

Automated PV Irrigation System for Red Chili

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Abstract

This paper presents the development of an automated photovoltaic (PV) irrigation system designed specifically for red chili cultivation. The system combines renewable energy with IoT-based real-time monitoring to enhance water efficiency and support sustainable farming. A 50W solar panel powers essential components including the ESP32 microcontroller, soil moisture and rain sensors, and a DC water pump. The system intelligently controls irrigation based on real-time soil moisture and rain detection, reducing water wastage. Monitoring and alerts are managed via Blynk and Telegram. Experimental results under different solar panel orientations (horizontal, vertical, 45°) show that optimal performance is achieved at a 45° angle. This integration enables low-cost, efficient irrigation suitable for small-scale farmers, aligning with sustainable agricultural goals.

1. Introduction

Smart agriculture has gained widespread attention as a modern solution to challenges in traditional farming, offering improvements in productivity, sustainability, and resource efficiency. By leveraging Internet of Things (IoT) technologies and automation, farmers are now able to monitor environmental conditions and control agricultural systems in real-time, enabling data-driven decisions that optimize crop management [1]. Among the crops that benefit significantly from such precision techniques is red chili (*Capsicum annuum*), which is both economically valuable and sensitive to improper irrigation and fertilization. Conventional manual methods often lead to inconsistent water and nutrient delivery, which can affect plant health and reduce yield [2]. Therefore, a system that ensures accurate fertigation tailored to the crop's needs is essential for improving output and reducing resource wastage. In parallel, the use of solar photovoltaic (PV) technology in agriculture offers a clean, sustainable, and cost-effective energy source especially suitable for countries like Malaysia that receive high solar irradiance throughout the year [3]. The integration of PV energy with automated systems provides an off-grid solution for farms in rural areas where access to electricity may be limited. This project aims to design and implement a solar-powered automated irrigation and fertilization system specifically for the cultivation of 300 red chili plants. The system utilizes Arduino-based control along with IoT sensors to monitor soil moisture levels and weather conditions, automatically mixing and distributing fertilizers A and B in proper proportions. By minimizing water and fertilizer waste, while enabling remote monitoring through platforms like Blynk and Telegram, the system is expected to enhance overall farming efficiency and support sustainable agricultural practices [4].

2. Methodology

To develop the system, both hardware and software components were integrated to create a solar-powered automatic irrigation setup specifically for red chili plants. The system operates using a 50W solar panel connected to a 12V rechargeable battery via a charge controller, supplying energy to all components. At the heart of the

system is the ESP32 microcontroller, which receives input from a soil moisture sensor and a rain sensor to determine when irrigation is needed. When dry soil is detected and there's no sign of rain, the system automatically activates a DC water pump to deliver water. The control logic was programmed using Arduino IDE, and the system also features an LCD screen for local monitoring. To keep users informed remotely, data is displayed through the Blynk application, and status updates like "Pump Active" or "Rain Detected" are sent via Telegram. Sensor calibration, battery usage, and solar energy performance at different angles (horizontal, vertical, and 45 degrees) were tested to optimize efficiency and ensure reliable operation in real conditions. This project utilizes a capacitive soil moisture sensor due to its cost-effectiveness, low power consumption, and seamless integration with the ESP32 microcontroller, making it well-suited for small-scale and rural agricultural applications. However, the system architecture is designed with modularity to accommodate future enhancements, including the integration of more advanced sensors such as Time Domain Reflectometry (TDR), Frequency Domain Reflectometry (FDR), pH and Electrical Conductivity (EC) sensors, or even AI-based modules to improve accuracy and expand system capabilities.

Fig.1 shows the circuit sketch diagram of how the microcontroller works. When the microcontroller is powered up, the monitoring input, soil sensors will start to read the soil conditions and send the data to the microcontroller to be processed. The status of soil conditions will be uploaded and displayed to the IoT platform, Blynk App. For the current and voltage sensor read the data from load and PV panel and display the value at Blynk.

