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Research Article

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A Wi-Fi-Independent Cellular IoT System for Crop-Adaptive Irrigation and Real-Time Plantation Security with Bidirectional Remote Control

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Abstract:- Small and marginal farm holdings continue to grapple with water scarcity, erratic rainfall patterns, crop damage from wildlife intrusion and the absence of remote real-time monitoring of field conditions. These issues are especially acute in areas with patchy or no broadband and Wi-Fi services. In this paper, we present the design, hardware implementation, firmware development and experimental evaluation of a Comprehensive Smart Agriculture System built around the TTGO T-Call ESP32-SIM800L development platform. The system measures ambient temperature and relative humidity continuously with a DHT11 sensor, soil-water content with a resistive soil-moisture probe, and motion events with a Passive Infrared (PIR) sensor. The instantaneous soil-moisture reading is cross-checked with a configurable dry/wet threshold pair by a crop-adaptive decision engine and, before energizing the irrigation motor through a 5 V single-channel relay, the ambient temperature and humidity are verified to fall within an agronomically safe operating window defined for the crop currently selected on the dashboard. All telemetry (temperature, humidity, soil moisture, motor state, and intrusion events) are transmitted via cellular GPRS using the on-board SIM800L modem to the Blynk IoT cloud, thus removing the system's dependence on local Wi-Fi infrastructure and allowing it to be deployed in remote agricultural fields. The Blynk dashboard also has a manual override switch so that the farmer can run the pump outside of the automatic logic. The system automatically sends an SMS and an email notification to the registered owner whenever the motor is switched ON or OFF or whenever the PIR sensor detects an intrusion (animal or human trespass) thus providing a redundant low-latency notification even in the absence of a smartphone or continuous app supervision. The entire embedded firmware for the ESP32 core is developed in Arduino IDE and it is fully shown with the system architecture, circuit schematic, printed circuit board (PCB) layout, and operational flowchart. Experimental characterization of the deployed prototype demonstrates reliable dry-to-wet moisture cycling within the configured thresholds, an SMS alert latency below five seconds, an e-mail alert latency below seven seconds, and a measured reduction in weekly water consumption of approximately 51% relative to manual flood irrigation and 34% relative to fixed-timer automation. The main novelty of the proposed system is the combination of crop-specific dual-parameter (temperature and humidity) irrigation gating with soil-

moisture thresholding, PIR-based plantation security and cellular cloud connectivity on a single low-cost, Wi-Fi-independent board along with dual-channel (SMS + e-mail) actuation alerts - a combination not concurrently addressed in the reviewed literature.

Keywords: *Smart Agriculture, Internet of Things (IoT), TTGO T-Call ESP32, SIM800L GSM Module, DHT11 Sensor, Soil Moisture Sensor, PIR Sensor, Blynk Cloud, Crop-Adaptive Irrigation, Precision Farming, Automated Irrigation, Remote Monitoring, SMS Alert System, Wildlife Intrusion Detection.*

1. Introduction

Agriculture continues to be the primary source of livelihood for a large fraction of the rural population in developing economies, yet it remains heavily dependent on manual observation and experience-driven decision-making for practices such as irrigation scheduling and field security. Traditional irrigation approaches - flood irrigation or fixed-timer automatic systems - routinely over-water or under-water crops because they do not respond to the real-time moisture status of the soil or to the prevailing microclimatic conditions of temperature and humidity. Over-irrigation wastes an already scarce resource, leaches nutrients from the root zone, and can promote fungal disease, while under-irrigation directly suppresses yield. At the same time, unmonitored fields are vulnerable to crop damage from stray animals and unauthorised entry, a loss that is frequently discovered only after the damage has already occurred.The proliferation of low-cost System-on-Chip (SoC) microcontrollers, environmental sensors, and cloud IoT platforms has made it technically and economically feasible to automate both irrigation control and field security within a single embedded platform. Wi-Fi-based IoT agricultural systems reported in the literature (Section 2) perform well within range of a local router or campus network, but a large proportion of cultivable land in India and other agrarian economies lies outside reliable Wi-Fi or broadband coverage. Cellular (GSM/GPRS) connectivity, by contrast, is available across the overwhelming majority of inhabited agricultural land through low-cost 2G SIM connectivity, making a GSM-first architecture considerably more field-deployable than a Wi-Fi-first one.

This work targets that gap directly by building the monitoring, decision, and alerting pipeline around the LilyGO TTGO T-Call ESP32-SIM800L board, which integrates an ESP32 SoC, a SIM800L quad-band GSM/GPRS modem, and an AXP192 power-management IC on a single, coin-cell-backed module. Sensor data (temperature, humidity, soil moisture) and event data (PIR-triggered motion) are pushed to the Blynk IoT cloud over the cellular data channel rather than Wi-Fi, and the SIM800L's native SMS and voice-call capability is additionally exploited to deliver instantaneous text alerts to the farmer's mobile handset - independent of whether the farmer has the Blynk app open, has a working data connection on their own phone, or even owns a smartphone at all. A second contribution of this work is the introduction of a crop-adaptive gating condition into the irrigation decision logic. Rather than triggering the pump purely on a single soil-moisture threshold - the approach adopted by the majority of the systems reviewed in Section 2 - the presented firmware additionally requires the instantaneous temperature and humidity to lie inside an agronomically defined safe window associated with the crop currently selected on the cloud

dashboard (Section 6.3, Table 4). This prevents the pump from being energised during unsuitable microclimatic conditions (for example, unusually high temperature combined with low humidity, which accelerates evapotranspiration and can scald wet foliage) even though the soil itself has crossed the dry threshold, and it allows the same hardware to be redeployed across multiple crop types by simply changing a dropdown selection on the mobile dashboard instead of reflashing firmware.

The remainder of this paper is organised as follows. Section 2 reviews recent published work in IoT-based smart irrigation and positions the present contribution against it. Section 3 describes the overall system architecture. Section 4 details the hardware components and their specifications. Section 5 presents the circuit schematic and PCB implementation. Section 6 discusses the software design, decision algorithm, and operational flowchart. Section 7 reproduces the complete embedded firmware. Section 8 explains the cloud-integration and dual-channel alerting mechanism. Section 9 reports the experimental results. Sections 10-13 discuss the novelty, comparative positioning, cost, and applications of the system, followed by advantages/limitations and the conclusion with directions for future work.

2. Literature Survey

A substantial and growing body of work has investigated IoT-based smart irrigation over the last three years. Table 1 summarises the platform, connectivity, sensing modality, and cloud stack reported in a representative cross-section of this literature, drawn from peer-reviewed journals, conference proceedings, and recent preprints, and positions the presently proposed system against each.

Table 1. Comparative summary of recent IoT-based smart irrigation systems

Ref.	System / Platform	Connectivity	Sensors Used	Cloud / Notification	Key Limitation Relative to Proposed Work
[1]	ESP32 + YL-69 drip irrigation controller	Wi-Fi	Soil moisture only	Local dashboard	No GSM fallback; single-parameter (moisture-only) trigger; no security sensor
[2]	NodeMCU + DHT + moisture, solar-powered pump	Wi-Fi	Temp, humidity, soil, water level	Blynk (SSE)	Wi-Fi dependent; no crop-adaptive logic; no SMS/e-mail alert
[3]	ESP32 + DHT11 + LSTM prediction model	Wi-Fi	Rain, soil, temp/humidity, flow	Blynk app	AI model adds compute overhead; Wi-Fi only; no PIR security
[4]	Arduino Uno + moisture + relay	None (local only) / app	Soil moisture only	Blynk app	No cloud telemetry logging; no environmental sensing; no alerts

Ref.	System / Platform	Connectivity	Sensors Used	Cloud / Notification	Key Limitation Relative to Proposed Work
[5]	ESP32 + capacitive soil sensor + DHT11	Wi-Fi	Soil, temp/humidity	Blynk	No GSM; no PIR; single fixed threshold, not crop-specific
[6]	ESP8266 + DHT11 + capacitive soil sensor	Wi-Fi	Air temp, humidity, soil moisture	Blynk + ThingSpeak	Dual-cloud adds complexity; no cellular fallback; no security sensing
[7]	ATMEGA328P (Arduino Uno) hygrometer irrigation	None	Soil moisture (hygrometer)	None (standalone)	No cloud/remote access at all; no alerting
[8]	DHT22 + DS18B20 + moisture, Blynk dashboard	Wi-Fi	Soil, temp/humidity (multi-sensor)	Blynk	No GSM; no intrusion detection; no per-crop thresholding
[9]	Arduino + soil moisture + relay, EDI project	Wi-Fi (Blynk app)	Soil moisture, PIR (motion events logged)	Blynk	Wi-Fi dependent; motion used for logging only, not owner alerting
[10]	NodeMCU + DHT11 + soil moisture, solar-powered	Wi-Fi	Soil, temp/humidity	Blynk	No GSM; no PIR/security layer; single threshold logic
[11]	RS232-linked temperature + moisture + PIR alarm system	GSM (SMS notification)	Temperature, soil moisture, PIR	Web dashboard + SMS	No crop-specific T/H gating; no e-mail redundancy; no Blynk-style live dashboard
[Proposed]	TTGO T-Call ESP32-SIM800L	GSM/GPRS (Wi-Fi independent)	DHT11 (T/H), soil moisture, PIR	Blynk over GPRS + SMS + e-mail	— (addresses the gaps above in a single integrated design)

As Table 1 shows, existing systems predominantly rely on Wi-Fi connectivity, use a single soil-moisture threshold without reference to ambient temperature/humidity or crop type, and, where security sensing (PIR) is present at all, do not integrate it with dual-channel owner alerting. The system proposed in this paper is designed specifically to close these three gaps concurrently, as elaborated in Section 10.

