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Internet of things based automated agriculture system for irrigating soil

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ABSTRACT

This work describes the design of an internet of things (IoT)-based prototype system for outdoor agriculture farmland that employs low-cost sensors for detecting basic agriculture parameters such as soil moisture level, air temperature, and air humidity to irrigate the farmland automatically and manually while tracing the water volume. Therefore, since the water requirement varies according to plant type and plant growth stages, this research focuses on a feature where user can adjust the soil moisture level from software according to the plant type and age stages so that a suitable moisture level can be maintained for plants. Apart from that, the system also has a feature to adjust the temperature threshold limit from the application software so that when the temperature sensor value exceeds the respective threshold limits, it sprinkles the water for a limited time so that plants are not damaged due to overheating. Google sheets is used for cloud storage, and Wi-Fi is used to send data to the cloud using the HTTP protocol. The Blynk application software is used to monitor and control purposes.

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1. INTRODUCTION

Agriculture is widely regarded as the world's oldest industry. It is the art and science of soil cultivation, food production, and livestock farming [1]. It has always been accountable for supplying food and necessary raw materials to the world's inhabitants. Thus, human existence cannot be conceived without agriculture. Hence, it is important to ask the question as to whether there have been any technological improvements in this sector.

In response to the aforementioned question, the answer is not that much significantly. No matter how large this industry is, it has not improved as much as other developed industries around the world. The traditional method of agriculture is still used by the majority of farmers (particularly in South-East Asia and Africa). Most farming and agricultural activities rely on prediction and forecasting. They like to do farming without analyzing the farmland. Their lack of information and data management skills has compelled them to study plant conditions solely with their eyes. They have been using a manual control irrigation technique, turning the water pump on and off regularly to irrigate the field. As a result, lot of water wasted in this sector [2]. Furthermore, manual, or traditional agricultural field management will not offer producers with an accurate image of the quantities available to satisfy the demands of plants at different growth phases [3].

About 97% of the earth's water is saltwater held by oceans and seas, with the remaining 3% being freshwater, more than two-thirds of which is frozen in the forms of glaciers and polar ice caps. Only 0.5% of the unfrozen freshwater is in the ground, and the rest is in the air [4]. According to Food and Agriculture

Organization (FAO) and International Water Management Institute (IWMI) 70-80% of freshwater consumption is devoted solely to irrigation needs, where major portion of water is wasted and became one of the core reasons for water pollution [5]. As a result, soil fertility is constantly declining, and various crop diseases appear, reducing crop production [6]-[8]. Therefore, farmers will suffer significant losses if it fails, and some of them commit suicide for not overcoming those losses [9]. In addition, farmers are losing interest in working in this sector, so many agricultural lands are being used for non-agricultural purposes [10]. Experts estimate that the world has lost one-third of its arable land in the last 40 years [11]. Which has become the biggest hurdle in tackling future food problems for the world.

To avoid such an incident, wastage and losses, researchers all around the world are working on it to make the agriculture sector more informative, interesting and reduce work for farmers. Embedded microcontrollers and the IoT are expected to take farming to the next level, allowing for smart or precise farming. Temperature, soil moisture (SM), air humidity, soil fertility, and availability of plant nutrients (as determined by pH and EC status) are the most common climate and soil variables to which most farmers pay attention [12]. Specially SM it is referring to the water that has been stored between soil particles. The water available to plants in the first 200 cm of the soil is referred to as root zone soil moisture [13]. Installing sensors to monitor the agricultural field and automating the irrigation system can help achieve this. Farmers can monitor their farms from anywhere [14]. Smart farming based on IoT is far more efficient than traditional farming [15]. Using precision irrigation may improve the conventional approach while lowering farm management costs. So, the farmer may choose irrigation water by predicting water requirements [16]. Furthermore, the use of communication and sensing by means of automated data collection, recording, and strategic farm management decisions may reduce waste and have a positive impact on the environment.

Over the last few years, it has been seen that sensor and vision-based technologies have recently gained popularity for analysing soil parameters. In vision-based technology, thermal image cameras and digital cameras are used to analyse recorded footage using a digital image processing algorithm. In the case of the sensor, the output voltage is also examined for soil moisture analysis [17]. There are now two types of sensors on the market for detecting soil moisture levels. They are resistive soil moisture sensor and capacitive soil moisture sensor. Based on those two sensors, most of the designers proposed their systems. However, due to the electrolysis process, the probes of resistive soil moisture sensors get corroded easily [18]. To prevent the damage, immersion gold is used in the new soil moisture sensor to prevent oxidation of the probes [19]. In the case of capacitive soil moisture sensors, they are non-corrosive and produce more precise results than resistance estimation by measuring dielectric permittivity of soil which varies with the amount of water present in the soil [20], [21]. Moreover, to measure ambient air temperature, the LM-35, DHT-11, and DHT-22 are widely used sensors.

Various recent research has shown how the irrigation process based on IoT can be effective for agriculture. The researchers have proposed different models to ensure optimal freshwater use during irrigation. Getu and Attia [22] proposed a system based on logic gate circuit and resistive SM sensors. The speed of the motor is controlled by the amount of moisture in the soil; the motor is turned off when the soil is wet and on when the soil is completely dry. A timer controls the length of time that water is pumped. Rajkumar *et al.* [23] proposed an irrigation monitoring system operated by Arduino and GSM network that allows pump control through SMS and Bluetooth. The proposed method keeps track of field irrigation in real-time. Kumar *et al.* [24] developed a Raspberry pi-based drip irrigation and sprinkler irrigation system that water plants after germination and uses multiple sensors to monitor soil moisture, rain, water level flow, and external atmosphere temperature.

The preceding discussion shows that nearly all authors used the same type of sensor (Resistive soil moisture sensors) and applied the same logic: the pump should run if the soil moisture sensor value is equal to or less than the threshold limits, or the temperature sensor value is equal to or greater than the threshold limit. Additionally, some authors include additional sensors, such as a raindrop sensor, to ensure that the system shuts off the pump as soon as the rain starts to fall. So, through this research the main objective is to design a IoT based system for monitoring and storing agricultural field parameters and automatically irrigate farmland by analyzing sensors parameters and recording water volume during irrigation.

