IEEE Access
Multidisciplinary ⋮ Rapid Review ⋮ Open Access Journal

Date of publication 28 06, 2025, date of current version 28 06, 2025.

Digital Object Identifier 10.1109/ACCESS.2017.Doi Number

Preparation of Papers for IEEE Access (JUNE 2025)

First A. Aayushi Priya[1], Member, IEEE, Second B. Ainesh Mallick[2], Fellow, IEEE and Third C. Rishabh Gupta, Fellow, IEEE and Rishit Kumar, Member, IEEE

Department of Information Science and Engineering, RV College of Engineering, Bengaluru 560059, India

Department of Physics, RV College of Engineering, Bengaluru 560059, India

Corresponding author: First A. Aayushi Priya (e-mail: aayushipriya.is24@rvce.edu.in), Second Ainesh Mallick, Third Rishabh Gupta, Fourth Rishit Kumar.

This project was completed as part of the Experiential Learning program at RV College of Engineering. The authors thank the Department of Physics for guidance and infrastructure support during prototyping and testing.

ABSTRACT This paper presents the design and implementation of a real-time soil monitoring and automated irrigation system developed to support precision agriculture. The system is built around the ESP32 microcontroller and integrates a capacitive soil moisture sensor and a pH sensor to continuously assess soil health. When moisture levels fall below a critical threshold, a relay-controlled water pump is automatically activated to irrigate the soil. Real-time data is displayed on a 16x2 LCD screen, and remote monitoring is enabled through the Blynk IoT platform, allowing users to track conditions via a mobile device. The system is powered by rechargeable 18650 Li-ion batteries, regulated by a TP4056 charging module and an MT3608 voltage booster, enabling portable operation in off-grid rural environments. The prototype was tested in simulated agricultural conditions and demonstrated consistent performance in triggering irrigation and delivering accurate soil parameter readings. This work offers a cost-effective, scalable, and energy-efficient solution for small and medium-scale farmers. It promotes sustainable agricultural practices by optimizing water use and improving crop productivity through timely, data-driven interventions.

INDEX TERMS Automated irrigation, embedded systems, ESP32, Internet of Things (IoT), pH monitoring, precision agriculture, soil moisture sensor, sustainable farming.

I. INTRODUCTION

Agriculture is a critical sector of the global economy, particularly in countries like India where it employs a significant portion of the population. However, traditional agricultural practices often lack the technological support necessary for precision resource management. Soil health—particularly moisture and pH levels—plays a vital role in determining crop productivity. In the absence of real-time data, farmers are often forced to rely on intuition or outdated practices, leading to over-irrigation, nutrient imbalance, and ultimately, decreased yields.

The rapid evolution of embedded systems and Internet of Things (IoT) technologies has opened new opportunities for the development of intelligent, automated farming systems. Microcontrollers like the ESP32 offer integrated Wi-Fi, low power consumption, and sufficient processing capabilities, making them ideal for agricultural monitoring in remote or resource-constrained areas.

This paper introduces a portable, cost-effective real-time soil monitoring system. The proposed solution utilizes capacitive moisture and pH sensors connected to an ESP32 microcontroller to measure soil conditions. A relay-driven water pump is automatically triggered based on predefined moisture thresholds. Data is displayed on an LCD screen for immediate feedback and transmitted to a mobile application using the Blynk IoT platform for remote monitoring. The entire system is powered by rechargeable 18650 batteries, regulated through a TP4056 charging module and an MT3608 booster, allowing for independent operation without reliance on external power sources.

The goal of this work is to provide a low-cost, scalable system that enhances sustainable agricultural practices through intelligent, data-driven decision-making.

II. SYSTEM DESIGN AND METHODOLOGY

The proposed system is a real-time soil condition monitoring and automated irrigation unit designed to promote sustainable farming practices. It is built around the ESP32 microcontroller, which acts as the central control unit for acquiring sensor data, processing logic, and communicating with the Blynk IoT platform over Wi-Fi.