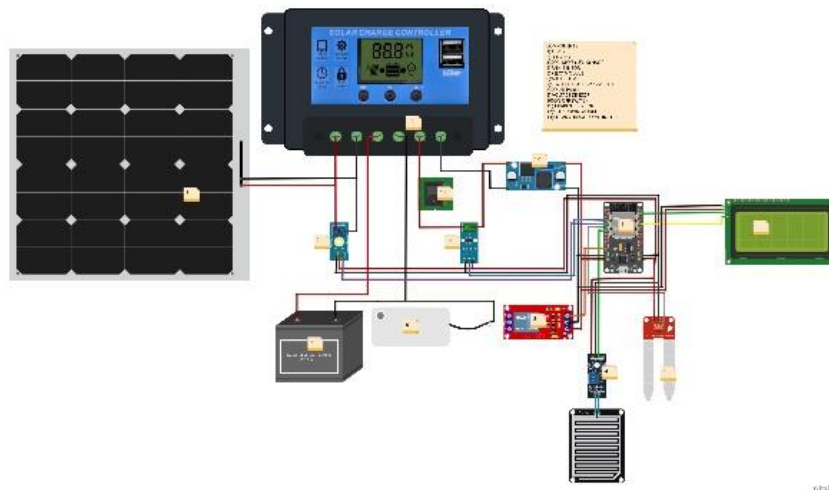


Fig. 1 Diagram of Automated PV Irrigation System for Red Chili

Fig.2 illustrates the system block diagram illustrates the overall architecture of the solar-powered automated fertilizer and irrigation system. The core of the system is the ESP32 microcontroller, which receives input signals from soil moisture and rain sensors. These sensors monitor environmental conditions in real-time. Based on the sensor readings, the microcontroller sends output signals to control a DC water pump via a relay module, ensuring irrigation occurs only when the soil is dry and no rainfall is detected. Power is supplied by a 50W solar panel, which charges a 12V lead-acid battery through a solar charge controller. The battery powers all system components, enabling it to function off-grid. Additional features include an LCD display for real-time local monitoring and IoT communication through the Blynk application and Telegram alerts.

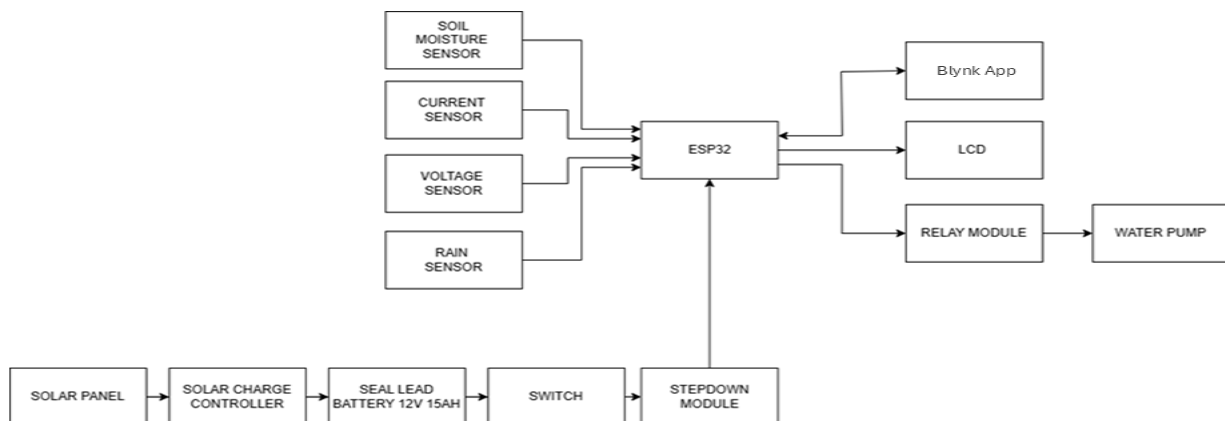


Fig. 2 Block Diagram of Automated PV Irrigation System for Red Chili

Fig.3 shows the the flowchart begins with the system initialization process, during which the device connects to Wi-Fi and links to the designated web application. Once connected, it reads data from several sensors, including a timer pump, rain sensor, soil moisture sensor, as well as solar voltage and current load. This collected data is both displayed on the LCD and transmitted to the web application for monitoring. The system then checks three key conditions in parallel. First, it verifies whether the timer pump is active; if not, the pump remains off. If the timer is triggered, the system further checks whether rain is detected and if the soil moisture is below 30%. If both conditions are true, the water pump activates for 10 seconds to irrigate the soil. Simultaneously, if the soil moisture level drops below 30%, a notification is sent to the web application alerting "soil moisture below 30%". Likewise, if rain is detected, the system sends a "rain detected" message to the web application. After each decision process, the system returns to its monitoring state, ensuring efficient irrigation control based on real-time environmental data.