2. METHOD

2.1. Basic concept

The proposed research focuses on developing a low-cost IoT system for farmers that will reduce the use of water during cultivation and assist them in acquiring basic agricultural parameter information. The central hypothesis for developing the prototype system is based on the plant's water requirements [25], [26] and its temperature tolerance limit [27]. Because water requirements vary by plant type, age stage and each plant have its own set of temperature tolerance limitations. As a result, such perimeters must be carefully selected during watering. Thus, the design of this study is such that all sensor variables can be monitored with the Blynk app and Google Sheets, and the air temperature and soil moisture threshold limits can also be adjusted with the same applications. At the same time, the irrigation water usage volume is calculated using the fluid dynamics equation.

$$Q = \frac{V}{t} \quad (1)$$

Where: Q is flow rate (m^3/s), V is water volume (m^3), t is flow time (s)

This experiment discovered that connecting the 4/7 mm hose pipe (inner diameter: 4 mm, outer diameter: 7 mm) adapter with the pump takes an average of 28s to fill a one-litre jar. Which means per second approximately 35.71 ml or 35 μm^3 water can be flow through the pipe. The volume of water used in this study was calculated based on the flow rate. However, once the hose pipe was connected, the pump's actual flow rate was compromised due to turbulence inside the pump.

2.2. System architecture and hardware connection

The system is intended for an outdoor setting but can also be installed indoors. The fundamental concepts for the development of this prototype are hardware and software. Figure 1 shows the basic hardware block diagram of the overall system, in which all analog sensors are connected via a multiplexer. The digital sensors DHT-22 (Digital humidity and temperature) and relay module are directly connected to the microcontroller unit. The program inside the microcontroller unit collects data from the sensor and sends it to the Blynk server for monitoring and control purposes, as well as to Google Sheets for cloud storage via Wi-Fi.

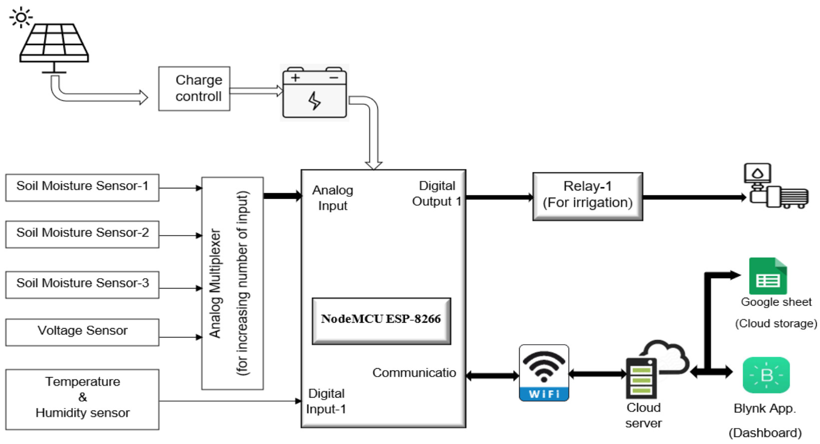


Figure 1. Basic block diagram

Since the system will be operating in an open field, providing an independent separate power supply is a significant challenge. As a result, the hardware is divided into two sections: system power unit and system core unit. Figure 2 represents the overall architectural flow, or how the various components of the overall system interact with one another.

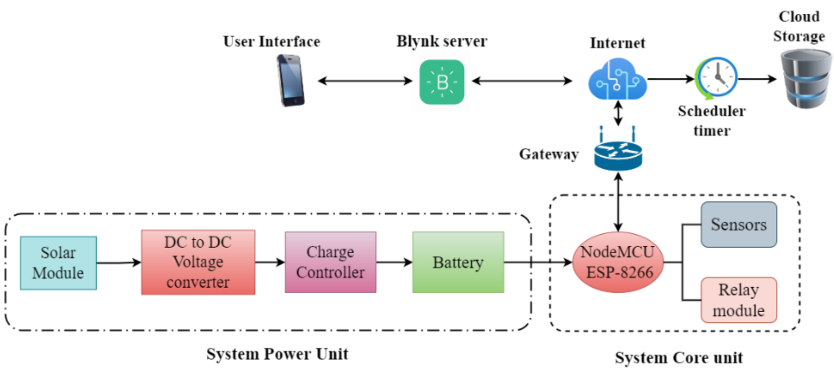


Figure 2. System architecture

The primary function of the power unit, in this case, is to supply power to the core unit by charging the battery. A 6V 4.5Ah battery is used to power the core unit. A solar module is used in conjunction with a DC-to-DC voltage controller and an overvoltage control unit to charge the battery. The adjustable DC-to-DC voltage is connected to the 12V, 15W solar module. The DC-to-DC converter is set to deliver 7.3V at 0.7A by adjusting the CV & CI potentiometers and by connecting the converter's output terminal to the input terminal of the charge control module via a diode (IN5822), ensuring that no reverse current flows back to the adjustable DC-to-DC converter module. The device's output terminal is connected to a 6V battery.

The charge controller module is set to allow power to flow while the battery voltage is equal to or less than 6.2V and to stop charging when the battery voltage reaches or exceeds 7.2V. Following that, it is routed from the battery connector to the core unit. Figure 3 shows the connection diagram and all the components after the connection has been completed.

