LoRa Based Envi-Rover

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***Abstract*—This paper describes the design and implementation of Envi-Rover, a LoRa-based IoT rover designed to perform real-time environmental monitoring over remote areas. The system utilizes the ESP32 microcontroller as its main processing unit. It works with a Cytron MDD10A motor driver to perform dual-channel motor control and an RYLR890 LoRa transceiver operating at 868 MHz for long-range, low-power wireless communication. Equipped with many sensors, such as a DHT11 for temperature and humidity measurement, an ultrasonic module on a servo motor for obstacle detection, an LDR to detect ambient light, and MQ-series sensors to monitor gas concentrations, the data acquired from these sensors are transmitted through LoRa to a base station and displayed on the Blynk IoT platform for real-time analysis. The rover can be driven in both manual and semi-autonomous modes by using a joystick controller for effective navigation in the field and continuous data gathering. Stable LoRa communications beyond one kilometer were observed in test results, along with accurate performance of all sensors. This proves that the system can be very helpful in environmental assessment, agricultural monitoring, and disaster management. The Envi-Rover merges IoT and robotics to form a low-cost, energy-efficient, and scalable solution toward environmental data collection at remote locations.**

***Index Terms*—LoRa, ESP32, Cytron Motor Driver, Environmental Monitoring, Blynk IoT Cloud, Rover, IoT**

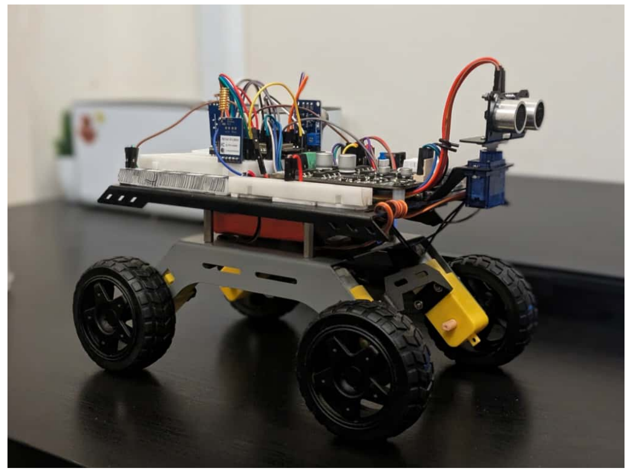

Fig. 1. Prototype of the LoRa-Based Envi-Rover developed using an ESP32 controller, Cytron MDD10A motor driver, and multi-sensor integration for environmental monitoring.

I. Introduction

Recent developments in the growth of IoT have completely changed the way environmental data is collected, analyzed, and shared. IoT-based monitoring systems have become very essential in precision agriculture, smart cities, and disaster response due to their capability for real-time visualizations using connected sensors and communication networks [13], [17]. However, most traditional communication technologies, such as Wi-Fi, ZigBee, and Bluetooth, suffer from a number of limitations. They are restricted by short-range coverage and high energy use that makes them unsuitable for use in deployments over large scales and in faraway areas [5], [18].

In order to overcome such limitations, solutions based on LPWAN technologies have recently gained more attention. One of such technologies is Long Range modulation, which proved to be effective and low-cost for long-range communications with low power consumption [17], [18]. Since LoRa works in unlicensed ISM frequency bands, normally operating at 868 MHz in Europe and 865–867 MHz in India, it has a very long range, high interference immunity, and thousands of low-power nodes can be connected to a single network [19]. Due to such an advantageous aspect, LoRa is one of the best wireless technologies to implement IoT-based environmental monitoring [18], [19].

Recent research has also demonstrated the performance of LoRa in real scenarios. Sánchez et al. implemented a UV radiation monitoring station based on LoRaWAN. The station is able to transmit environmental data to a server, proving its range and reliability over an urban environment [19]. In another attempt, Alorda-Ladaria et al. developed a LoRa-enabled linear network for power line monitoring. This contribution has shown that LoRa's self-configuring approach enhances scalability and robustness against failures in demanding terrains [17]. Several IoT systems based on LoRa are already employed in agriculture to provide temperature, soil moisture, and gas concentration readings. These support smart decision-making by way of remote sensing [2], [13].