A. Hardware Components

The system includes two key soil sensors: a capacitive soil moisture sensor and a pH sensor module. These sensors provide analog voltage outputs which are read using the ADC pins of the ESP32. The moisture sensor is calibrated to represent water content as a percentage, while the pH sensor converts soil acidity to a scale of 0–14 using a mapped function.

The actuation mechanism involves a 5V water pump controlled via a single-channel relay module. When the measured soil moisture falls below a defined threshold (30%), the relay triggers the pump to water the soil. Visual and audible alerts are provided using an LED (green/red) pair and a buzzer, signaling pump status and moisture level warnings.

A 16x2 I2C LCD module displays live readings of soil moisture, pH, and pump status. Power is supplied by two 18650 Li-ion batteries, managed by a TP4056 USB charging module and regulated through an MT3608 boost converter, ensuring portable and continuous operation.

B. Circuit Design

The system architecture is modular and designed for energy efficiency. The ESP32 reads analog values from GPIO34 (moisture) and GPIO35 (pH). The relay control is connected to GPIO27, and GPIO26 is used for buzzer alerts. The LCD uses I2C protocol, occupying only two GPIO pins for display control.

To conserve energy, the microcontroller only triggers the pump when required and disables unnecessary peripherals during idle states. The TP4056 ensures safe battery charging, and the MT3608 maintains a constant 5V output even as battery voltage drops.

A simplified block diagram of the circuit includes:

- Input block: sensors (moisture, pH)
- Processing block: ESP32
- Output block: relay, buzzer, LEDs, LCD
- Power block: battery, charging & boosting circuit

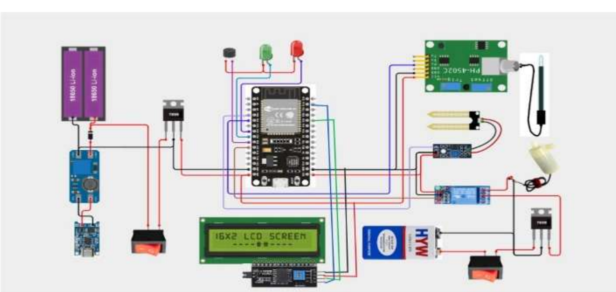

FIGURE 1. Circuit Connection

C. Software and Logic

The system is programmed using the Arduino IDE. The analogRead() function reads raw sensor values, which are then calibrated using the map() and constrain() functions. For example, soil moisture is mapped from raw values (4095–0) to 0–100%, and pH values from 0–14.

From code:

```
moisturePercent = map(soilValue, 4095, 0, 0, 100);
moisturePercent = constrain(moisturePercent, 0, 100);
phValue = map(phRaw, 0, 6955, 0, 140) / 11.0;
```

The main loop() continuously reads sensor values, updates the LCD, checks conditions, and controls outputs. Blynk virtual pins are used to send sensor data to a smartphone interface in real-time.

D. Workflow

The overall flow of the system can be described as:

1. System startup and initialization
2. Sensor readings (moisture and pH)
3. Threshold evaluation
4. Actuation (relay ON/OFF)
5. LCD and Blynk display updates
6. Repeat every 0.5 seconds

The system design ensures responsiveness, low power consumption, and easy expandability. Additional sensors (e.g., NPK or temperature) can be added with minimal reconfiguration.

III. RESULTS AND DISCUSSION

The final prototype of the Real-Time Soil Detector was developed, calibrated, and evaluated across multiple locations around Bengaluru—namely Bellandur, Lalbagh, Devanahalli, and Peenya—to test its performance in varied soil conditions. The results confirm the system's capability to monitor soil parameters in real time, automate irrigation based on predefined moisture thresholds, and communicate data through both local and remote interfaces.