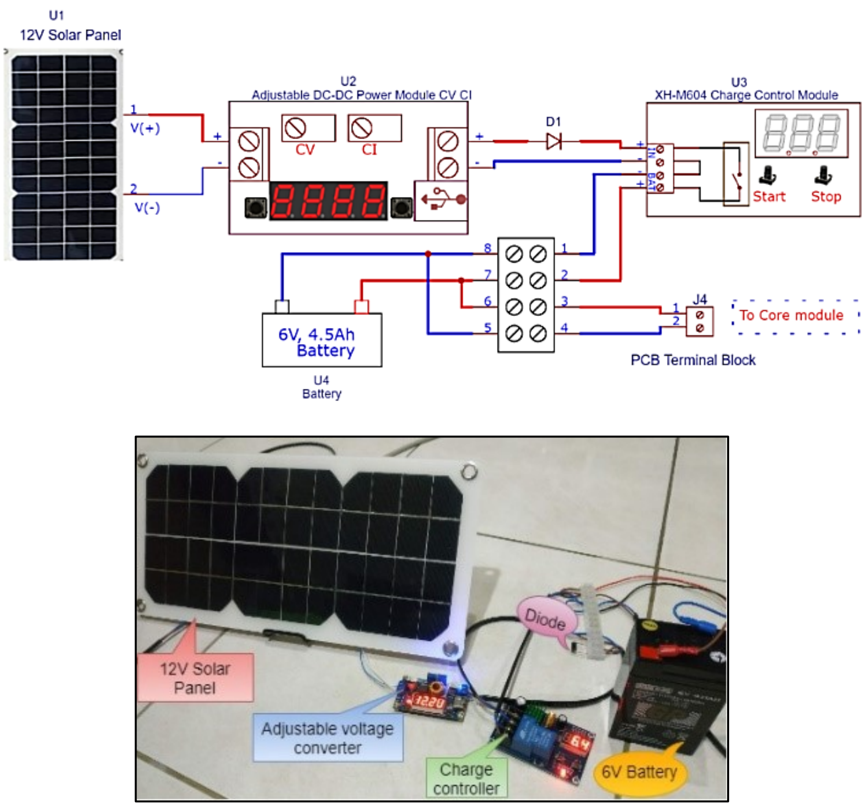


Figure 3. System power unit

On the other hand, the core unit consists of three soil moisture sensors, one temperature sensor, an analog voltage sensor, and a two-channel relay module as an example model. Based on demand more sensors can be included in the system. The 6V battery is connected to the two-pin PCB terminal port, which is connected to the NodeMCU ESP8266 Vin (pin no. 30) and GND (pin no.29) pin via a sliding switch. The connection allows the user to disconnect the system from the battery in case of emergency or during maintenance. Two LEDs were used to indicate the status of the power connection. The DHT-22 data pin is connected to the GPIO-02 pin labelled as D4 in the NodeMCU ESP-8266 body. The microcontroller pin no. 10 supplies 3.3V supplies, and pin no. 9 connects to the ground. To periodically control the switching of multiplexer four channels, GPIO pins no. 4 and 5 are connected to multiplexer S0 pin and S1 pin, respectively, and multiplexer "SIG" pin is connected to MCU's A0 pin to acquire analog sensor data.

To eliminate any noise interference during multiplexer switching, S3 and S4 are grounded. At the same time, only four of the sixteen available channels are being used to acquire analog sensor data. As a result, the rest of the channel must be grounded. Otherwise, noise interference is a real possibility. In this case, channel "C0-Ch-2" is designated for three soil moisture sensors, and "C3" is designated for analog voltage sensors. The multiplexer and soil moisture sensors are powered by 3.3V supplied by microcontroller pins no. 26 and 25. Figure 4 and Figure 5 shows the core unit after connecting all components according to the schematic diagram and component photos.