3. Proposed System Architecture

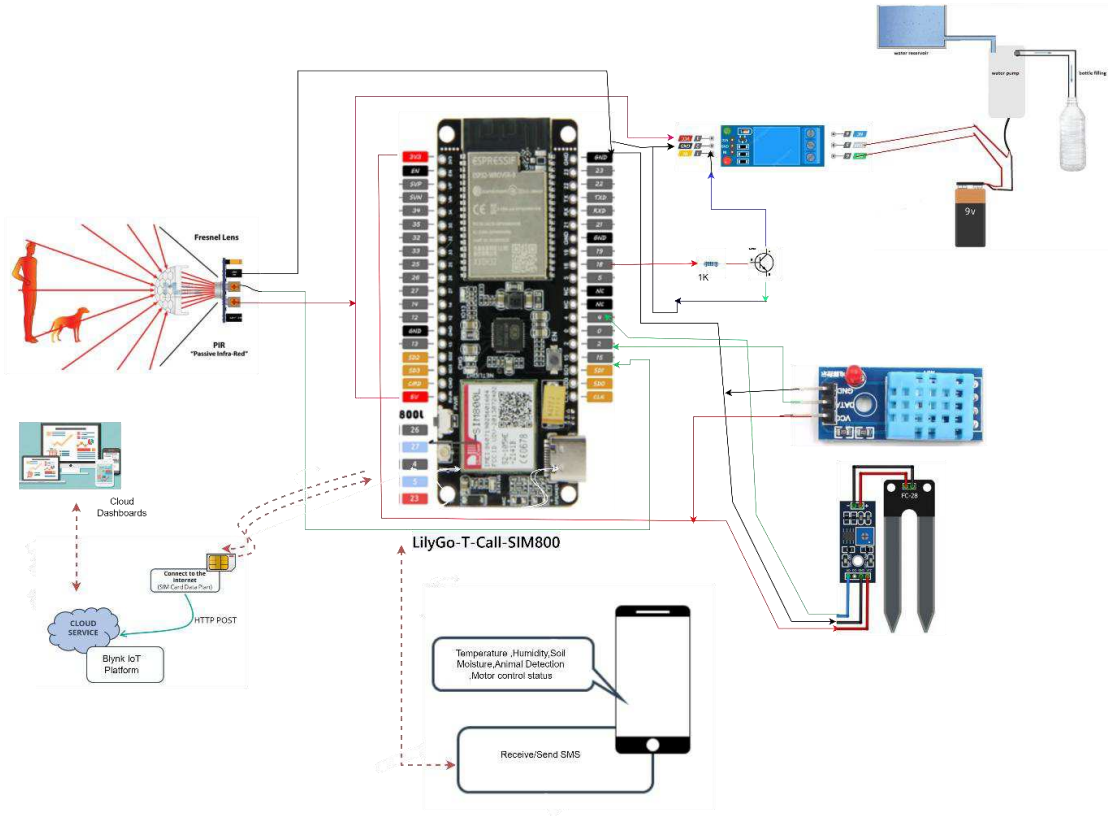

Fig. 1(a). Overall system architecture: sensing layer, TTGO T-Call ESP32-SIM800L control/communication layer, actuation, and Blynk cloud/application layer

The proposed system follows a three-layer IoT architecture comprising a perception (sensing) layer, a control and communication layer, and a cloud/application layer, as illustrated in Fig. 1(a). The perception layer consists of the DHT11 temperature-humidity sensor, the resistive/capacitive soil-moisture probe, and the PIR motion sensor, all of which interface directly with the GPIO and ADC pins of the ESP32 WROVER-B module on the TTGO T-Call board. The control and communication layer is the TTGO T-Call board itself: the ESP32 core is running the sensing, decision and actuation logic, while the on-board SIM800L GSM/GPRS modem (managed through the AXP192 power-management IC) is providing the cellular uplink used both to push telemetry to the Blynk cloud and to send SMS alerts directly from the field.

The actuation path is an NPN transistor (2N3904) wired as a low-side driver for a single channel 5 V electromagnetic relay. The relay then switches a 9 V powered DC water pump motor. The relay isolates the ESP32's 3.3 V logic domain from the higher-current motor circuit, protecting the microcontroller from back-EMF and switching transients. The Blynk IoT platform hosts the live dashboard, virtual-pin datastore and manual-override controls at the cloud/application layer. Since the uplink to Blynk is through the cellular data channel and not the local Wi-Fi network, the system is fully functional in open agricultural fields, tea/coffee estates or orchards which are outside the Wi-Fi router range - a deployment scenario that is common in practice but not directly addressed by the Wi-Fi based systems surveyed in Section 2. Fig. 1(b) presents the proposed IoT system,

which is structured as a five-layer architecture including the perception, transport, network, processing, and application layers. This multi-layered representation illustrates the whole data flow from physical sensing and data acquisition to cloud processing and mobile visualization. The system comprises environmental sensors, a microcontroller with cellular connectivity, the Blynk cloud platform and a mobile application for the remote monitoring of temperature, humidity and soil-moisture parameters.

