collected in a bottle after each watering session and the results are recorded.

Fig. 10. Plants growth under the scheduled watering system (on the right) versus smart farming system (on the left).

Figure 10 presents a comparative analysis between the plants under two watering methods. The corresponding results are tabulated in Table 1. In 5 days, the smart farming system consumed a mere 240 ml of water while the scheduled watering utilized 480 ml of water. This shows that the smart farming system uses significantly less water compared to the scheduled watering system. The system demonstrated its efficiency by abstaining from watering the plant on two rainy days, as the soil moisture was adequate. Conversely, the other plant was watered before the rainfall and only stopped after raining. Consequently, it is evident that the smart farming system optimizes the usage of water resources by utilizing them judiciously and only when necessary, unlike the traditional method.

Table 1. Smart farming system versus the scheduled watering system on the water usage

Days	Water usage (ml)	
	Smart Farming System	Scheduled Watering System
1	110	120
2	80	120
3	0	60
4	0	60
5	50	120
Total	240	480

4. Conclusion

This paper discusses the development of an affordable smart farming system that uses renewable energy and promises thousands of benefits when implemented in the agricultural sector. The project aims to assist family, small, and large-scale farmers in monitoring crop conditions and accessing crop data. This data is essential for other smart farming practices such as data analysis and decision-making. The system is designed to enable farmers to wirelessly monitor their crop conditions and remotely irrigate them when suitable conditions arise. The irrigation system is automated to activate the water pump if the soil moisture level falls below a predefined threshold.

The integration of IoT into this system allows data on all these soil attributes to be transmitted to the IoT cloud and displayed in real-time on IoT platforms for analysis.

The incorporation of a dual-mode power feature enables the smart farming system to function using both solar and wired power sources, thus ensuring continuous functionality in the absence of solar power. The utilization of solar power not only reduces the system's carbon footprint but also establishes it as a sustainable innovation. This project promises to revolutionize the agricultural industry by opening up more possibilities for greater technological advancements.

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Author contributions

Iskandar Zulkarnaen: Conceptualization, methodology, validation, formal analysis, investigation, writing—original draft preparation, visualization. **Chu-Liang Lee:** Conceptualization, writing—review and editing, supervision, project administration, funding acquisition. **Gwo-Ching Chung**: writing—review and editing, supervision. **Sew-Kin Wong:** writing—review and editing, supervision. **Kah-Yoong Chan:** writing—review and editing.

Conflicts of interest

The authors declare no conflicts of interest.

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