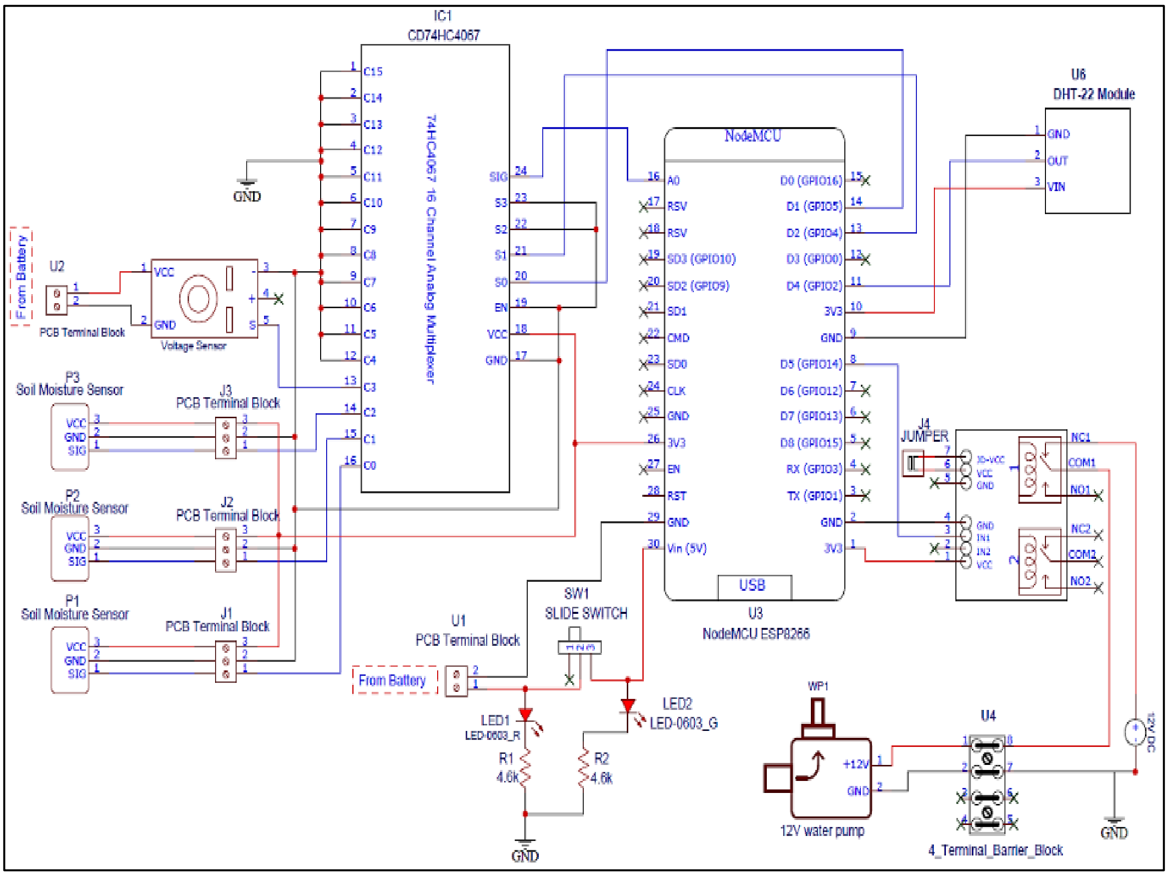


Figure 4. Core unit connection diagram

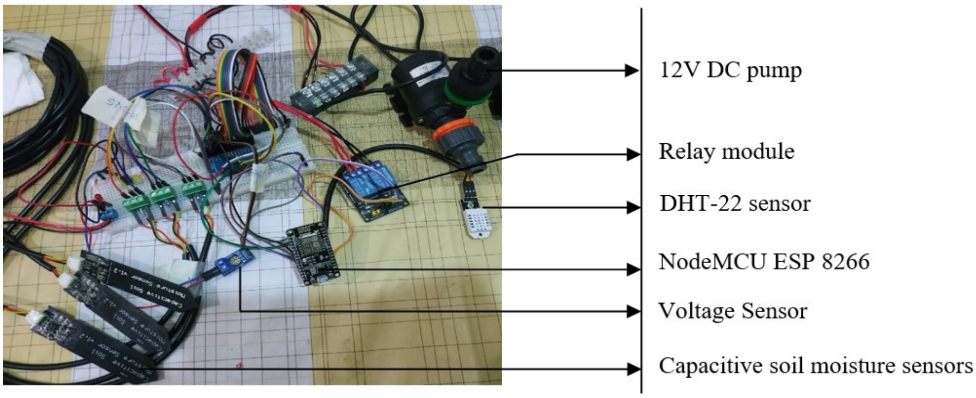


Figure 5. Core unit

To control the 12V DC PUMP via the dual-channel 3.3V relay module, 3.3V is supplied from NodeMCU ESP-8266 pins 1 and 2 and the control pin IN1 connected to GPIO pin no. 4. Since the relay model is powered by the NodeMCU esp-8266, JD-VCC and VCC are shorted through a jumper. The 12V supply is connected to the relay module "COM" (Common terminal) terminal, and the "NO" (Normally open) is connected to the pump positive terminal. The pump will start running whenever the relay module is activated.

2.3. Software programming

The software for this system is written in the Arduino programming language, which is similar to the C/C++ language. The main program is written such that it will perform three basic operations, which are data collection, controlling relay for irrigation purpose and sending data to Google sheet for cloud storage. Figure 6 showing the flow chart of overall program structure.

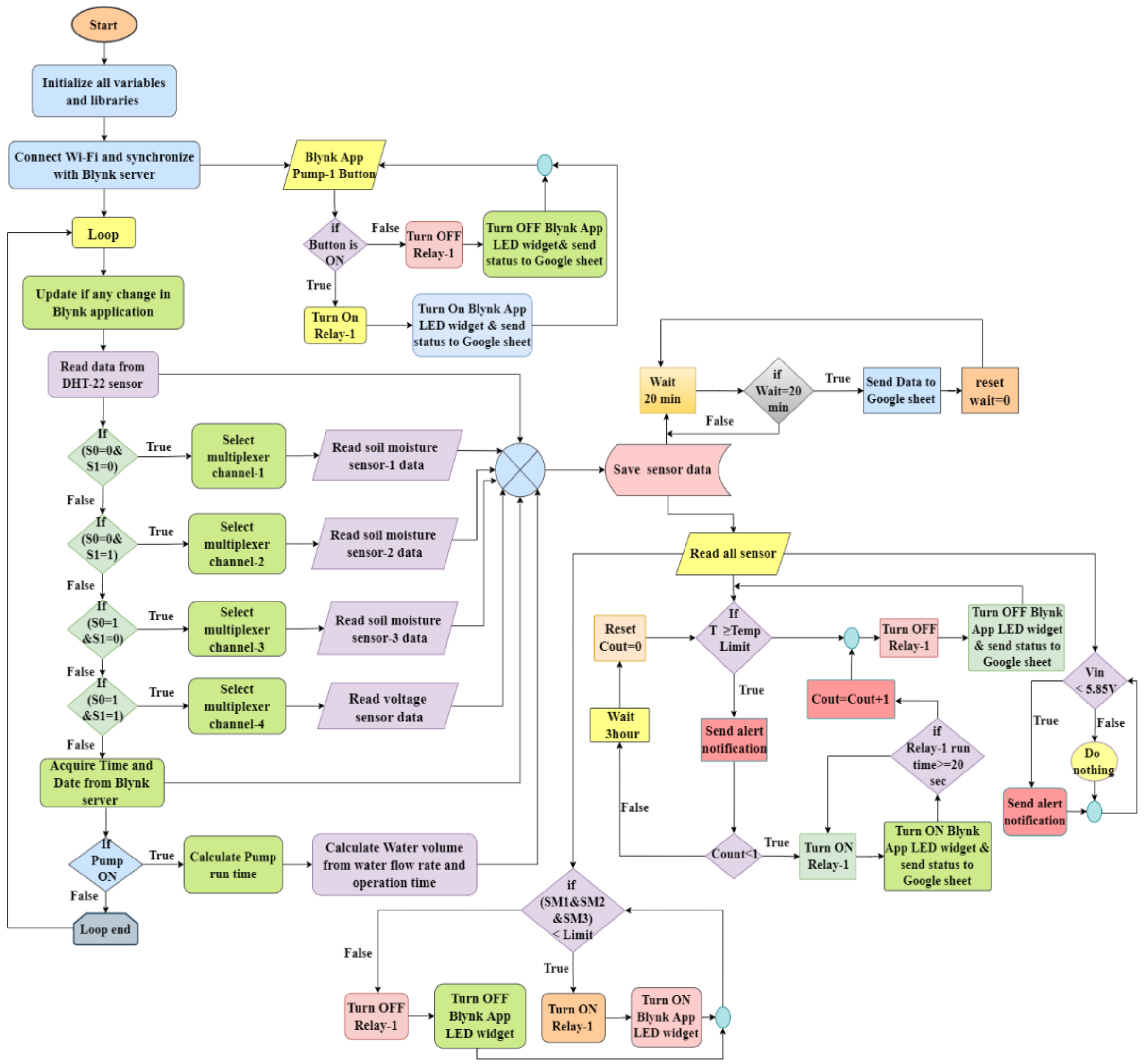


Figure 6. System flow chart

In this system Blynk App is used as graphics user interface (GUI). It collects data from micro-controller unit display data through display widget and control the pump via button widget if manual irrigation is required. RTC widget is used to collect date and time, Notification widget is used allow Eventor widget to send notification to the user if system get offline for three hour or battery voltage is below 5.85V. This mode also allow user to create any additional event base task without changing the main source code. Two slider widget is used for controlling soil moisture and temperature threshold limit. So that, user can adjust those threshold limit according to the plant type and age stage. Figure 7 depicts all the widgets used in this research.