Most of the current LoRa-based monitoring systems have the weakness of being static and, thus, lack mobility. They rely on fixed sensor nodes, which are confined to specific locations - hence it is difficult to gather information dynamically from hazardous or dispersed areas [7], [16]. This addresses the need for implementing mobile IoT platforms with the ability to navigate through complex environments while maintaining long-range reliable communication. The integration of sensor networks with motion control and edge computing abilities has resulted in autonomous mobile robots and rovers that strongly address the above problem [10], [16].

The Envi-Rover project fills this gap by combining robotic mobility with LoRa-based communication for real-time environmental monitoring. The system implements an ESP32 microcontroller, featuring a dual-core architecture, embedded with a Wi-Fi and Bluetooth module. This facilitates seamless integration of the control logics and data transmission [14]. Onboard sensors, namely DHT11, ultrasonic, LDR, and MQ-series modules, have been integrated on the rover that enable monitoring of various environmental factors such as temperature, humidity, light levels, and air quality. Motor control relies on a Cytron MDD10A driver, ensuring proper direction control with stability over different terrain.

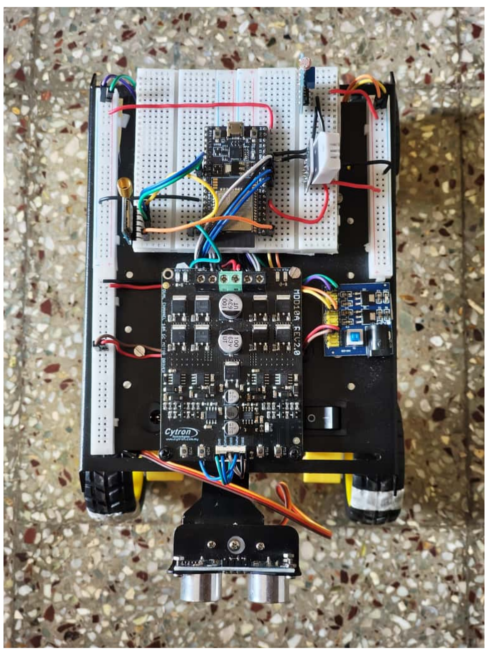

Fig. 2. Top view of the LoRa-Based Envi-Rover prototype showing the arrangement of the ESP32 DevKitC, Cytron MDD10A motor driver, and environmental sensors integrated on the rover chassis.

Envi-Rover employs the Blynk IoT platform to enable accessibility and visualization of the data. The platform provided real-time cloud monitoring of sensor readings on mobile and web dashboards. LoRa is employed for hybrid setup communication in long-range with low power while Wi-Fi is used for short-range visualization with high bandwidth, which can keep the system reliable even with poor internet connectivity [15], [19].

This paper covers the design, development, and testing of the LoRa-Based Envi-Rover system. The objectives are to (1) design a mobile rover with sensors to monitor environmental data; (2) employ LoRa modules operating at 868 MHz for long-distance data transmission; (3) create real-time data visualization with Blynk IoT interface; and (4) evaluate its real-world performance on the ranges of communication, accuracy, and power efficiency of the rover.

The rest of the paper is organized as follows. Section II presents the system design, including hardware components, communication architecture, operation methodology, and performance results. Section III compares the proposed Envi-Rover with the existing solutions for environmental monitoring in order to outline the benefits of mobility and long-range communication. Section IV concludes the paper by summarizing key findings and outlining possible future improvements that could be made to the system.