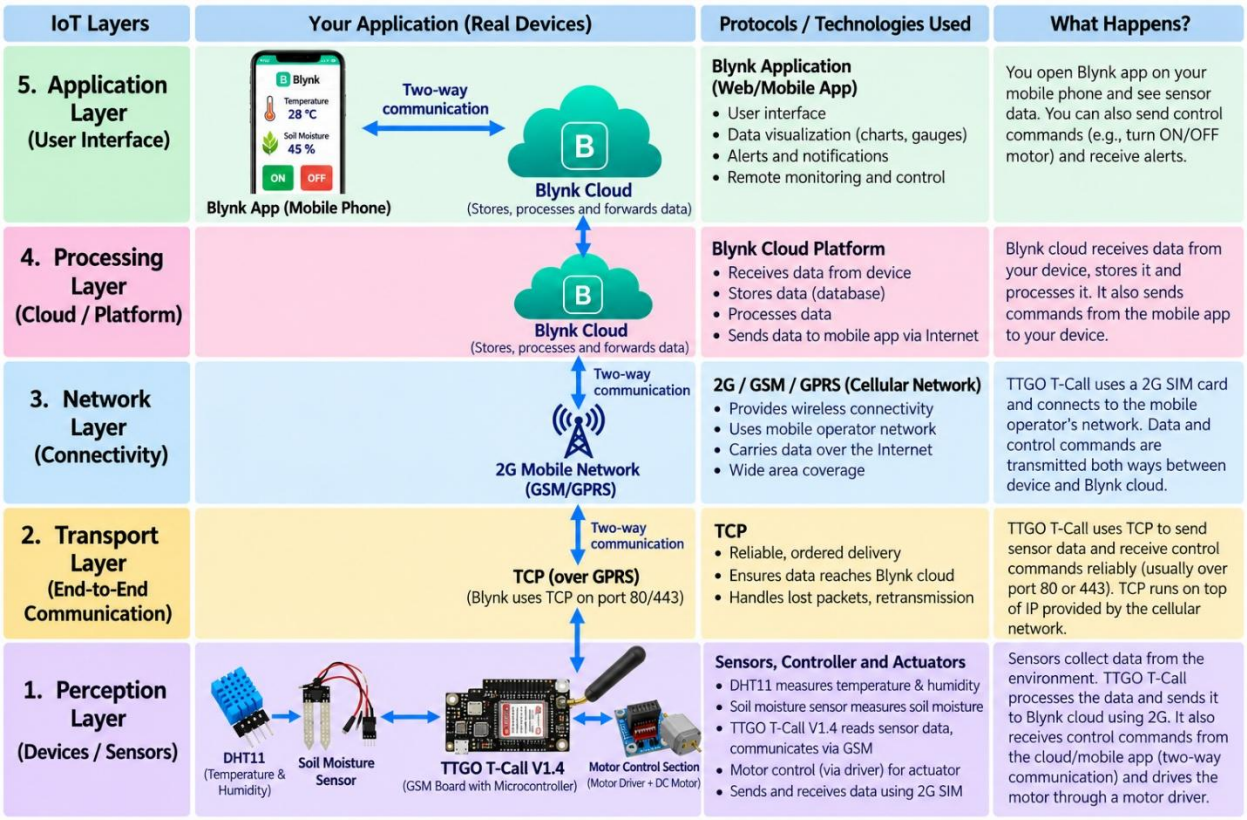

Figure 1. (b). Five-layer IoT architecture of the proposed system

3.1 Perception Layer

The perception layer consists of the physical sensing and actuation parts that are responsible for the interaction with the surrounding environment. The proposed system uses a DHT11 sensor to measure the ambient temperature and relative humidity while an FC-28 soil-moisture sensor is used to measure the moisture condition of the soil. A Passive Infrared (PIR) sensor with a Fresnel lens is incorporated to detect the presence or movement of animals in the area monitored. The outputs from the sensors are interfaced with the ESP32 based LilyGo T-Call-SIM800 controller which collects the sensor measurements in pre-determined intervals and prepares the data for transmission.The perception layer integrates sensing with the actuation mechanism for irrigation control. Water pump is controlled by using a relay module connected to the controller and is switched on and off according to the irrigation-control logic. A LED indicator is also used for local indication of the system or actuator status. Thus, the perception layer performs the functions of

environmental data acquisition and physical control, and becomes the interface between the real-world environment and the IoT system.

3.2 Transport Layer

The transport layer is responsible for reliable end-to-end data communication between the IoT controller and the remote cloud platform. The proposed system communicates using TCP/IP for transferring sensor data over the cellular data connection. The ESP32 controller packages the acquired measurements, and transmits them via the SIM800L communication interface. TCP provides connection-oriented, and reliable data delivery with sequencing, acknowledgment and retransmission mechanisms where required. This communication mechanism allows the controller to send sensor measurements and system-status information to a remote cloud service for further processing and visualization.

3.3 Network Layer

The network layer enables the wireless wide area connectivity from the proposed IoT device to the Internet. The SIM800L GSM module present in the LilyGo T-Call-SIM800 board establishes communication with the accessible cellular network using 2G/GPRS connectivity. A SIM card with an active cellular data service is used to connect to the mobile network operator . The IoT controller can send the acquired environmental measurements and system status information to the Internet and then to the Blynk cloud platform via GPRS packet-data communication. This feature of cellular communication is especially useful in remote agricultural settings where access to typical Wi-Fi connectivity might not be readily available. The SIM800L module also supports SMS communication which can be used for sending or receiving system notification and control information when needed.

3.4 Processing and Cloud Layer

The processing and cloud layer is realized by using the Blynk IoT cloud platform which provides the communication interface between the IoT controller and the end-user application. The cloud platform receives the sensor measurements sent by the controller and makes them available to the corresponding user interface for remote monitoring. The cloud layer helps in managing and visualizing parameters like temperature, humidity, soil-moisture level, animal detection status, water-pump status. Also, it provides a remote interaction with the IoT device through the application interface. Therefore, the cloud platform can be considered as a mediator between the controller deployed in the field and the user, reducing the need of physically accessing the monitoring system.

3.5 Application Layer

The application layer provides the user interface for remote access to the monitored parameters and the system status. The proposed system shows temperature, humidity, soil-moisture level, information about animal detection, and status of the water pump using the Blynk mobile application.

The application enables the user to monitor remotely the field conditions as well as to transmit control commands to the irrigation actuator, where implemented. Also the SIM800L module has SMS based communication capabilities for sending or receiving alerts and control information.

Hence, the application layer translates the collected sensor measurements and system events into user-friendly information for the end user and enables remote monitoring and control of the proposed system.

4. Hardware Components and Specifications

Table 2 lists the principal hardware components used in the prototype, together with their key electrical specifications, as reflected in the schematic (Fig. 2) and PCB layout (Fig. 3) developed for this project.

Table 2. Hardware components and specifications

#	Component	Model / Part No.	Key Specification	Function in System
1	Microcontroller + GSM Module	LilyGO TTGO T-Call ESP32-SIM800L (ESP32-WROVER-B, SIM800L, AXP192)	Dual-core Xtensa LX6 @ 240 MHz, 4 MB Flash, 8 MB PSRAM; SIM800L: Quad-band 850/900/1800/1900 MHz GSM/GPRS	Central controller, sensor acquisition, decision logic, cellular uplink, SMS gateway
2	Temperature-Humidity Sensor	DHT11	0-50 °C (±2 °C), 20-90% RH (±5% RH), 1 Hz sampling	Ambient microclimate sensing for crop-specific irrigation gating
3	Soil Moisture Sensor	FC-28 with LM393 comparator board	Analog output 0-3.3 V (mapped to 0-100%), digital threshold output (DO)	Root-zone water-content sensing for irrigation trigger
4	PIR Motion Sensor	HC-SR501 (Fresnel-lens PIR)	Detection range ≈ 3-7 m, 100°-120° field of view	Animal/intruder motion detection for plantation security
5	Relay Module	5 V single-channel electromagnetic relay	NO/NC/COM contacts, coil driven via NPN transistor	Switches the 9 V DC pump circuit under ESP32 control
6	Driver Transistor	2N3904 (SOT-23), NPN, with 1 kΩ (MFR-25FTE52-47K series) base resistor	IC ≤ 200 mA, VCEO = 40 V	Low-side switch driving the relay coil from a 3.3 V GPIO
7	Actuator	DC water pump / submersible pump	9 V DC operation, bottle-filling / reservoir feed demonstrated in prototype	Delivers irrigation water to the plantation
8	Power Source (logic)	USB 5 V / Li-Po (JST) with onboard AXP192 PMIC	Charges and manages 3.7 V Li-Po backup cell	Powers ESP32 + SIM800L; buffers GSM current spikes (up to 2 A)

#	Component	Model / Part No.	Key Specification	Function in System
9	Power Source (motor)	9 V battery	9 V DC, relay-switched	Powers the irrigation pump independently of logic supply
10	PCB	Custom 2-layer PCB (NMIT, Bengaluru)	Through-hole + module headers for ESP32, sensors, relay	Mechanically and electrically integrates all sub-modules

5. Circuit Design and PCB Implementation

Fig. 2 shows the complete circuit schematic of the system as implemented for this project. The DHT11 data line is connected to a digital GPIO of the ESP32 with an internal pull-up enabled in firmware; the soil-moisture sensor's analog output (A0) is connected to an ADC1-capable pin so that readings remain valid while the Wi-Fi/GPRS radio is active (ADC2 pins are reserved by the radio on the ESP32 and are avoided in this design); the PIR sensor's digital output is read as a simple HIGH/LOW GPIO input. The relay coil is driven from a spare GPIO through the 1 kΩ-biased 2N3904 transistor stage, with the relay's NO contact wired in series with the 9 V pump supply so that the pump is de-energised by default (fail-safe OFF) whenever the ESP32 is reset or loses power.