To send data to a Google sheet via APIs and the use of Google script (Gscript), it is necessary to first open a new sheet first and then prepare it to receive data from the device by creating a Google script to connect the sheet to the NodeMCU ESP-8266. The App script is written in such a way that columns “A” and “B” will store the date and time respectively from the internet time server. When new data arrives, the data from the internet time server pertaining to the time zone is updated. The program will then save temperature, humidity, soil moisture, voltage sensor, soil moisture threshold limit, temperature threshold limit, pump status, and volume of water, respectively, from column “C” to “L. To communicate with NodeMCU ESP 8266 via Google Sheets, the HTTP protocol with port number 443 is used. The program is designed to send data from sensors every 20 minutes. Since the data are not particularly sensitive, this time difference will have no effect on the system's performance. However, whenever the system notices any change in soil moisture limits, temperature limits, or relay status, programmers immediately update the data on the sheet. If the code fails to send any data to Google Sheets, it displays an error message in the serial monitor. Figure 8 shows a screenshot of the sheet after a successful data transfer.

A binary sigh code was used to identify relay-1 operation events in order to denote which irrigation pump was operated. Is it triggered by the Blynk app, the soil moisture sensor logic, or the high-temperature logic? Table 1 depicts the logic code's truth table, which can be used to deduce the valid reason for pump action.

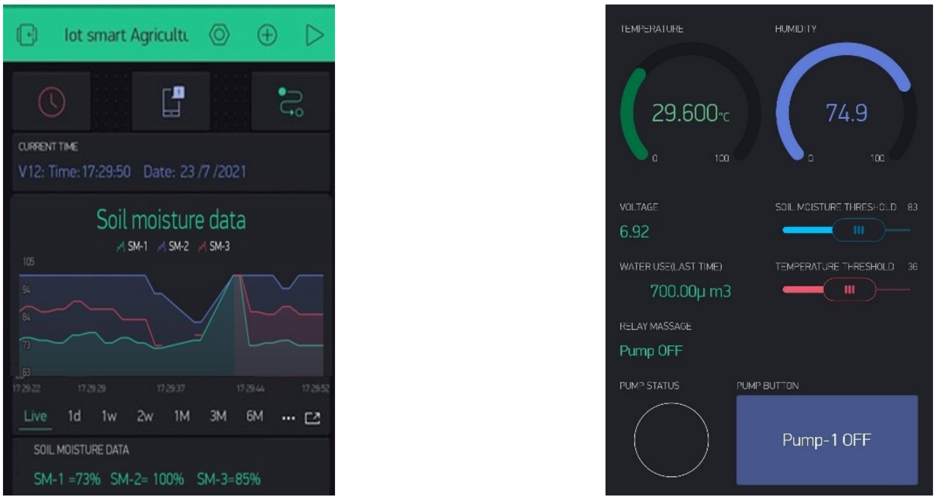


Figure 7. Blynk app widgets

Date	Time	Temperature (°C)	Humidity (%)	SM1 (%)	SM2 (%)	SM3 (%)	Battery Voltage (V)	Soil moisture threshold (%)	Tempareture threshold (°C)	Pump status	Water Volume in (μ m3)
28/04/21	19:38:27	29.9	75	85	85	82	7.24	85	36	000	
28/04/21	19:58:27	29.9	74	85	85	82	7.12	85	36	000	
28/04/21	20:18:27	29.3	74	84	85	82	6.68	85	36	000	
28/04/21	20:38:28	29.4	75	84	85	82	6.60	85	36	000	
28/04/21	20:58:30	29.3	74	84	85	81	6.56	85	36	000	
28/04/21	21:18:32	29.4	74	84	85	81	6.50	85	36	010	0.00
28/04/21	22:18:55	29	74	102	102	102	6.48	85	36	000	805.00
28/04/21	22:38:37	29.1	74	102	102	105	6.48	85	36	010	
28/04/21	22:58:34	29.1	74	102	104	102	6.40	85	36	000	
28/04/21	23:18:34	29.3	73	102	104	100	6.40	85	36	000	
28/04/21	23:38:37	29.2	73	102	104	100	6.38	85	36	000	
28/04/21	23:58:35	29.4	72	100	100	102	6.37	85	36	000	
29/04/21	0:18:34	29.3	70	103	100	102	6.35	85	36	000	
29/04/21	0:38:36	29.3	69	103	100	102	6.29	85	36	000	

Figure 8. Data and event log stored in Google sheets

Table 1. Truth table for relay status

SL NO	Blynk app button logic (A)	Soil moisture sensor logic (B)	Temperature sensor logic (C)	Relay status	Relay massage
1	0	0	0	111	Pump on (all switch active)
2	0	0	1	110	Pump on (APP & SM active)
3	0	1	0	101	Pump on (APP & Temp active)
4	0	1	1	100	Pump on (APP active)
5	1	0	0	011	Pump on (SM & Temp active)
6	1	0	1	010	Pump on (SM active)
7	1	1	0	001	Pump on (Temp active)
8	1	1	1	000	Pump off

3. RESULTS AND DISCUSSION

For experiment, the developed system has been tested in a test bench on Chilli plant. The temperature threshold limit was set at 36˚C and soil moisture threshold limit was set at 85% till seeds are germinated and as the plant size and root system developed this soil moisture threshold limit reduced gradually. During this experiment period all sensors are monitored regularly. All sensor data and event logs are automatically saved in Google Sheets during this testing period, as it is designed to do and are accessible in real-time via the Blynk app as well. Figure 9 shows the test bench setups respectively.

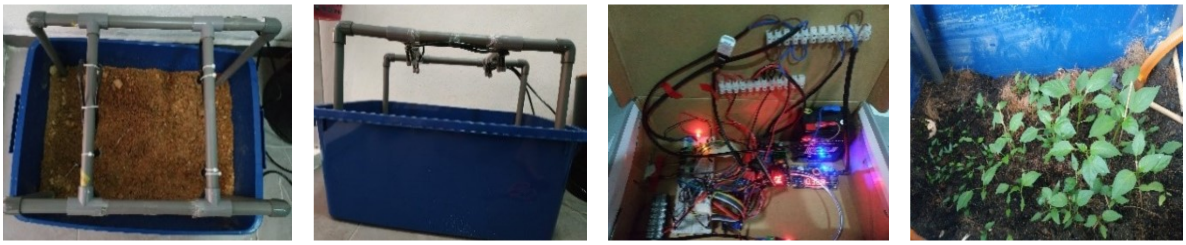


Figure 9. Test bench

3.1. Battery voltage

The battery voltages were monitored using a voltage sensor; the entire system was set up in direct sunlight. The purpose of this test is to determine how well the solar module performs and whether it can charge the battery voltage. Figure 10 depicts a line diagram of the battery voltage where data was collected daily from 10 a.m. to 4:30 p.m. between 4/4/2021 and 12/4/2021.