II. System Design

A. Hardware Components

1) **ESP32 MICROCONTROLLER:** The brain of the system is the ESP32 microcontroller. The ESP32 is a dual-core 32-bit processor fabricated by Espressif Systems. It integrates Wi-Fi and BLE modules on its board and has powerful computing capacity for multitasking and real-time data handling. For this project, the ESP32 board was used due to its flexibility, cost-effectiveness, and IoT embedded capabilities reducing the need for external interfacing [14]. The chip enables multiple communication protocols such as UART, SPI, and I²C. It allows seamless interface connections with sensors, the Cytron motor driver, and the LoRa transceiver. Compared to older microcontrollers such as Arduino Uno, ESP32 features a higher maximum clock speed of up to 240 MHz, with more memory of 520 kB SRAM and on-chip power management functions, thus fitting well into distributed sensing and control applications. [14], [17] Its capability for Wi-Fi cloud transmission and serial LoRa communication concurrently makes it a promising unit that can ensure a consistent dual-channel data flow in field operations.

2) **CYTRON MDD10A MOTOR DRIVER:** The Cytron MDD10A controls the dual DC motors of the rover. This provides the needed structure for precision in both the forward and reverse directions and assists the drives in regulating their speed. It is fully capable of 10 A per channel with onboard protection of internal flyback diodes and high efficiency due to MOSFETs. It reduces power loss with less heat generated due to long operation [7]. The MDD10A was chosen because of its robustness within mobile robotics and can work within various input voltages. As a result, it's perfect for field conditions where voltage changes are experienced often. Its compact design lets it connect directly to the ESP32 GPIO pins, making integration easy and providing the agility of fast motor responses on uneven grounds [16].

3) **LoRa RYLR890 Module (868 MHz):** The RYLR890 LoRa transceiver module operates at 868 MHz

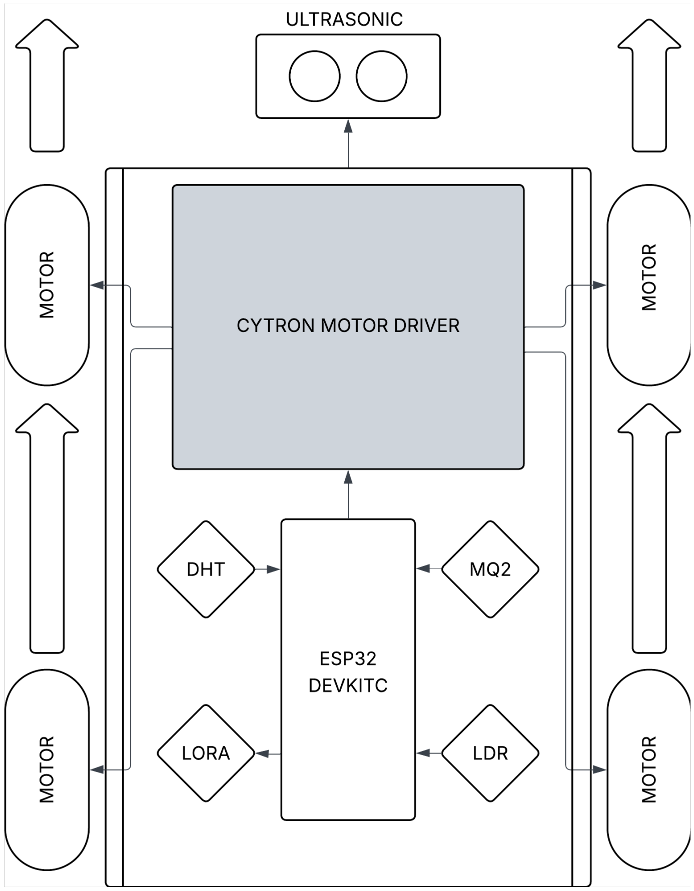

Fig. 3. Prototype hardware layout of the LoRa-Based Envi-Rover showing the arrangement of key components including the ESP32 DevKitC, Cytron motor driver, sensors (DHT, MQ2, LDR, Ultrasonic), and motor configuration.

and represents the main communication part of the proposed rover for long-range low-power data exchange between the rover and its base station. Utilizing CSS modulation, it achieves communication distances of over one kilometer in line-of-sight conditions and with minimal interference [18], [19]. Broad link budget and high immunity to noise enable LoRa to outperform other legacy RF and Wi-Fi systems in the absence of a line-of-sight [5], [17]. The module interfaces over UART to the ESP32 and relies on standard AT commands in order to set up a network, addressing, and data transfer. With low power consumption-less than 15 mA in receive mode-and a large frequency range, it is an excellent choice in many energy-constrained IoT platforms [5]. The frequency of 868 MHz meets global LPWAN regulations and provides excellent penetration through vegetation and mild obstacles. This is very important for outdoor monitoring systems [19].