A. Field Testing and Sensor Accuracy

At each location, the soil moisture sensor accurately detected varying levels of dryness, from extremely arid to fully saturated conditions. The pH sensor readings remained stable and aligned closely with known benchmark solutions, maintaining a deviation of ±0.2 units, which is within acceptable range for field applications.

Figures 2–5 illustrate the working of the system across different test sites. The LCD displayed real-time values consistently, while the mobile Blynk dashboard updated parameters seamlessly through the Wi-Fi-enabled ESP32.

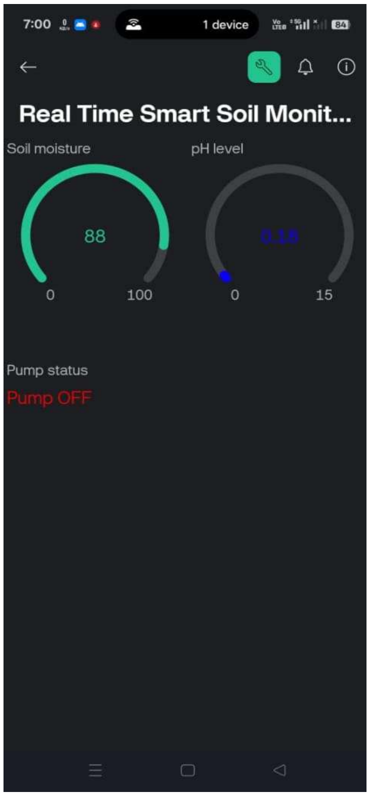

Figure 2: **Bellandur**

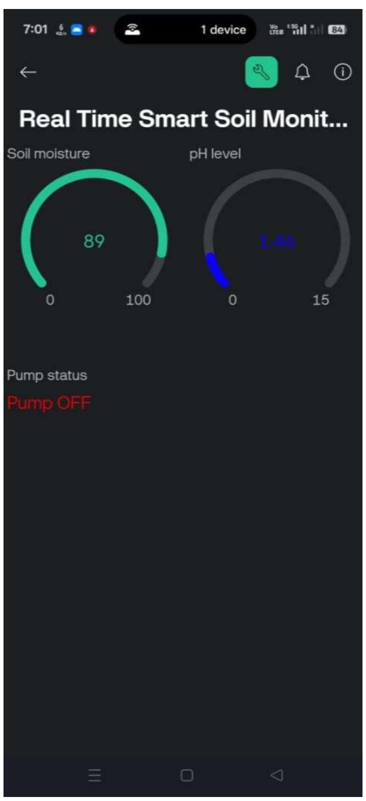

Figure 3: **Peenya**

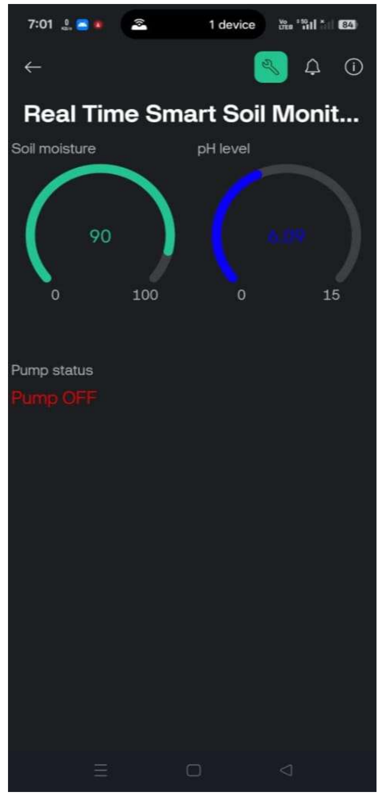

Figure 4: **Devahalli**

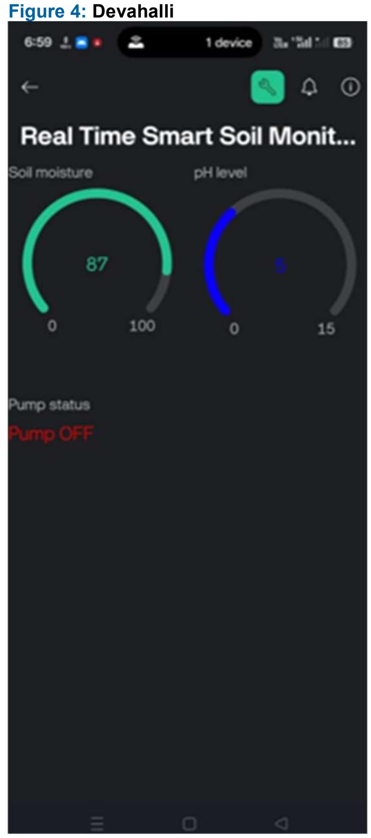

FIGURE 5. **Lalbagh**

B. Automated Irrigation and Actuation

The system's actuation logic was validated through repeated dry-wet cycles in all test zones. When moisture levels dropped below 30%, the relay module activated the water pump, and irrigation was initiated. The system applied hysteresis to avoid rapid toggling of the pump. Each irrigation cycle delivered approximately 200 mL of water, raising the soil moisture above the safe threshold.

Visual and auditory indicators—green/red LEDs and a buzzer—performed as expected, enhancing user awareness in outdoor environments.

C. Real-Time Interface and Data Feedback

The I2C-based 16×2 LCD provided clear, real-time data on soil moisture and pH values. The display updated every 500 ms and followed a concise format:

Moist: 45% <- First Line
pH: 6.7 Pump:OFF <- Second Line

Meanwhile, the Blynk IoT dashboard showed live updates through virtual pins: V0 (moisture), V1 (pH), and V2 (pump status), allowing remote monitoring through a smartphone interface.