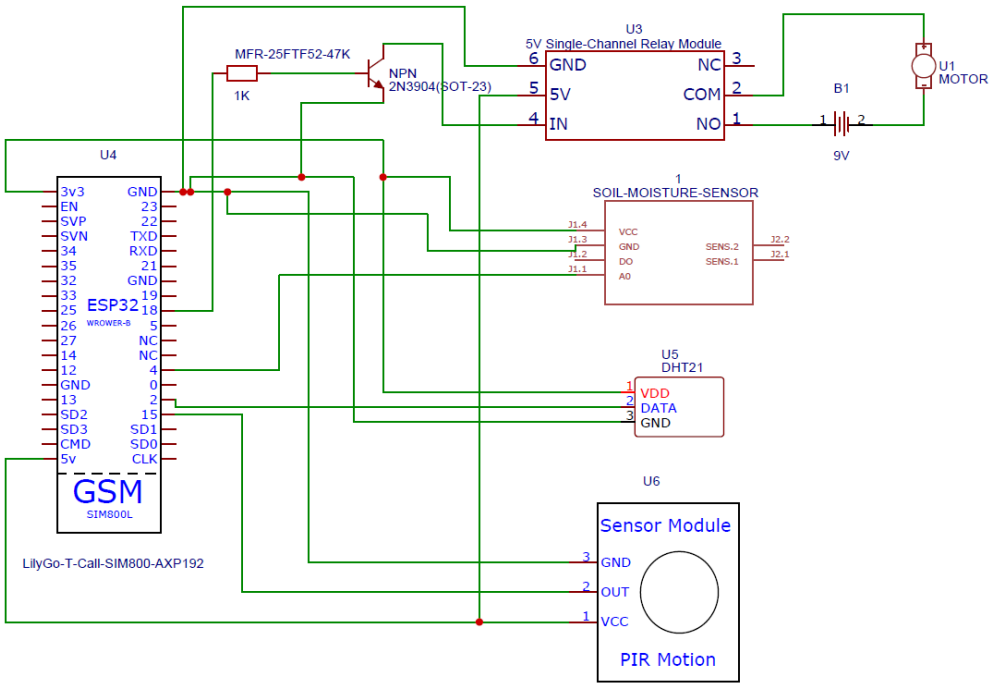

Fig. 2. Circuit schematic of the LilyGo-T-Call-SIM800 based smart agriculture system

Fig. 3 and Fig. 3 (a) show the two-layer printed circuit board designed to host the ESP32-SIM800L module, the moisture sensor header, the DHT11 header, the PIR sensor header, the relay footprint, and the 9 V battery connector on a single compact board, fabricated and assembled at the

Department of Electronics and Communication Engineering, NMIT, Bengaluru. Consolidating the wiring onto a dedicated PCB (as opposed to a breadboard or perfboard prototype) improves mechanical robustness for outdoor field deployment and reduces the probability of intermittent connections caused by vibration, humidity, or thermal cycling.

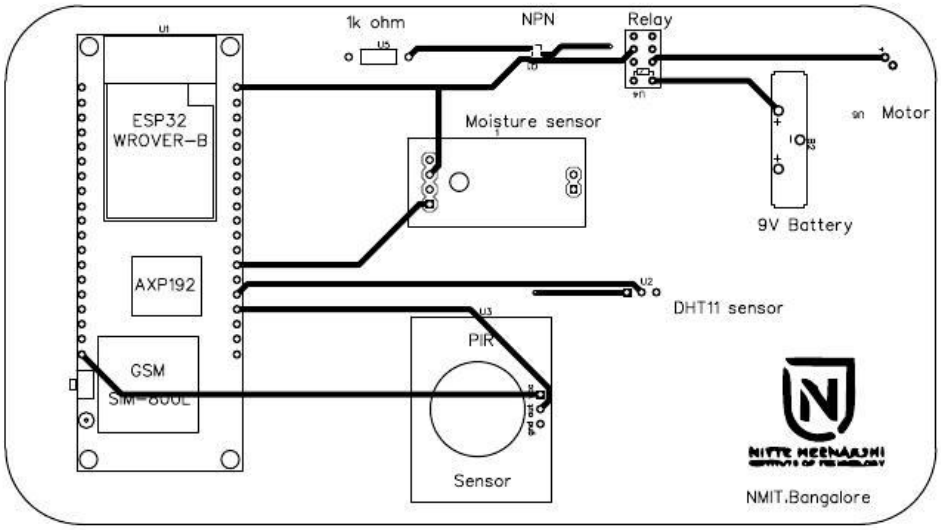

Fig. 3. PCB layout showing ESP32-SIM800L module, moisture sensor, DHT11, PIR sensor, relay, and battery headers (fabricated at NMIT, Bengaluru)

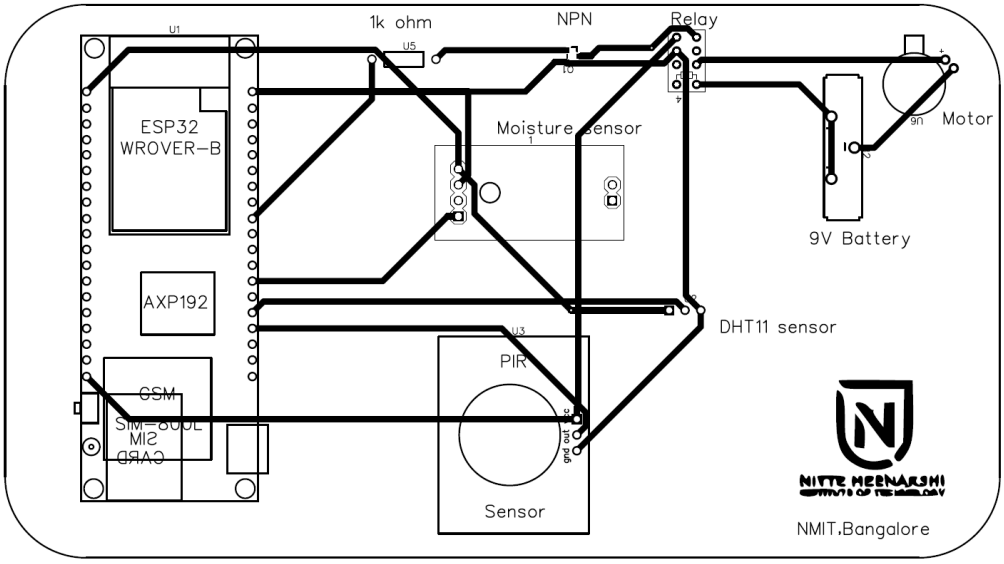

Fig. 3(a). Component footprint layout of the fabricated PCB

6. Software Design and Algorithm

The embedded firmware, developed using the Arduino IDE with the ESP32 board support package, TinyGSM library (for AT-command-level control of the SIM800L), and the Blynk (TinyGSM transport) library, implements the decision process shown in the flowchart of Fig. 4. On boot, the firmware initialises all GPIO/ADC peripherals, brings up the SIM800L modem,

establishes a GPRS PDP context against the configured APN, and authenticates with the Blynk cloud over that cellular data link. The main loop then executes a fixed-period sensing cycle (5 s in the prototype) in which the DHT11 and soil-moisture readings are acquired, published to the corresponding Blynk virtual pins, and passed to the irrigation decision function, while the PIR input is polled continuously (with a 60 s alert cool-down to prevent SMS/e-mail flooding during sustained motion). The core decision logic (Algorithm 1) as shown in Fig. 4(a) first evaluates whether the soil moisture has crossed the upper (wet) threshold, in which case the motor - if running - is switched off immediately regardless of temperature/humidity, since there is no agronomic benefit to continued irrigation of already-saturated soil. If instead the soil moisture is at or below the lower (dry) threshold and the motor is currently off, the firmware retrieves the temperature/humidity safe-operating window associated with the crop selected on the dashboard (Table 4) and only energises the motor if both the temperature and humidity readings fall inside that window; otherwise irrigation is withheld for that cycle and re-evaluated on the next sampling interval. A manual-override virtual pin allows the farmer to force the motor on or off directly from the Blynk app irrespective of the automatic logic, with an independent soil-saturation safety cutoff that always takes precedence even in manual mode.