4) **Sensors:**

- **DHT11:** It is a digital sensor that measures temperature and humidity. The device transmits the collected calibrated data in a single-wire serial interface. The sensor has a temperature range of 0 to 50°C and an accuracy of ±5% for humidity. Though small and affordable, it provides stable and reliable readings good for outdoor use [11], [21].
- **Ultrasonic Sensor (HC-SR04):** The HC-SR04 unit emits ultrasonic pulses that gauge the distance of the rover from the obstacles around it using the time recorded for the echo to return. The sensor is an obstacle detection device that works within 2 cm to 400 cm range to stop the robot from colliding with the surroundings during real-time operations if it is fixed on a servo motor [12]. The servo offers 180° rotation. Therefore the rover can cover more area for path planning and obstacle avoidance [10]
- **LDR (Light Dependent Resistor):** An LDR sensor for light is a unit that detects the intensity of radiation by changing its resistance depending on light levels. This allows the rover to determine the brightness of the surroundings and differentiate between daylight and dim light during operation. LDR sensors are easy to use and low-power, making them ideal for continuous environmental monitoring [11].
- **Gas Sensor (MQ-Series):** The MQ-series gas sensors (MQ-2 and MQ-135) detect the concentration of gases like carbon monoxide (CO), methane (CH_4), and other volatile compounds. These sensors use a tin dioxide (SnO_2) semiconductor layer that changes resistance when exposed to gases. This change allows the ESP32 to measure differences in air quality. These sensors are commonly used in environmental and industrial IoT systems to detect air pollution and harmful emissions [13], [20].

B. *Sensor Calibration and Validation*

In order to support accurate environmental monitoring, a calibration and validation procedure was implemented through comparison of the onboard sensors with standard reference instruments prior to field deployment. The DHT11 temperature-humidity sensor was compared to a calibrated digital thermo-hygrometer in both indoor and outdoor controlled environments. The temperature difference was always within $\pm 1.8°$C, and the relative humidity change was also within $\pm 4.5\%$ RH, thus both being within the tolerance range set by the manufacturer.

The calibration for the MQ series gas sensor was based on baseline readings that were first recorded in open outdoor air (clean-air reference). The response variation was then observed when the sensor was briefly exposed to controlled gas sources (incense smoke for VOC/CO simulation). The sensor's capability to respond to the change in gas concentration was marked by the relative change of its output voltage.

The LDR light intensity sensor was verified by analog output comparison to lux readings from a standard lux meter under three different lighting conditions: bright sunlight, indoor fluorescent lighting, and low light condition. The excellent match between the two measurements was an indication of the proper analog response scaling of the LDR sensor.

Known distances to an obstacle were used to check the performance of the ultrasonic sensor (HC-SR04 with servo). The average measurement error of five reference points (10 to 100 cm) was less than ± 1.5 cm; therefore, the sensor was verified to have accurate short-range obstacle detection capability.

The calibration results of the sensors incorporated into the Envi-Rover system show that the sensors are functioning within reasonable error limits for field-based environmental monitoring uses, thus confirming the system's readiness for a real-world deployment.

C. Communication Architecture

The Envi-Rover communication setup is designed to provide a robust, energy-efficient, and long-range connection between the mobile rover and the ground control station. The primary system is based on LoRa technology which operates at 868 MHz. This makes the communication link between the joystick controller and the rover unit very reliable with low power consumption. LoRa's Chirp Spread Spectrum (CSS) modulation extends the range of the communication signal and makes it less susceptible to noise. In other words, it guarantees that the signal can be followed even if there is no direct line of sight and the area is blocked [5], [18].