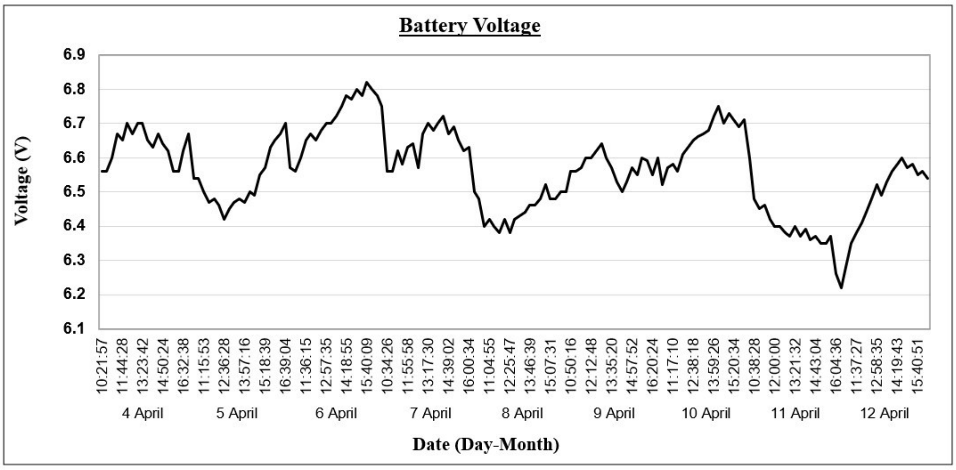


Figure 10. Battery voltage data

The battery's voltage level increases daily between 10 a.m. and 2.30 p.m., as shown in Figure 10, and then begins to drop between 3 p.m. and 4:30 p.m. The reason for this is that the sun's position changes over time; therefore, solar cells do not receive adequate sunlight throughout the day. In the morning, the solar cell receives direct sunlight, and the light intensity is sufficient to charge the battery; however, after 3 p.m., the sun moves in the opposite direction of the solar panel, and the panel does not receive the optimal light intensity; as is well known, light intensity is a critical factor in solar module performance [28]. This means, when the light intensity is adequate, the solar module can charge the battery quickly; when the light intensity is insufficient, charging the battery takes a long time, and in some cases, the module cannot charge the battery at all.

3.2. Temperature and humidity

The temperature and humidity of the surrounding air were monitored using a DHT-22 sensor. Temperature and humidity data were obtained for three weeks, beginning on 14/4/2021 and ending on 4/5/2021, with the system collecting data 24 hours a day. Figure 11 to show the temperature data for three consecutive weeks, while in Figure 12 demonstrate the humidity data, which is plotted on a weekly basis.

Figure 11 show the temperature was varied from 27 ˚C to 32 ˚C during the entire time and that this was the optimum condition for Chilli cultivation. Because the temperature never exceeded the threshold limit, the system did not automatically sprinkle water. Figure 12 show that the humidity level was between 66 and 85% for the entire three weeks. When the temperature rises, especially during the day, the percentages of air humidity begin to fall. When the temperature falls at night, the humidity percentages level begins to rise. This is due to the fact that when the temperature rises, the relative air can hold more water molecules. The water holding area increases due to the knighting energy of water molecule movement; as the temperature decreases, the relative water molecule holding decreases, as well.

In addition, because the system is designed for an outdoor farm area, there are not many options for controlling outdoor air humidity levels. However, the data can assist users in analysing crops' health. Plant transpiration may be limited when the humidity is excessively high, affecting the plant's nutrient supply system from the roots to the shoots. Calcium deficiency is common in those conditions, especially in younger leaves. The leaves lose so much water at very low humidity that the xylem cannot fully replenish it, and the plant cells lose their turgor. Because the cell walls are not pushed outwards, the plant cells are not stimulated to expand [29].

Since the pump did not operate due to the temperature threshold limit during that three-week test period, the value of the Blynk app temperature threshold slider widget was artificially reduced to 24 ˚C to see if the system is working automatically or not. Figure 13 shows screenshots of the Blynk app and the Google (in appendix) sheets page. Figures 13(a)-(c) shows that when the temperature sensor value exceeds the threshold limit, the pump starts and then turns off. It shuts down automatically after 21 seconds. After three hours, the pump restarts, and this time it runs for 20 seconds. According to the Google Sheets data, the pump status was the same as it was programmed to be (see Table 1). Since the pump runs for 21 and 20 seconds, it sprinkles 735 µm^3 and 700 µm^3 of water, respectively.