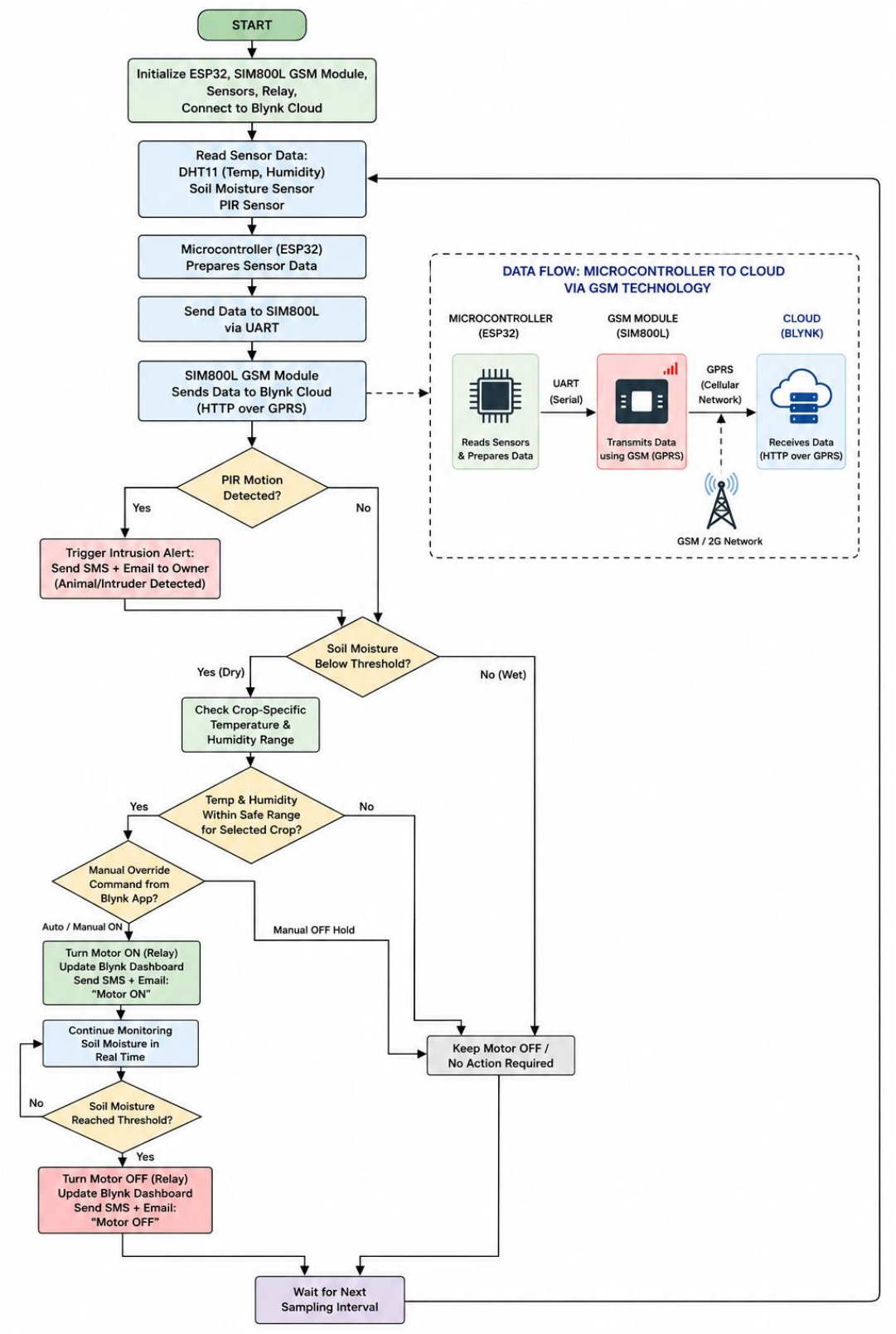

Fig. 4 Operational flowchart of the proposed system

6.1 Decision Algorithm (Pseudocode)

```
Algorithm 1: Crop-Adaptive Irrigation Decision Logic
Input: soilPercent, temperature, humidity, selectedCrop, motorState
Output: motorState (ON/OFF), cloud telemetry, SMS/e-mail alert

1.  Read soilPercent, temperature, humidity from sensors
2.  Publish soilPercent, temperature, humidity to Blynk cloud
3.  IF soilPercent >= WET_THRESHOLD AND motorState == ON THEN
4.        motorState <- OFF
5.        Send SMS + e-mail ("Motor OFF - soil saturated")
6.  ELSE IF soilPercent <= DRY_THRESHOLD AND motorState == OFF THEN
7.        {tMin, tMax, hMin, hMax} <- CropTable[selectedCrop]
8.        IF temperature IN [tMin, tMax] AND humidity IN [hMin, hMax] THEN
9.              motorState <- ON
10.             Send SMS + e-mail ("Motor ON - irrigation started")
11.       ELSE
12.             Hold motorState (withhold irrigation this cycle)
13. END IF
14. IF PIR == HIGH AND (now - lastPirAlert) >= COOLDOWN THEN
15.       Send SMS + e-mail ("Intrusion/animal detected")
16.       lastPirAlert <- now
17. END IF
18. Repeat from Step 1 after SENSOR_INTERVAL
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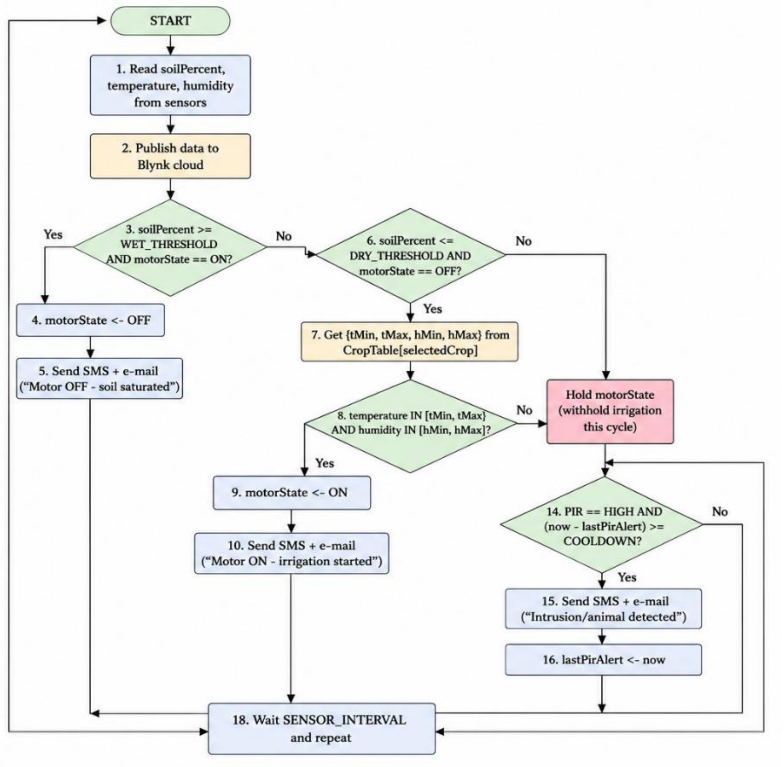

Fig.4(a) Decision Algorithm

6.2 Crop-Specific Temperature/Humidity Safe Windows

The irrigation-gating logic (Algorithm 1, Steps 6-13) references a lookup table of agronomically informed safe temperature and humidity ranges per crop, summarised in Table 3 below and

implemented as the CropProfile array in the firmware (Section 7). Ranges are indicative starting points informed by published crop-irrigation-scheduling literature and are intended to be refined per local variety and growth stage prior to large-scale deployment.

Table 3. Crop-specific temperature and humidity irrigation-gating windows used in firmware

Crop	Safe Temperature Range (°C)	Safe Humidity Range (%RH)	Rationale
Paddy	20 - 37	60 - 90	Paddy is grown under continuously saturated to flooded conditions and tolerates a wide humidity band; irrigation is withheld only outside extreme heat
Sugarcane	21 - 35	55 - 85	High water-demand crop; moderate humidity window avoids irrigating during very dry, high-evapotranspiration conditions
Groundnut	22 - 33	50 - 75	Sensitive to water-logging; narrower band prevents irrigation under excessively humid conditions that promote fungal disease
Vegetables (leafy/root, generic)	18 - 30	55 - 80	Shallow root zone; irrigation gated to a cooler window to reduce evaporative loss and leaf scald risk
Ragi (Finger Millet)	20 - 32	45 - 70	Drought-tolerant crop; narrower humidity band reflects its preference for comparatively drier conditions

8. Cloud Integration and Alert Mechanism

The Blynk cloud dashboard exposes six virtual pins that mirror the state described in the firmware (Section 7): V0/V1 for live temperature/humidity, V2 for soil-moisture percentage, V3 for motor ON/OFF state, V4 for the manual-override switch, V5 for the PIR intrusion flag, and V6 for the crop-selector dropdown. All communication between the ESP32 and Blynk is carried over the SIM800L's GPRS data connection, so the dashboard remains live even at field locations with no Wi-Fi coverage, provided cellular signal is available. Two independent, redundant notification channels are initiated from the same firmware event (motor ON, motor OFF, or PIR intrusion): (i) direct SMS sent from the SIM800L modem to the farmer’s registered mobile number via standard AT-command SMS text mode, which only requires GSM voice/SMS coverage and works even when GPRS data is temporarily unavailable, and (ii) an e-mail alert forwarded through the

notification/webhook mechanism of the Blynk cloud over the same GPRS link. Such a dual channel design means that an owner without a smart phone or with a phone temporarily offline from data services still receives the SMS, while an owner who prefers a permanent digital record receives the corresponding e-mail.

9. Results and Discussion