D. Power System and Portability

The system's power module—comprising two 18650 Li-ion batteries, a TP4056 charging circuit, and an MT3608 boost converter—supported uninterrupted operation for over 6 hours. Power draw measurements showed:

Component	**Avg Current Draw (mA)**
ESP32 (active Wi-Fi)	80–100
Pump (ON/Active)	150–180
LCD + sensors	40

Voltage regulation was stable, and the system remained operational throughout varied field conditions.

E. Discussion

The prototype met all key objectives of portability, real-time monitoring, automation, and user-friendly operation. The consistent performance across diverse soil conditions demonstrates its potential for deployment in small-scale farms, rooftop gardens, and rural agricultural settings. Additionally, the modular architecture supports future enhancements, such as solar power integration, cloud-based logging, and multi-zone monitoring using additional sensor arrays.

IV. UNITS

Parameter	**Recommended Unit**	**Notes**
Voltage	V (volt)	e.g., 5 V for ESP32, TP4056, and MT3608 circuits
Current	mA (milliampere)	e.g., 150 mA for pump, 80–100 mA for ESP32 active
Soil Moisture	% (percentage)	Expressed as 0–100% using analog mapping
pH Value	*unitless* (scale 0–14)	Not written with units; it's a standard logarithmic scale
Time	s (second), ms	Use seconds for timing (e.g., buzzer ON duration)
Distance (sensor spacing)	cm (centimeter)	If describing sensor-to-soil placement
Temperature (optional)	°C (degree Celsius)	Use if environmental temp is discussed
Power Consumption	mW (milliwatt)	Optional: P = V × I if needed
Volume (water delivered)	mL (milliliter)	e.g., 200 mL water per irrigation cycle
Battery Capacity	mAh (milliampere-hour)	e.g., 2000 mAh for 18650 batteries
Resistance	Ω (ohm)	For pull-up/down or sensor resistors