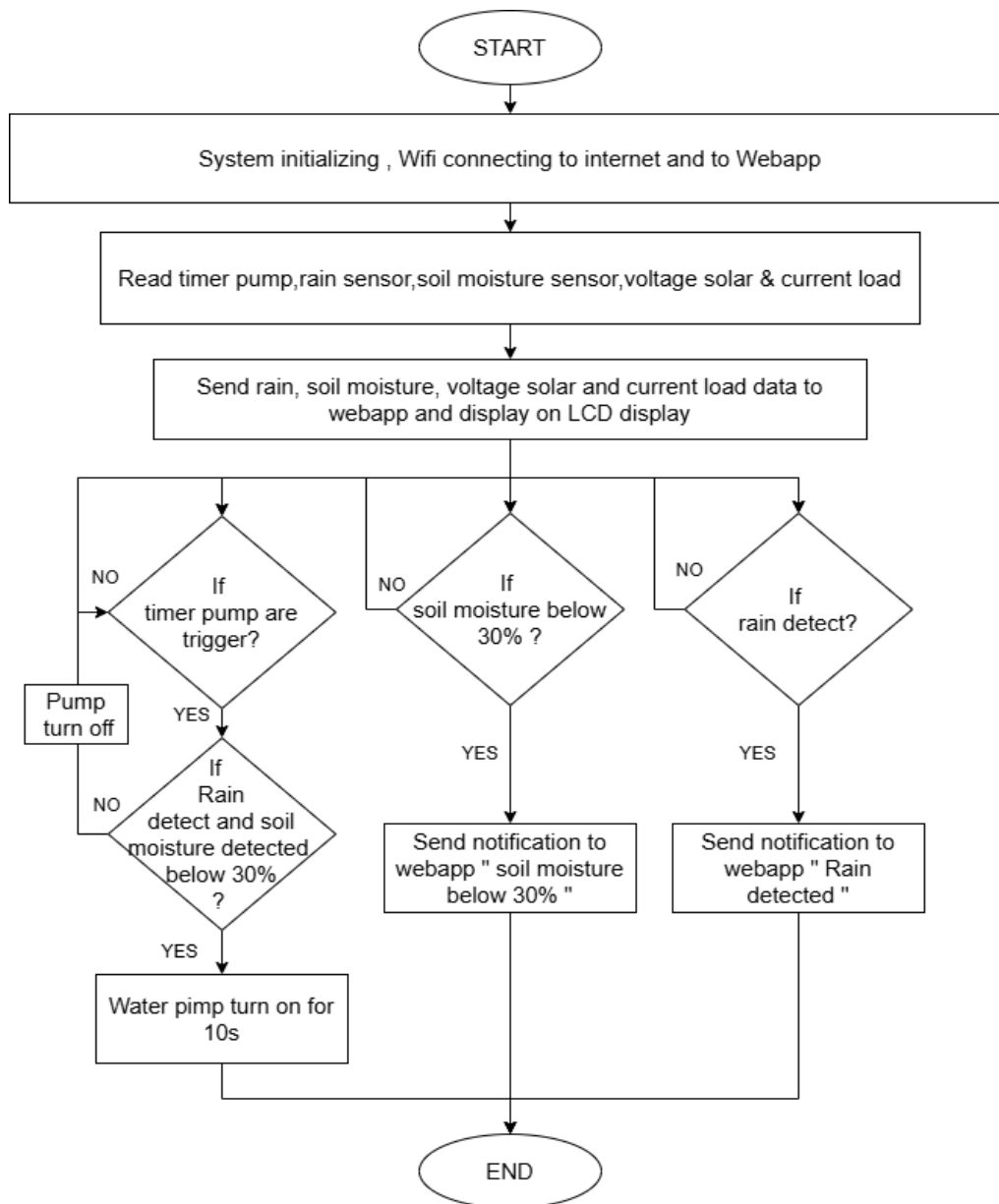


Fig. 3 Flowchart of Automated PV Irrigation System for Red Chili

In summary, hardware development includes assembling and testing all components in a compact, weather resistant enclosure. Software development focused on building logic for sensor reading, control actions, and communication. To evaluate the system's energy performance, testing was conducted with the PV panel placed in three orientations horizontal, vertical, and tilted at 45° to compare voltage, current, and power output throughout

the day. This analysis ensured the system operates reliably in varying sunlight conditions while maintaining energy efficiency.