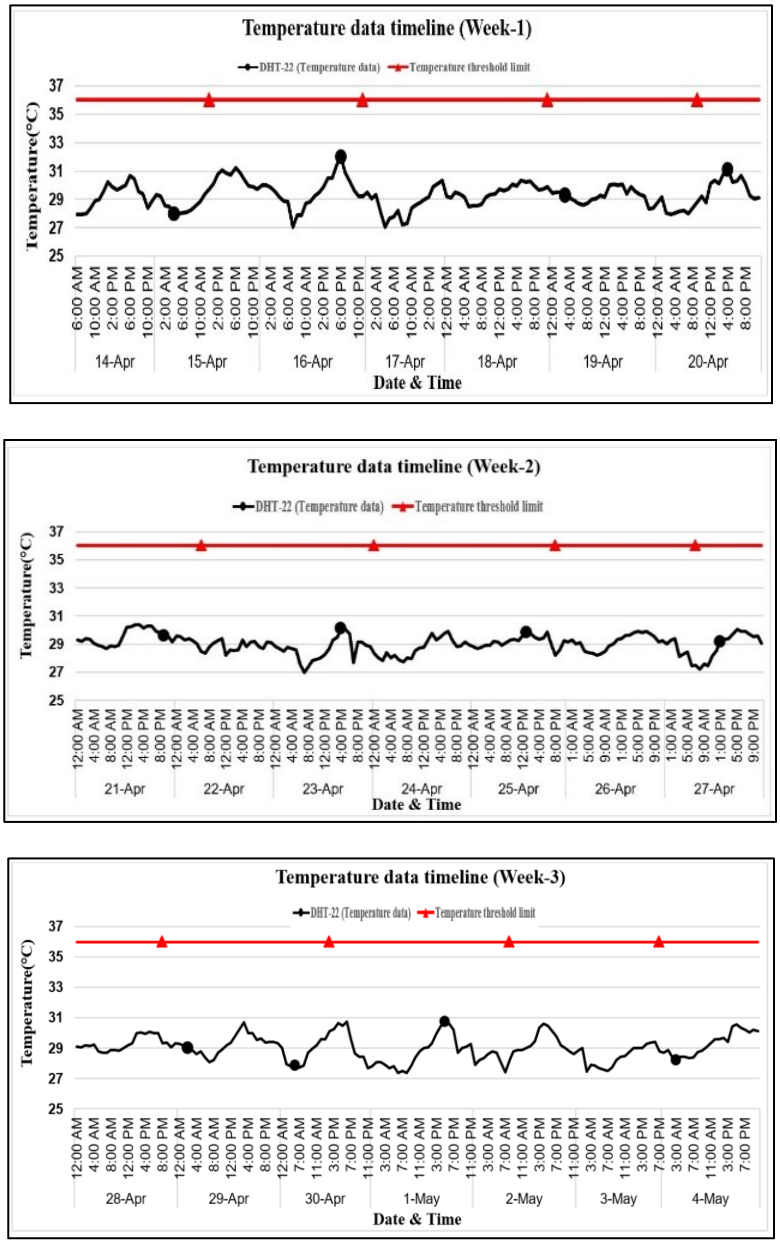
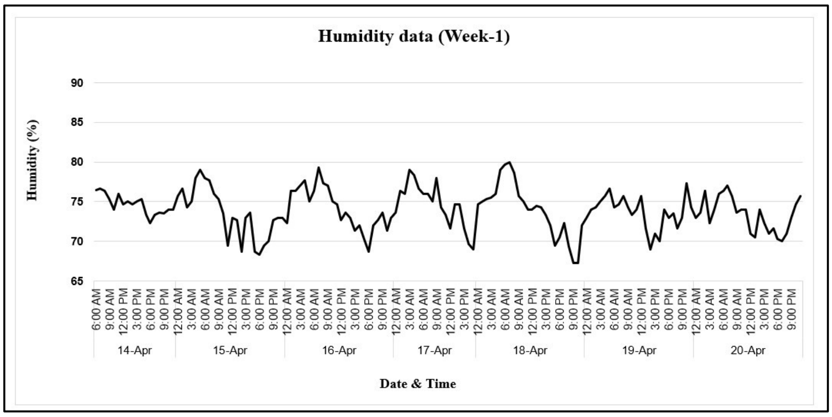
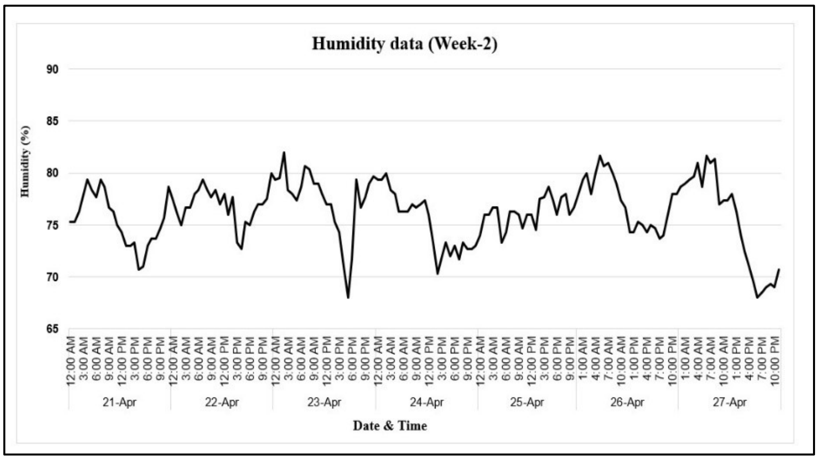


Figure 11. Temperature sensor data





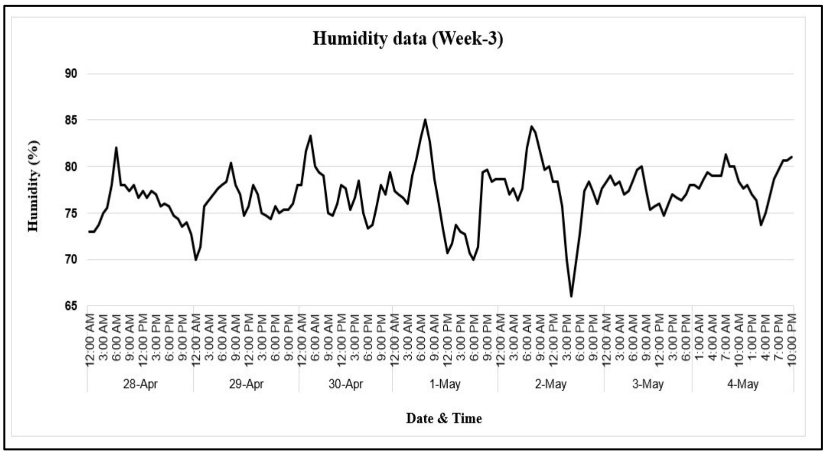


Figure 12. Humidity sensor data vs. time graph chart

3.3. Soil moisture level and auto irrigation

The soil moisture level is the most important parameter in this prototype. The test bench for soil moisture level was monitored using three capacitive soil moisture sensors, and the sensor data was analysed using the Blynk app and Google Sheets. Three weeks of data are gathered from Google Sheets for analysis during this phase. Figure 14 shows the soil moisture sensors data over a three-week period.

In Figure 14, the blue, red, and green lines represent three soil moisture sensors, respectively, and the black line represents the soil moisture threshold limit, which can be adjusted from the Blynk app without changing the code. During the first two weeks, the soil moisture threshold limit was kept at 85% since more water is required during germination and early stages of the plant, and later, that value was reduced to 80% because the plant grew a little bigger.