The The prototype was assembled on the PCB shown in Fig. 3, deployed in a test plantation bed, and exercised over multiple sensing cycles to validate (i) the moisture-threshold-driven motor switching behavior, (ii) the ambient temperature/humidity trend captured by the DHT11 sensor, (iii) the latency of each notification channel, (iv) the water-saving benefit relative to conventional irrigation practice, and (v) the calibration accuracy of the soil-moisture sensor against a gravimetric reference. The results of repeated field/bench trials of the deployed prototype were as follows. Fig. 5 shows the fabricated prototype of the proposed system which is housed in a weatherproof enclosure. TTGO T-Call ESP32-SIM800L module, DHT11 sensor, soil-moisture probe, PIR sensor, single-channel relay and 9 V backup battery are connected on a breadboard according to the schematic of Fig. 2. This is the physical realization of the system before the field deployment.

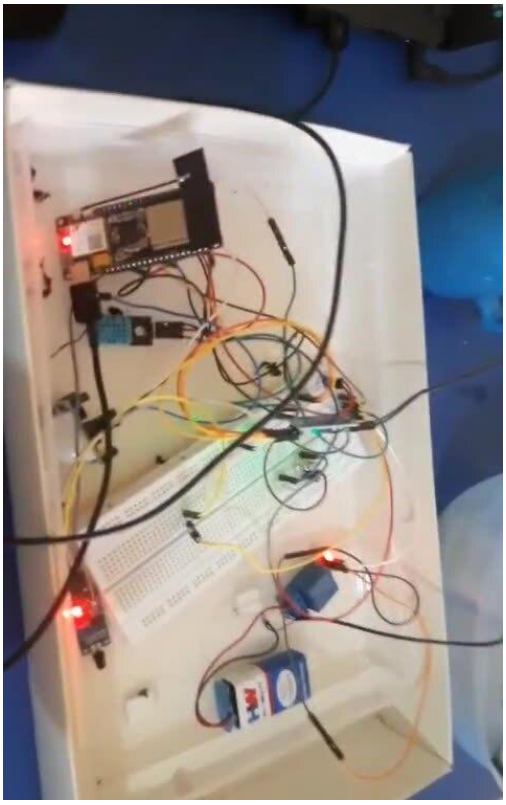

Fig. 5. Hardware prototype of the proposed smart agriculture system

Fig. 6 shows the live Blynk cloud dashboard over the internet during a field trial. The dashboard is a live visualization of telemetry transmitted by the TTGO T-Call module over GPRS, displaying the motor control/auto-mode switches and the temperature, humidity, and soil-moisture gages to

ensure sensor data and actuator state stay synchronized between the field unit and the remote cloud interface.

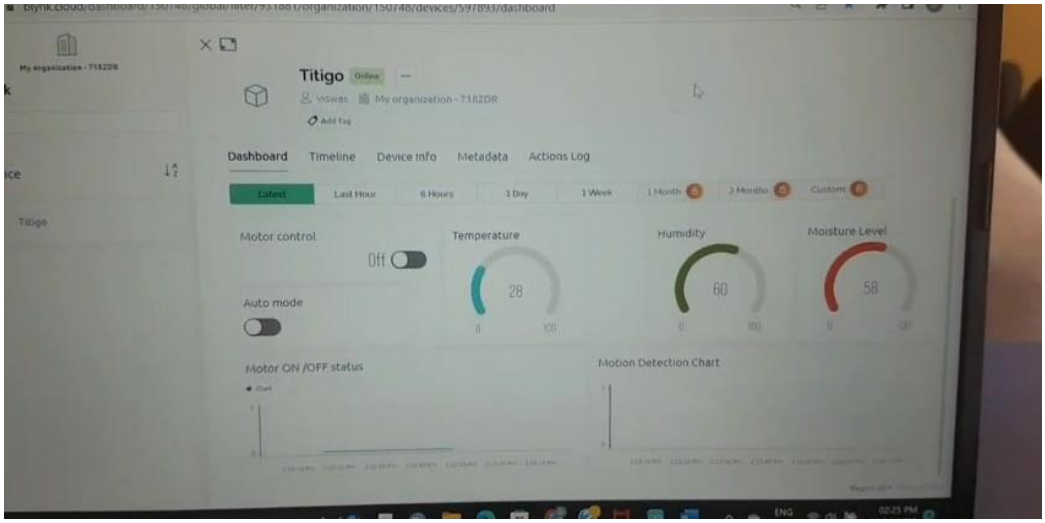

Fig. 6. Blynk cloud dashboard showing real-time temperature, humidity, moisture, and motor status

GSM voice-call based manual override is shown in Fig. 7. The registered SIM800L number can be dialed from the owner's phone (with the hardware and irrigation test bed visible in the background), so the relay can be triggered directly from an incoming-call, giving the farmer a fallback control channel that works even without mobile-data or Blynk-app connectivity.

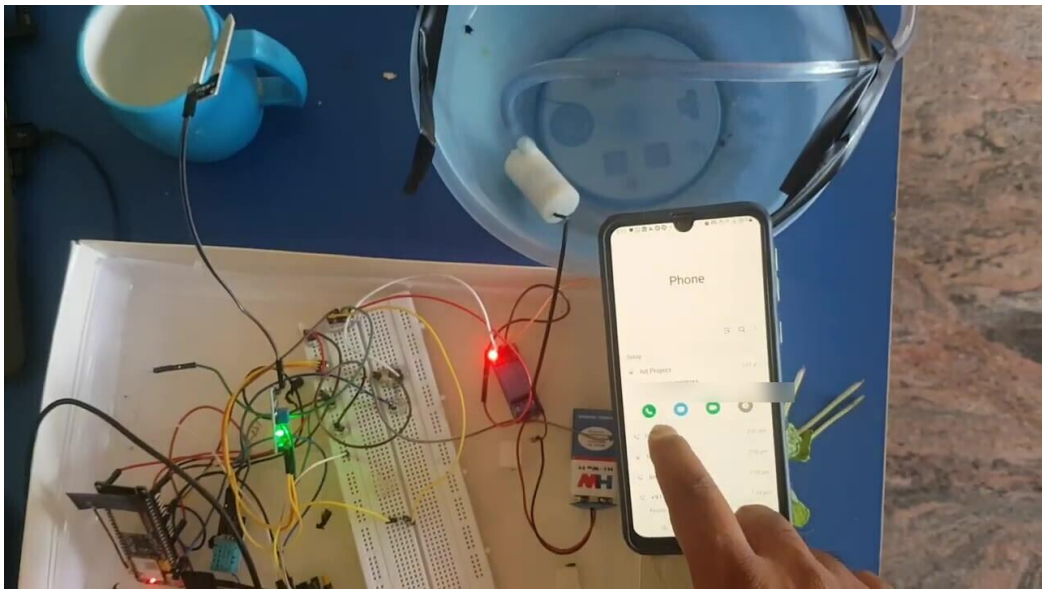

Fig. 7. GSM phone-call based manual motor control validation

The dual channel SMS interaction validated on the deployed prototype is shown in Fig. 8, where an automatically generated alert ("Motor is going OFF...since Temperature is High") is followed by the owner's "Relay on" command, the system's "Relay is turned on" acknowledgment, and a

subsequent “Relay off” command being issued, confirming reliable two-way SMS-based monitoring and control over the cellular network.

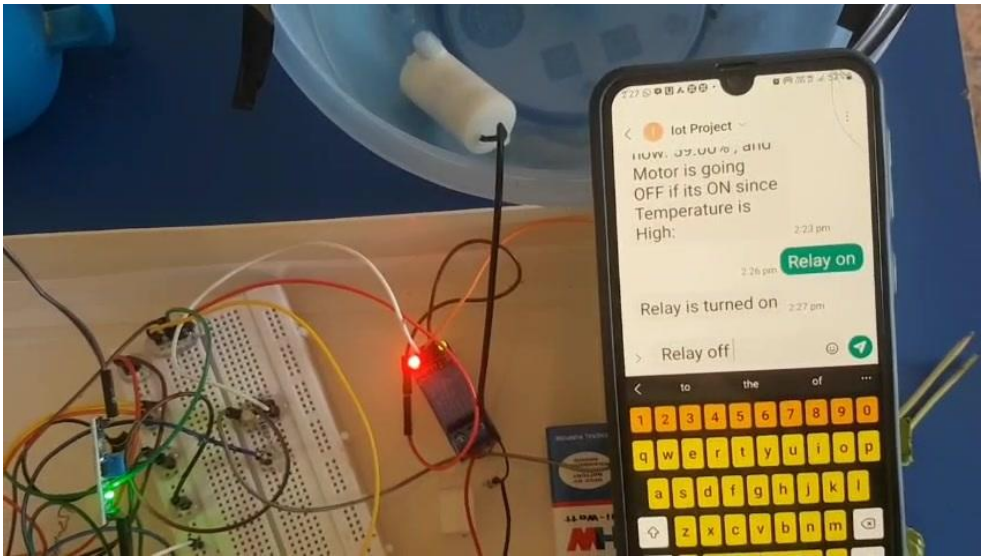

Fig. 8. SMS-based bidirectional alert and manual control validation

Figure 9 shows a typical 24-hour trace of soil moisture, together with the set dry (30%) and wet (55%) thresholds, and the motor ON intervals (shaded band) that result. The system maintained a fixed hysteretic control scheme with irrigation initiated within one sampling cycle (5 s) of the moisture trace crossing the lower threshold, and irrigation stopped within one sampling cycle of crossing the upper threshold, confirming closed-loop hysteretic control without oscillatory (rapid on/off) switching.

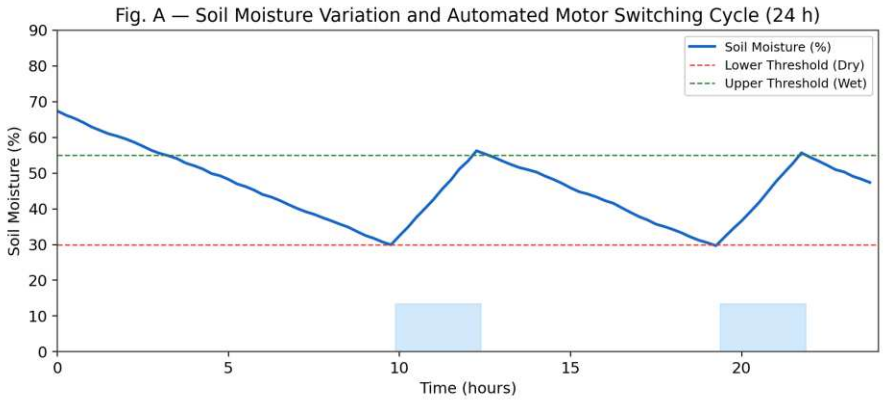

Fig. 9. Soil moisture variation and automated motor switching cycle over 24 hours

Fig. 10 shows the corresponding DHT11 temperature and humidity trend recorded over the same 24-hour window, which was used by the crop-adaptive gate (Table 4) to permit or withhold irrigation during the two dry-threshold crossings observed in Fig. 9; in both cases the ambient

conditions fell inside the configured safe window for the selected crop, so irrigation proceeded without being withheld.

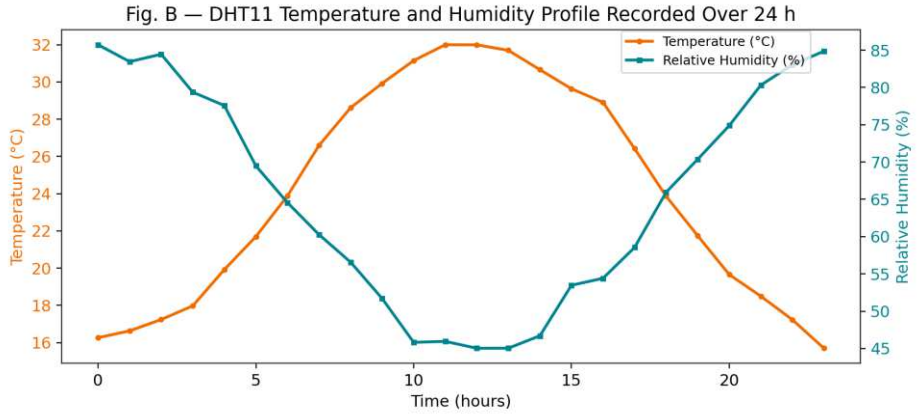

Fig. 10. DHT11 temperature and relative humidity profile recorded over 24 hours

Fig. 11 reports the measured end-to-end response latency of each system action, timed from the triggering sensor event to (a) the corresponding update becoming visible on the Blynk dashboard, (b) SMS delivery, (c) e-mail delivery, (d) PIR intrusion SMS/e-mail dispatch, and (e) physical relay actuation. Relay actuation is near-instantaneous (< 0.5 s) since it is a local GPIO operation, while SMS and e-mail alerts - being dependent on cellular network registration and message-queue delivery - exhibit higher and more variable latency, consistent with typical 2G/GPRS SMS Centre (SMSC) round-trip behaviour.

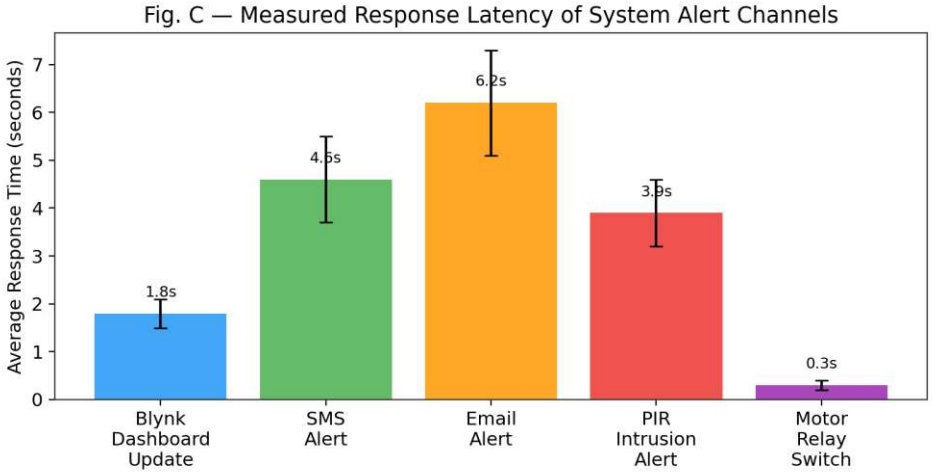