2.1 Performance Evaluation with Different Axis of PV System

Outdoor testing has been done to show the functionality of the horizontal, vertical and 45° degrees axis solar towards sunlight as shown in Fig. 4. The outdoor testing is done on 1st June 2025, and the weather is in good condition. Comparison of V_{oc} (V), I_{sc} (A), power, and efficiency between horizontal, vertical axis and 45° solar panels with fixed angles. Testing and data analysis are taken starting from 0800 hours until 1700 hours.

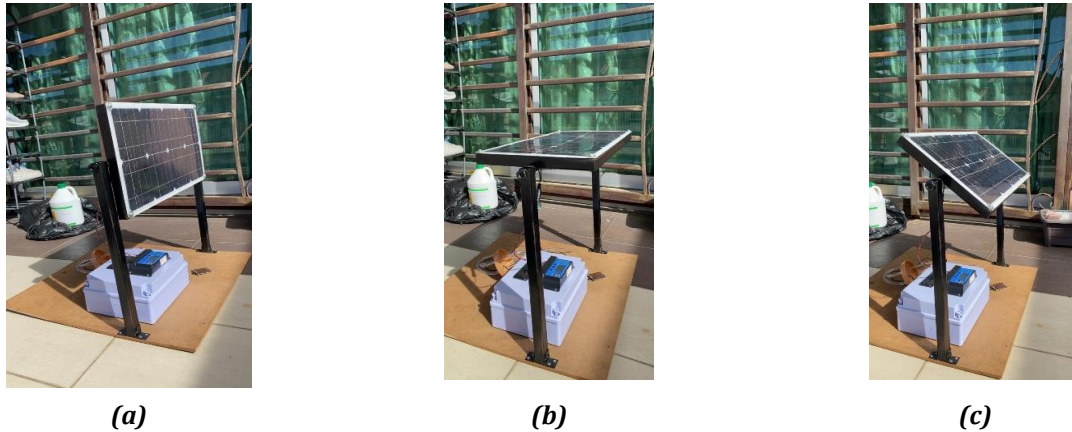


Fig. 4 Horizontal axis (a), Vertical axis (b), 45° axis (c)

3. Results and Discussion

To assess the designed solar-powered irrigation system's responsiveness, energy efficiency, and performance in real-world settings, tests were conducted. The system effectively activated the DC water pump for a predetermined period of 10 seconds in response to environmental inputs, such as low soil moisture and no rain. System parameters were shown on the Blynk IoT platform and LCD panel, and notifications were issued simultaneously via Telegram. The precision and dependability of the automation and sensing procedures were validated by these tests. The solar panel was tested in three distinct orientations horizontal, vertical, and tilted 45 degrees for three days to evaluate its energy performance. Table 1 provides a summary of the voltage and current output measurements made during the hours of greatest sunlight.

Table 1 Solar Panel Output at Different Tilt Angles

Panel Orientation	Average Voltage (V)	Average Current (A)	Average Power (W)
Horizontal	15.8	1.75	27.65
Vertical	12.3	1.62	19.93
45° Tilt	18.2	2.10	38.22

The maximum power output was obtained from the tilted position of 45° with an average of 38.22W. This confirms that the optimal placement of the panel would help in harvesting solar energy, especially in Malaysia's tropics where sun angles vary throughout the day.

Among the three panel orientations tested (horizontal, vertical, and 45° tilt), the 45° configuration consistently delivered the highest and most stable power output. Therefore, only the graph for Day 1 in Fig.5 representing the 45° tilt condition under load is presented in this article, as it best reflects the optimal and realistic performance of the solar-powered irrigation system.