Movements of the joystick controller are communicated to the onboard ESP32 microcontroller. The microcontroller decodes the signals and changes the motor operation with the help of the Cytron MDD10A driver. Such a procedure guarantees fast responses and accurate motion control while maintaining a stable communication link over long distances. LoRa transceiver modules, configured with AT commands, operate in a bidirectional mode that can handle both control signals and telemetry data. With this configuration, the rover can receive movement instructions and transmit environmental data such as temperature, humidity, and gas concentration back to the controller [17], [19].

With bidirectional communication, closed-loop feedback becomes possible, thus enabling the remote recording of environmental changes and the enhancement of situational awareness. With a sensitivity of up to -137 dBm and a high link budget, the RYLR890 LoRa module ensures reliable data exchange even in the presence of interference. This makes it an ideal choice for outdoor and agricultural monitoring conditions [18]. The long-range, low-bandwidth link used here minimizes packet collisions and power consumption, which are crucial factors for a battery-operated mobile platform [5], [7].

Besides LoRa, the Envi-Rover has Wi-Fi-based data transmission through the ESP32's native module to facilitate real-

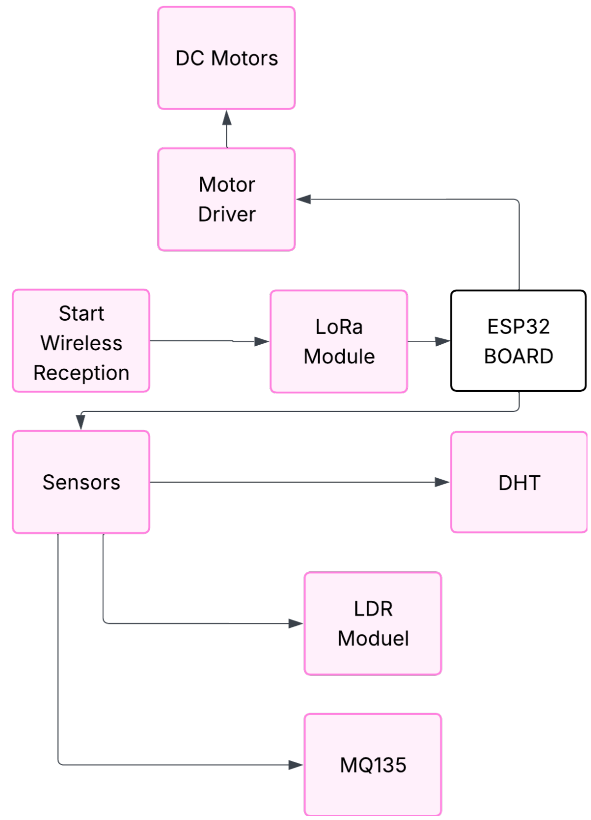

Fig. 4. Rover-side block diagram showing the interaction between ESP32, LoRa module, motor driver, and environmental sensors (MQ135, DH, and LDR).

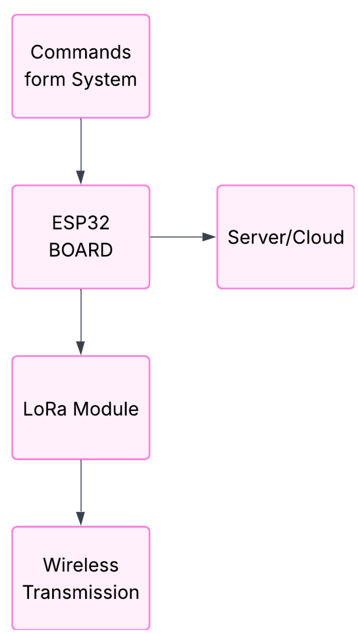

Fig. 5. Communication flow diagram illustrating command input, ESP32 control, LoRa-based wireless transmission, and cloud connectivity.

time visualization and data recording. The device displays environmental parameters such as temperature, humidity, gas concentration, and light intensity on the Blynk IoT platform via a mobile or web dashboard. This cloud-based interface allows users to monitor system performance and access environmental trends through live charts and graphical indicators.