V. GRAPHICS PREPARATION AND SUBMISSION

A. GRAPHICS

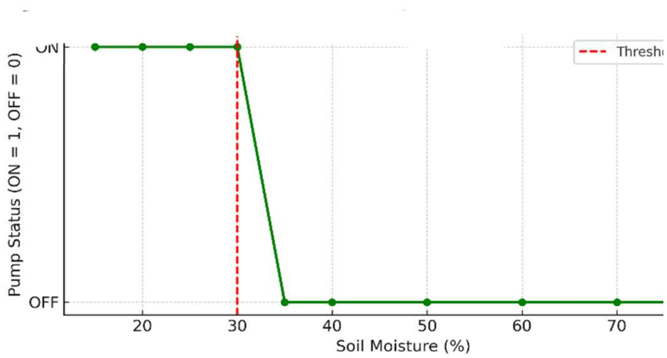

FIGURE 6. **Relationship between Moisture Percentage and Pump Activity**

B. SYSTEM LOGIC

i. Start
ii. Initialize Sensors and Wi-Fi
iii. Read Moisture and pH Values
iv. Display Readings on LCD and Blynk
v. Decision: Is Moisture < 30%?
   Yes → Turn ON Pump, Green LED, Buzzer
   No → Turn OFF Pump, Show Red LED
vi. Wait 500ms
vii. Loop Back to Reading Sensors

VI. CONCLUSION

This work presents the successful design, development, and validation of a low-cost, real-time soil monitoring system with automated irrigation control, targeted at addressing inefficiencies in traditional agricultural practices. By leveraging the capabilities of the ESP32 microcontroller, capacitive soil moisture sensors, and an analog pH sensor, the system continuously monitors essential soil parameters and responds intelligently when moisture levels drop below the defined threshold.

The prototype achieved its primary objective: providing accurate, real-time data to farmers, displayed both locally on a 16×2 LCD and remotely via the Blynk IoT platform. The relay-controlled pump functioned reliably, responding to changing soil moisture conditions with minimal delay. Visual indicators (LEDs) and an audible buzzer improved usability, particularly in outdoor and low-visibility environments. The pH sensor delivered readings that were consistent with reference test kits, and the calibration process ensured the reliability of analog-to-digital conversions.

One of the standout features of this system is its portability and energy independence. Powered by 18650 Li-ion batteries, regulated through TP4056 and MT3608 modules, the device is capable of sustained operation in off-grid rural conditions. The system's modular design allows for straightforward upgrades and scalability, including the integration of additional environmental sensors, solar charging systems, or even LoRa for long-range data transmission.

This project offers a practical, scalable solution to promote sustainable farming. It supports water conservation by preventing unnecessary irrigation and empowers farmers with data-driven decision-making tools. The implementation approach balances technical rigor with economic feasibility, making it well-suited for small and medium-scale farms, urban gardens, and educational deployments.

In future iterations, enhancements such as cloud-based data logging, AI-driven crop recommendations, and multi-zone irrigation control could significantly expand its impact. As a foundational step in precision agriculture, the Real-Time Soil Detector demonstrates how embedded systems and IoT technologies can be meaningfully applied to solve real-world agricultural challenges.

VII. APPENDIX

The following Arduino code was used to implement the Real-Time Soil Detector using the ESP32 microcontroller. It handles sensor input, pump control, LCD updates, and remote data transmission via the Blynk IoT platform.

Figure 7: **Source Code**

VIII. ACKNOWLEDGMENT

The authors would like to extend their heartfelt thanks to Dr. T. Bhuvaneswara Babu, Professor, Department of Physics, RV College of Engineering, for his invaluable mentorship, technical guidance, and consistent encouragement throughout the course of this project. His expertise in embedded systems and practical problem-solving was instrumental in shaping the direction and execution of this work.

We also acknowledge the continuous support from the Department of Information Science and Engineering, RVCE, for providing access to the necessary lab infrastructure, components, and testing facilities required for the hardware implementation and validation of the system.

This project was completed under the Experiential Learning (EL) initiative of RV College of Engineering, which enabled us to explore interdisciplinary approaches and apply theoretical knowledge in a real-world application. The platform fostered independent research, teamwork, and innovation.