Based on measurements from table and graph, the tilt angle of 45° yielded the best solar power output both under no-load and load conditions. This orientation had the highest power values, implying that it is the best angle to use for harnessing maximum solar irradiation in the Malaysian climate. Thus, the direction of 45° was employed as the benchmark for further system performance analysis in this study.

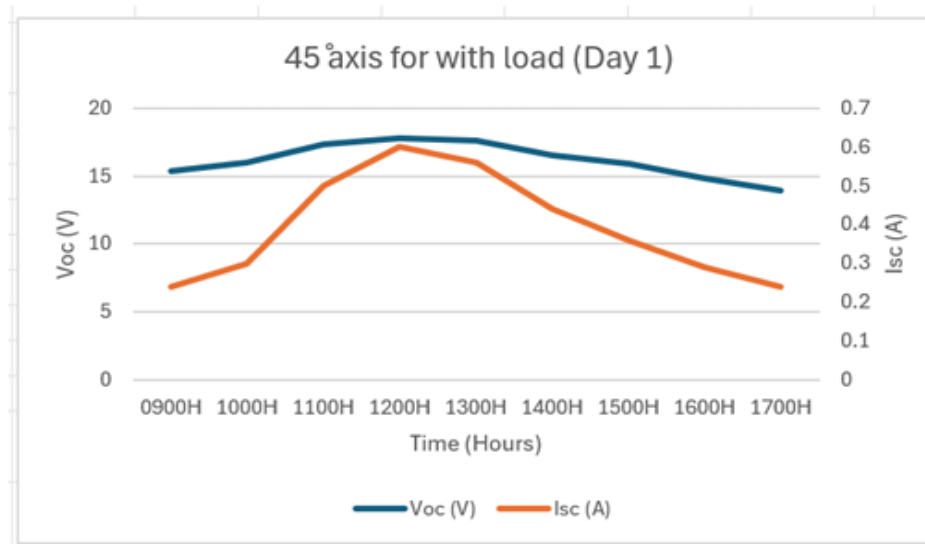


Fig. 5 Graph 45° axis with load for Day 1

3.1 Performance of Irrigation System

The irrigation system also performed well under test with consistent pump engagement whenever soil moisture dipped below 30% and during periods of no rain as shown in Fig. 6. This guaranteed irrigation occurs only in dry weather conditions, ensuring that water was utilized to the maximum extent possible. Proper engagement was reflected on the OLED display and confirmed by real-time Telegram messages, indicating that the decision-making logic and the communication elements of the system functioned as such.