Figure 14 shows that the value of moisture sensors starts to decrease from 100% on 16th April and on 19th April, the data timeline shows that the value of sensors 1 and 3 are below the threshold limit. As a result, whenever the value of sensor-2 fell below the threshold limit, the pump automatically started and stopped when the all-sensor value rose above the threshold limit, as observed in Figure 14. A similar pattern was also seen on the 28th of April data timeline, where the pump started due to a low soil moisture sensor value, and the value of all sensors increase to 100%.

It has been observed that once the irrigation process is initiated due to insufficient soil moisture, the sensor value returns to 100% when the pump is turned off. When the irrigation procedure is configured in this manner, it will automatically stop when the sensor value reaches the threshold limit. It was noticed throughout the investigation that the capacitive soil moisture sensor takes a long time to update the reading, causing the pump to run longer.

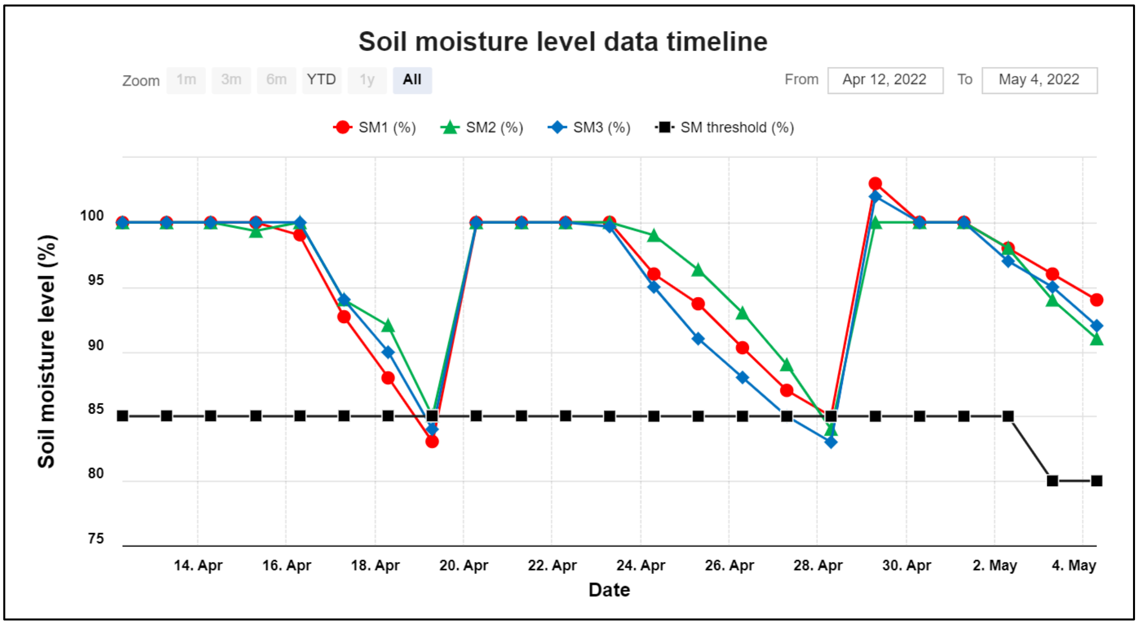


Figure 14. Soil moisture sensor data

4. CONCLUSION

In this study, an IoT-based agriculture system was developed to monitor various agricultural field parameters (temperature, humidity, and soil moisture) and for an automated irrigation system that provides information on water consumption during the irrigation process. Throughout this research, it is discovered that the temperature was optimal for chilli plant culture and did not exceed the threshold limit; thus, the pump did not operate during that period. The pump automatically activates when the value of all soil moisture sensors falls below the moisture threshold limit and automatically deactivates when the sensor value rises above the moisture threshold limit. However, the watering process was observed to be harmed by the sensors' sluggish data read procedure. As a result, the quality of sensors available on the market should be improved even further. Otherwise, the performance of this type of irrigation system will be jeopardized.

During the experiment, it was observed that the system successfully calculated the pump operation time. By multiplying this operation time with flow rate, the volume of water was calculated, which is updated both in the Blynk app and Google Sheets after pumping off. However, the pump's actual flow rate has been compromised in this research because the diameters of the pump inlet, the outlet of the hose pipe adapter are not identical. This is about 6.3 times less than normal pump flow rates. According to Bernoulli's theory, colossal pressure was created inside the pump to maintain the outlet flow rate of 35µm3/s, reducing water velocity. Such constraints can be overcome in a real-world scenario if the system is used in a broad area with appropriate pipe sizes and fittings. While the system can provide a rough estimate of how much is consumed, water flow sensors are highly recommended for obtaining more accurate figures.

APPENDIX

(a)

(b)

Date	Time	Temperature (°C)	Humidity (%)	SM1 (%)	SM2 (%)	SM3 (%)	Battery Voltage (V)	Soil moisture threshold (%)	Tempareture threshold (°C)	Pump status	Water Volume in (μ m3)
23/07/21	17:27:52	29.6	76	96	105	100	6.77	83	24	001	0.00
23/07/21	17:28:13	29.6	76	100	105	100	6.61	83	24	000	735.00
24/07/21	17:47:01	29.6	75	103	105	105	6.75	83	24		
23/07/22	18:07:03	29.5	75	103	105	105	6.77	83	24		
25/07/21	18:27:02	29.8	75	103	105	105	6.89	83	24		
23/07/23	18:47:02	29.7	74	103	105	105	6.71	83	24		
26/07/21	19:47:21	29.4	74.3	103	105	105	6.79	83	24		
23/07/24	19:56:40	29.5	73.8	103	105	105	6.90	83	24		
27/07/21	19:57:50	29.5	73.9	103	105	105	6.89	83	24		
23/07/25	19:57:57	29.5	73.9	103	105	105	6.89	83	24		
28/07/21	19:58:01	29.5	73.9	103	105	105	7.04	83	24		
23/07/26	19:58:09	29.5	73.9	103	105	105	6.89	83	24		
29/07/21	20:26:20	29.5	74	103	105	105	7.04	83	24	001	0.00
23/07/27	20:26:41	29.6	74	103	105	105	6.90	83	24	000	700.00

(c)

Figure 13. Screenshots of the Blynk app and Google sheets during temperature-induced pump operation (a) when pump is ON, (b) when pump is OFF, and (c) Google sheet data

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