The dual-channel configuration—employing LoRa for command and telemetry exchange and Wi-Fi for cloud synchronization—provides both local control and remote access. Thus, data transmission continues even if there is a temporary break in internet connectivity [13], [17], [19].

The combination of these two communication networks increases the Envi-Rover system's dependability and scalability. LoRa enables low-power, long-distance operation, while Wi-Fi allows quick visualization and data storage for later analysis. The seamless cooperation of these two technologies makes the rover highly effective in diverse scenarios, ranging from small research areas to large agricultural and environmental monitoring fields [7], [13], [18], [19].

To display environmental parameters visually in real time, enable remote monitoring, and keep cloud records, the Envi-Rover employs the Blynk IoT platform. The ESP32 gathers sensor readings and sends them to the Blynk server at regular intervals. Users can view the information from a customized web and mobile dashboard featuring gauges, graphs, and notifications. Similar IoT-based agricultural monitoring systems using Blynk have been successfully applied for remote irrigation control and farmer alerts [22], smart humidity monitoring and data logging in storage facilities [23], and scalable sensor networks for environmental resource management [24]. This arrangement ensures that, while LoRa handles long-range communication and rover control, users can still observe environmental data trends from anywhere with internet access.

D. Methodology

1) Motor Control: The data update frequency is adjustable in the Blynk environment. This allows users to balance refresh rate and power consumption. If the network is temporarily unavailable, local LoRa communication continues to maintain control. Sensor data is stored for later synchronization. Together, these two methods ensure uninterrupted monitoring and control even when the device is in offline mode. Because of this, the Envi-Rover is highly adaptable to field operations [5], [7], [13], [18].

E. Power Supply and Runtime Analysis

The Envi-Rover operates with a 12 V Li-ion 2500 mAh battery, which powers both the motor driver and control electronics. A regulated power divider module converts the voltage to 5 V and 3.3 V rails for the ESP32 controller, LoRa transceiver, and sensor modules. Toggle switches on the main battery supply and regulated output stage allow selective power control for energy saving during standby periods.

The average current consumption of the rover was measured under three operating conditions: standby (no motion), sensor sampling with telemetry transmission, and active locomotion.

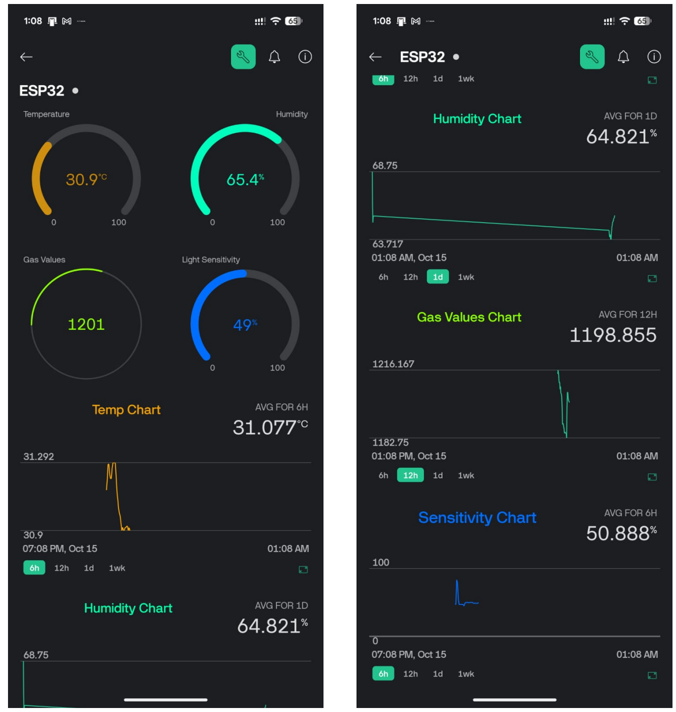

Fig. 6. Blynk IoT mobile dashboard interface for the Envi-Rover system showing (a) real-time parameter gauges for temperature, humidity, gas values, and light sensitivity, and (b) corresponding time-series charts displaying data trends.

When the device is idle but sensors remain active, the system consumes approximately 180–200 mA.