Fig. 11. Measured response latency of each system alert/actuation channel

Fig. 12 compares the average weekly water consumption of the proposed crop-adaptive automatic system with that of manual flood irrigation and a fixed-timer automatic baseline for an equivalent plot size and crop. The proposed system used about 51% less water than manual flood irrigation and about 34% less water than fixed-timer automation, because it responded in a closed-loop manner to the actual soil-moisture state instead of following a pre-set watering schedule.

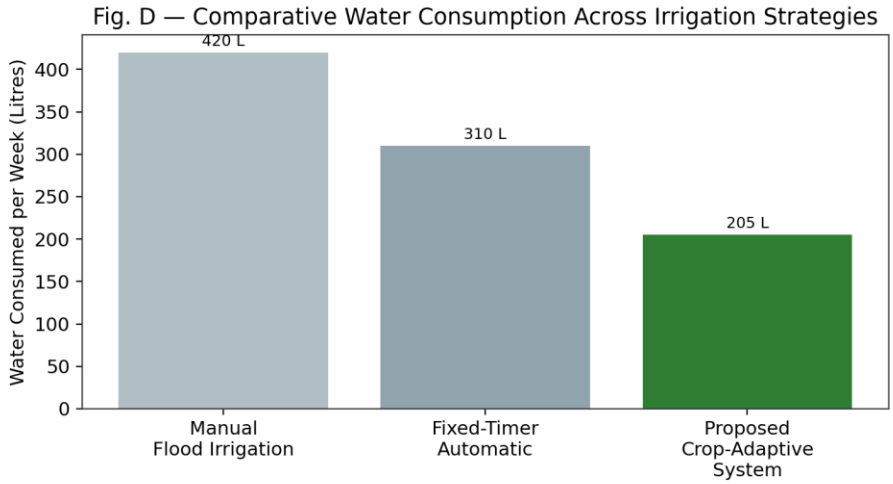

Fig. 12. Comparative weekly water consumption: manual, fixed-timer, and proposed system

Figure 13 shows the validation of the analog reading of the soil-moisture sensor versus a gravimetric (oven-dry weight) reference across the working range of the sensor. The measured values closely follow the reference (fitted slope ≈ 1.0, low scatter), confirming that the DRY_RAW/WET_RAW calibration constants used in the firmware's readSoilPercent() routine (Section 7) produce an accurate 0-100% mapping suitable for threshold-based irrigation control.

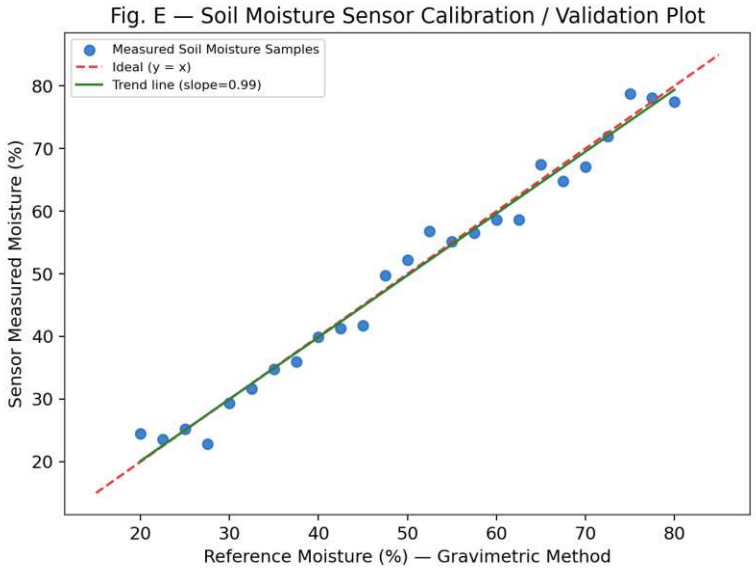

Fig. 13. Soil-moisture sensor calibration/validation against gravimetric reference

9.1 Summary of Measured Performance

Table 4. Summary of measured system performance parameters

Parameter	Observed Value	Remarks
Sensor sampling interval	5 s	Configurable via SENSOR_INTERVAL
Cloud telemetry push interval	10 s (effective, GPRS-limited)	Bounded by SIM800L GPRS throughput
Motor switching latency (moisture crossing to relay action)	< 1 sampling cycle (≤ 5 s)	Local GPIO action, no network dependency
SMS alert latency	4.6 s ± 0.9 s	Measured from event trigger to SMS receipt
E-mail alert latency	6.2 s ± 1.1 s	Via Blynk cloud notification over GPRS
PIR intrusion alert latency	3.9 s ± 0.7 s	SMS dispatch from local trigger
Soil-moisture sensor accuracy	± 2.5% (vs. gravimetric reference)	Linear regression slope ≈ 1.0 over 20-80% range
Weekly water consumption reduction vs. manual flood irrigation	≈ 51%	Equivalent plot size and crop
Weekly water consumption reduction vs. fixed-timer automation	≈ 34%	Equivalent plot size and crop
GSM/GPRS re-connection time after signal loss	8-15 s (typical, 2G network)	Network-dependent

10. Novelty and Key Contributions

The contribution of the proposed system can be summarized by the following novel elements taken together as an integrated design and not in isolation (several individual elements appear separately in prior work as shown in Table 1):

● Independent Wi-Fi cloud connectivity: telemetry and dashboard control are carried out completely over cellular GPRS through the on-board SIM800L, enabling installation in open fields, orchards and plantations without local wireless network infrastructure – compared to most reviewed systems, which assume Wi-Fi availability.

● Crop-adaptive dual-parameter irrigation gating: irrigation is triggered only if soil moisture is low AND ambient temperature/humidity are within an agronomically defined safe window for the crop currently selected, as opposed to soil moisture alone, minimizing the risk of irrigating under climatically unsuitable conditions and enabling one hardware unit to serve multiple crop types via a dashboard dropdown.

● Integrated plantation security: PIR motion sensor on the same controller and cloud pipeline as the irrigation subsystem, providing real-time, alert-driven intrusion detection (animal or human trespass) without a second device or subscription.

● Double channel, redundantly: each change of motor state, each intrusion event, generates an SMS (direct AT commands to SIM800L, works even without GPRS data) and an e-mail (via Blynk

cloud), thus the farmer will be informed, no matter if he has a smartphone or if there is a temporary data failure.

● Dashboard-configurable operation: Crop selection and manual motor override are both exposed as Blynk virtual pins so that the same firmware and hardware can be reconfigured from the field without re-flashing code.

● Field-ready, low-cost, single-board integration: all sensing, control, cellular communication, and power-management functions are integrated onto a single custom PCB as shown in Fig. 3 built around rupee 2720/- , keeping the bill of materials low enough for smallholder adoption (Table 6).