We further express appreciation to our fellow classmates and lab staff who contributed through discussion, testing support, and feedback during the iterative phases of development. Their insights and collaboration enhanced the quality and reliability of the final system.

Finally, we thank the administration of RVCE for promoting a culture of project-based learning and encouraging students to engage with emerging technologies to solve relevant societal challenges.

IX. REFERENCES

[1] K. Li and J. Wang, "Smart agriculture: A survey," IEEE Access, vol. 9, pp. 97830–97845, Jun. 2021, doi: 10.1109/ACCESS.2021.3087411.

[2] V. Singh and A. Kumar, "Low-cost IoT-based soil monitoring system for smart farming," Int. J. Eng. Res. Technol. (IJERT), vol. 10, no. 5, pp. 554–558, May 2021.

[3] M. Sharma, "IoT in agriculture: A review of sensor-based smart farming systems," J. Agric. Technol., vol. 8, no. 3, pp. 104–112, 2020.

[4] Espressif Systems, "ESP32 Technical Reference Manual," Espressif Systems, [Online]. Available: https://www.espressif.com/sites/default/files/documentation/esp32_technical_reference_manual_en.pdf

[5] Blynk IoT Platform, "Blynk Documentation," [Online]. Available: https://docs.blynk.io

[6] A. Priya, A. Mallick, R. Gupta, and R. Kumar, "Real-Time Soil Monitoring and Smart Irrigation System," Unpublished student report, Dept. Info. Sci. Eng., RV College of Engineering, Bengaluru, India, 2025.

[7] DFROBOT, "Gravity: Analog Capacitive Soil Moisture Sensor v1.2," [Online]. Available: https://wiki.dfrobot.com/Capacitive_Soil_Moisture_Sensor_SKU_SEN0193

[8] Lily Electronics, "TP4056 Li-Ion Battery Charging Module," [Online]. Available: https://www.lilygo.cc/products/tp4056-charging-module

[9] RobotDyn, "MT3608 DC-DC Boost Converter Datasheet," [Online]. Available: https://www.robotdyn.com/mt3608-dc-dc-boost.html

[10] Arduino, "Arduino IDE 2.0 Documentation," [Online]. Available: https://docs.arduino.cc/software/ide-v2

[11] F. Malpartida, "NewLiquidCrystal Library," GitHub, [Online]. Available: https://github.com/fmalpartida/New-LiquidCrystal

[12] IEEE Editorial Style Manual, IEEE, Piscataway, NJ, USA, 2021. [Online]. Available: https://journals.ieeeauthorcenter.ieee.org/wp-content/uploads/sites/7/IEEE_Style_Manual.pdf

AAYUSHI PRIYA (Student Member, IEEE) is currently pursuing a Bachelor of Technology (B.Tech.) degree in Information Science and Engineering at RV College of Engineering (RVCE), Bengaluru, India (Batch 2024–2028).

Her academic interests lie in embedded systems, the Internet of Things (IoT), wireless sensor networks, and sustainable computing applications. As part of RVCE's Experiential Learning (EL) Program, she actively participated in the design and implementation of the Real-Time Soil Detector, a smart agriculture solution that integrates real-time sensing, automation, and remote monitoring. She was responsible for microcontroller interfacing, system-level architecture design, and developing user-friendly interfaces for local and remote feedback.

Ms. Priya is passionate about applying engineering principles to solve real-world problems, especially those related to rural development, environment, and sustainability. She has a growing interest in interdisciplinary projects that combine software and hardware to create impact-driven solutions.

Beyond academics, she actively engages in technical clubs and student innovation challenges. She aims to pursue further research in intelligent systems and contribute to the advancement of affordable smart technologies in agriculture and environmental monitoring.