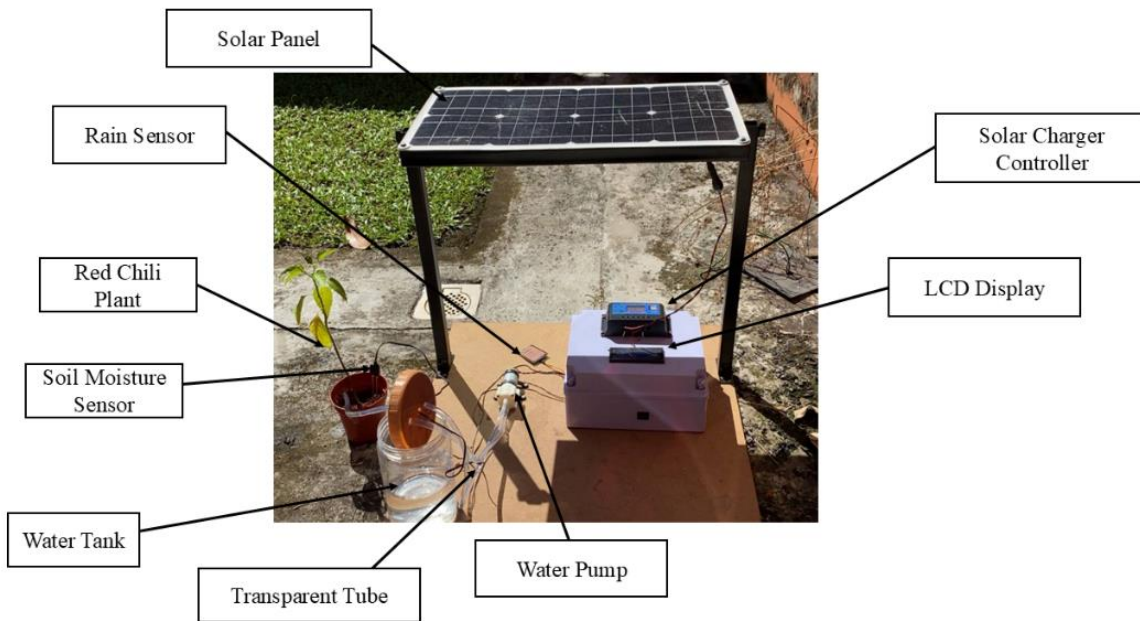


Fig. 6 Automated PV Irrigation System Prototype

Fig. 7 illustrates the section of the Arduino code responsible for controlling the water pump. In this code, the ESP32 microcontroller sends a HIGH signal to the relay module to activate the pump when irrigation is required. After a fixed delay typically 10 seconds the pump is turned off automatically. This routine ensures that water is delivered efficiently without manual intervention.

```

// if timer are trigger Status Pump
if (state == 1) {
  // if rain not detected and Soil moisture below triiger point
  if (rainSensor == 1 && soilMoisturePercentage <= soilTrigger) {
    // Sent to telegram
    bot.sendMessage(CHAT_ID, "Pump Active !!!", "");
    delay(2000);
    digitalWrite(relayPumpWaterPin, HIGH);
    delay(5000);
    digitalWrite(relayPumpWaterPin, LOW);
    state = 0;
  } else {
    // Do Nothing Here
  }
} else {
  // do nothing here
}

// Sent to Blynk
Blynk.virtualWrite(vPin_soilMoisture, soilMoisturePercentage);

// Display on Serial Monitor
Serial.println("Rain : " + String(rainSensor) + ", Moisture : " + String(soilMoisturePercentage));
}

```

Fig. 7 Code for water pump in irrigation system

The code implementation for reading data from the rain and soil moisture sensors is displayed on Fig. 8. While the rain sensor detects the existence of rainfall, the soil sensor uses analogue input to assess how dry the soil is. The loop () method repeatedly evaluates these readings. The mechanism then turns on the pump if the soil is dry and no rain is detected. The system can make intelligent irrigation decisions depending on current environmental circumstances thanks to sensor-based logic.

```

// if timer are trigger Status Pump
if (state == 1) {
  // if rain not detected and Soil moisture below triiger point
  if (rainSensor == 1 && soilMoisturePercentage <= soilTrigger) {
    // Sent to telegram
    bot.sendMessage(CHAT_ID, "Pump Active !!!", "");
    delay(2000);
    digitalWrite(relayPumpWaterPin, HIGH);
    delay(5000);
    digitalWrite(relayPumpWaterPin, LOW);
    state = 0;
  } else {
    // Do Nothing Here
  }
} else {
  // do nothing here
}

// Sent to Blynk
Blynk.virtualWrite(vPin_soilMoisture, soilMoisturePercentage);

// Display on Serial Monitor
Serial.println("Rain : " + String(rainSensor) + ", Moisture : " + String(soilMoisturePercentage));
}

```

Fig. 8 Code for rain sensors and soil moisture sensor in irrigation system

3.2 Monitoring Solar Output Using Voltage and Current Sensors

The code in Fig. 9 and 10 demonstrates how the ESP32 reads and processes real-time data from both the voltage and current sensors to evaluate the performance of the solar panel. These readings are used to monitor system power status and are displayed via OLED and the Blynk app.

```

void readVoltageSensor() {
  // Read the Analog Input 0 - 4095
  adc_value_solar = analogRead(voltageSolarPin);

  // Determine voltage at ADC input
  adc_voltage_solar = (adc_value_solar * ref_voltage) / 4095.0;

  // Calculate voltage at divider input
  in_voltage_solar = (adc_voltage_solar * (R1 + R2)) / R2;

  // // Print results to Serial Monitor to 2 decimal places
  // Serial.print("Analog = " + String(adc_value_solar));
  Serial.print("Input Voltage solar = ");
  Serial.println(in_voltage_solar, 2);

  in_voltage_solar = in_voltage_solar - 1.0;

  if (in_voltage_solar <= 0) {
    in_voltage_solar = 0;
  } else {
    in_voltage_solar = in_voltage_solar;
  }

  // Send Data to blynk
  Blynk.virtualWrite(vPin_voltageSolar, in_voltage_solar);
}