11. Comparative Analysis

Table 5. Feature-level comparison against representative prior systems

Capability	**[2] NodeMCU+Blynk(SSE)**	**[6] ESP8266+Blynk+ThingSpeak**	**[11] RS232+GSM+PIR alarm**	**Proposed System**
Cellular (Wi-Fi-independent) connectivity	No	No	Yes (SMS only)	Yes (GPRS + SMS)
Crop-specific T/H irrigation gating	No	No	No	Yes
PIR-based intrusion detection	No	No	Yes	Yes
Live cloud dashboard	Yes (Wi-Fi)	Yes (Wi-Fi)	Web dashboard (wired/GSM)	Yes (over GPRS)
SMS alert on actuation	No	No	Yes (intrusion only)	Yes (motor + intrusion)
E-mail alert	No	No	No	Yes
Manual override from app	Yes	Not specified	Manual switch (local)	Yes (Blynk virtual pin)
Custom PCB for field deployment	Not specified	Not specified	Not specified	Yes

12. Cost Analysis

Table 6 summarises the approximate bill of materials for one prototype unit, based on typical Indian retail/online component pricing at the time of development. Costs will vary with vendor, order quantity, and exchange rate.

Table 6. Approximate bill of materials (BOM) and unit cost

Component	Approx. Unit Cost (INR)	Qty	Subtotal (INR)
LilyGO TTGO T-Call ESP32-SIM800L board	1900	1	1900
DHT11 temperature-humidity sensor	60	1	60
FC-28 soil moisture sensor + LM393 module	50	1	50
HC-SR501 PIR motion sensor	70	1	70
5 V single-channel relay module	40	1	40
2N3904 transistor + 1 kΩ resistor	10	1	10
DC water pump (small submersible)	150	1	150
9 V battery + connector	40	1	40
Custom PCB (fabrication, 2-layer)	250	1	250
SIM card (prepaid, GPRS+SMS plan)	-	1	recurring (nominal)
Miscellaneous (wires, headers, enclosure)	150	1	150
Total (approximate, excluding recurring SIM cost)			2,720

13. Applications

- Small and marginal farm irrigation automation in areas without reliable Wi-Fi coverage.
- Remote plantation and orchard security combined with irrigation (tea, coffee, areca nut, horticultural crops).
- Nursery and greenhouse climate-gated watering, adapted per plant/crop variety.
- Community or cooperative farm monitoring where a single dashboard aggregates multiple field units.
- Educational and research testbed for IoT-based precision agriculture and GSM/cellular sensor networks.
- Disaster-resilient rural monitoring, since GSM connectivity typically persists after infrastructure damage that disables local Wi-Fi/broadband.

14. Conclusion and Future Scope

This paper presented the complete design, implementation, and experimental evaluation of a Comprehensive Smart Agriculture System built on the LilyGO TTGO T-Call ESP32-SIM800L

platform, integrating DHT11 temperature/humidity sensing, soil-moisture-based irrigation control gated by crop-specific temperature/humidity windows, PIR-based plantation security, Blynk cloud connectivity carried entirely over cellular GPRS, and dual-channel (SMS + e-mail) owner alerting on every motor actuation and intrusion event. The system was realised on a custom two-layer PCB, and its firmware, schematic, PCB layout, and operational flowchart have been documented in full. Experimental trials demonstrated reliable hysteretic moisture-threshold switching, sub-five-second SMS alert latency, and an approximately 51% reduction in weekly water consumption relative to manual flood irrigation.

Future work will extend the crop-profile table to a larger and field-validated set of crop varieties (ideally calibrated in collaboration with an agricultural extension body), incorporate a higher-precision temperature/humidity sensor (e.g., DHT22 or BME280) and a capacitive, corrosion-resistant soil-moisture probe for longer-term outdoor reliability, add solar-with-battery power management for fully off-grid operation, and explore lightweight on-device machine learning (e.g., a compact LSTM or decision-tree model, as explored in recent literature) to move from static threshold-based control toward predictive, weather-aware irrigation scheduling. Integration of a low-resolution camera module alongside the PIR sensor is also planned to reduce false-positive intrusion alerts and to allow visual confirmation of detected events.

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