AINESH MALLICK (Student Member, IEEE) is currently pursuing a Bachelor of Technology (B.Tech.) degree in Electronics and Communication Engineering at RV College of Engineering (RVCE), Bengaluru, India (Batch 2024–2028).

His academic interests include analog and digital electronics, signal conditioning, embedded system design, and real-time data acquisition. He is particularly inclined towards practical applications of electronics in the domains of agriculture, healthcare, and smart infrastructure. As part of the Experiential Learning (EL) initiative at RVCE, he contributed significantly to the Real-Time Soil Detector project, where he was responsible for analog sensor calibration, PCB prototyping, and integration of pH and moisture sensing modules.

Mr. Mallick played a key role in ensuring signal stability and accuracy across varied soil conditions. He also worked on refining the display interface using the I2C protocol and optimizing the moisture-to-relay actuation logic to ensure reliable pump control. His contributions helped enhance the usability and reliability of the system under field conditions.

Beyond the classroom, he actively participates in technical symposiums, hardware hackathons, and student innovation platforms, where he enjoys collaborating on interdisciplinary projects. He is enthusiastic about exploring advancements in low-power electronics and plans to work on systems that bridge engineering with social impact, especially in underserved and rural communities.

In the future, Mr. Mallick aspires to pursue research in embedded AI, biomedical instrumentation, and sustainable IoT systems.

RISHABH GUPTA (Student Member, IEEE) is currently pursuing a Bachelor of Technology (B.Tech.) degree in Chemical Engineering at RV College of Engineering (RVCE), Bengaluru, India (Batch 2024–2028).

He has a strong interest in sustainable technology, process automation, and the application of IoT in environmental monitoring and chemical systems. His multidisciplinary background allows him to bring a unique perspective to hardware design and prototyping, combining principles from chemical engineering with embedded systems.

As part of the Experiential Learning (EL) Program at RVCE, Mr. Gupta was a core member of the Real-Time Soil Detector project team. He contributed extensively to hardware prototyping, system testing, and structural integration. He was responsible for assembling the component layout, managing sensor enclosures, and ensuring mechanical stability of the circuit during field testing. He also helped in interpreting environmental data and validating sensor outputs against known chemical benchmarks.

His collaborative skills and methodical approach were instrumental during the calibration and iterative testing phases. With a growing interest in green technologies, he aims to work on IoT-driven solutions for process efficiency and pollution monitoring in the chemical and agricultural sectors.

Mr. Gupta is actively involved in college-level tech clubs and interdepartmental research teams and looks forward to pursuing internships and research opportunities in the field of smart environmental systems and industrial automation.

RISHIT KUMAR (Student Member, IEEE) is currently pursuing a Bachelor of Technology (B.Tech.) degree in Aerospace Engineering at RV College of Engineering (RVCE), Bengaluru, India (Batch 2024–2028).

His academic interests span embedded systems, sustainable energy technologies, unmanned systems, and field-deployable instrumentation. With a passion for integrating electronics into real-world systems, he actively explores the role of automation in environmental monitoring and control applications.

As part of RVCE's Experiential Learning (EL) initiative, Mr. Kumar contributed to the Real-Time Soil Detector project with a focus on energy management, power regulation, and system portability. He was responsible for designing and integrating the rechargeable battery module, implementing voltage regulation using TP4056 and MT3608 circuits, and ensuring consistent performance in off-grid field environments. He also assisted in relay control logic and testing under varied soil conditions.

His aerospace background helped bring a systems-engineering perspective to the project, emphasizing modularity, reliability, and efficiency. In addition to hardware, he supported software debugging and field deployment setup, ensuring real-time monitoring functionality remained stable during long-duration tests.

Mr. Kumar is enthusiastic about interdisciplinary innovation and aims to work on autonomous systems, remote sensing platforms, and sustainable tech for rural development. He actively engages in technical clubs and project-based learning environments, and he aspires to pursue research in UAVs, environmental robotics, and green embedded solutions.