```

Fig. 9 Code for voltage sensor

```

//=====
void readCurrentSensor() {
  // Read current from sensor
  acs712_I = sensor.getCurrentDC();

  if (acs712_I <= 0) {
    acs712_I = 0;
  } else {
    acs712_I = acs712_I;
  }

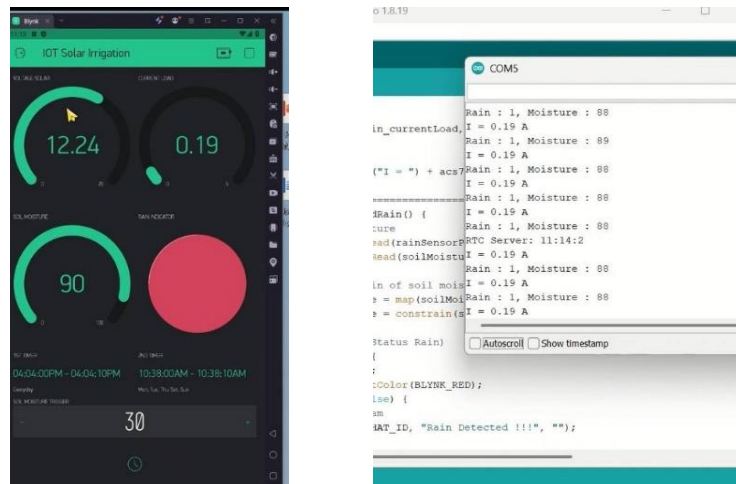
  Blynk.virtualWrite(vPin_currentLoad, acs712_I);

  // Send it to serial
  Serial.println(String("I = ") + acs712_I + " A");
}
//=====

```

Fig. 10 Code for current sensor

As shown on **Fig. 11**, the device configuration was set up in the Blynk template, where the system is connected to Wi-Fi and linked to specific virtual pins for sensor data and control functions. Through the Blynk Home Overview, the user can select the connected device, define the Wi-Fi settings, and create virtual variables to monitor system performance. Widgets were added to visualize real-time data such as soil moisture percentage, rain detection status, battery voltage, and current. These visual indicators allow users to easily track irrigation activity and system power conditions. **Fig. 11 (b)** displays the serial monitor if the system is on.



(a) **(b)**
Fig. 11 Blynk Interface (a), Serial Monitor on Arduino IDE (b)

4. Conclusion

This project was able to successfully create a solar-powered automated irrigation system that is intended for small-scale red chili farming. An ESP32 microcontroller and Blynk platform together with Internet of Things-based monitoring were used in such a way that the system could make decisions in real time based on the soil moisture and rain, only turning on the water pump when necessary. After testing the 50W PV panel with varying tilt angles, it was determined that the 45° orientation provided maximum and consistent energy output for guaranteed off-grid use. The system met all the project requirements by conserving water usage, eliminating excess manual labor utilization, and mechanizing irrigation chili plants. Blynk and Telegram also made remote checking of the system status by users simpler. This solution addresses the limitations of traditional irrigation methods, especially in rural areas with limited access to electricity, and demonstrates strong potential for future expansion by incorporating additional sensors such as pH or temperature for even smarter farming.

Acknowledgement

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Conflict of Interest

Authors declare that there is no conflict of interest regarding the publication of the paper.

Author Contribution

The authors confirm contribution to the paper as follows: **study conception and design:** Nor Ainul Mardhiah Binti Mohamed, Rohaiza Binti Hamdan; **data collection:** Nor Ainul Mardhiah Binti Mohamed; **analysis and interpretation of results** Nor Ainul Mardhiah Binti Mohamed, Rohaiza Binti Hamdan; **draft manuscript preparation** Nor Ainul Mardhiah Binti Mohamed, Rohaiza Binti Hamdan. All authors reviewed the results and approved the final version of the manuscript.

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