During active LoRa transmission and control processing without movement, the current draw is around 250–280 mA. The Cytron MDD10A motor driver and dual DC motors are the main contributors to increased total current consumption, reaching approximately 300–360 mA depending on terrain load during rover movement.

The estimated runtime of the system can be calculated as:

$$\text{Runtime (hours)} = \frac{\text{Battery Capacity (mAh)}}{\text{Average Operating Current (mA)}} \tag{1}$$

Assuming an average operating current of approximately 320 mA during normal rover movement:

$$\text{Runtime} = \frac{2500}{320} \approx 7.8 \text{ hours} \tag{2}$$

Therefore, the rover is able to function continuously for about 7–8 hours per full battery cycle under normal movement and sensing conditions. When stationary (no motion), the operating time between charges increases to approximately 10–12 hours.

F. Result

The Envi-Rover prototype was tested in both indoor and outdoor environments to evaluate the effectiveness of its communication, sensor accuracy, obstacle detection, and real-time data visualization. A single RYLR890 LoRa module operating at 868 MHz enabled the rover and the control unit to communicate wirelessly over distances approaching one kilometer in open areas. The system maintained stable communication up to approximately 650 meters in partially obstructed environments, demonstrating that LoRa technology provides reliable long-range, low-power data transmission [17]–[19]. The very low packet loss rate (less than 2%) and stable data throughput confirmed the system's capability to deliver uninterrupted real-time telemetry, consistent with earlier studies on the field performance of LoRa-based systems [5], [18].

Fig. 7. LoRa communication field test range between Point A and Point B showing a direct line-of-sight distance used for performance evaluation.

During initial testing, the ESP32 microcontroller efficiently executed multiple operations concurrently. It controlled the motor, collected sensor data, and transmitted LoRa data simultaneously without any noticeable delay. The average time interval for joystick motion command execution was between 210 and 250 milliseconds. This ensured smooth navigation and instantaneous control. Such quick response time demonstrates the microcontroller's dual-core processing capability and the effective use of PWM motor control logic [14], [16].

The ultrasonic sensor was mounted on a servo that rotated to different angles, giving the rover a wide field of view. Using this method, the rover performed a 180° sweep for obstacle detection. The system reliably detected and avoided obstacles within a 20–30 cm range, demonstrating dependable short-range detection. The servo-based scanning method not only extended environmental coverage but also minimized collision risks during operation. These observations are consistent with other research findings regarding ultrasonic sensor use for mobile robot navigation [10], [12].

Environmental sensing performance validated the dependability of the built-in sensor suite. The DHT11 sensor recorded temperature and humidity values differing from standard references by less than ±2°C and ±5% relative humidity, confirming reliable environmental data collection [11], [21]. The MQ-series gas sensors effectively detected changes in gas concentration and provided stable readings during simulated emission tests. Furthermore, the LDR sensor accurately captured variations in ambient light, confirming that the rover operates effectively in both bright and dim conditions [13], [20].

LoRa communication efficiency was evaluated in both open and partially obstructed environments to assess signal reliability and performance limits. Ground experiments employed RYLR890 868 MHz LoRa transceivers with a spreading factor (SF) of 7 and transmission power of +20 dBm. Under unobstructed line-of-sight conditions, the maximum stable communication range was approximately 1.05 km; sensor telemetry and control commands were transmitted continuously without packet loss. In semi-obstructed environments containing buildings and vegetation, reliable communication was maintained between 650 m and 780 m.

The Received Signal Strength Indicator (RSSI) values ranged from about –78 dBm for strong signals at distances under 200 m to approximately –123 dBm at the farthest test point. Packet loss remained below 2% up to 800 m, gradually increasing to 6–8% near the maximum distance limit. These findings confirm that LoRa provides a robust, long-range, low-power, and interference-resistant communication link suitable for remote environmental monitoring in agricultural and rural fields.

LoRa's communication remained stable during all testing periods, while Wi-Fi signals weakened beyond 100 m, leading to connection drops. The strong and consistent LoRa link resulted from its high link budget and the efficient Chirp Spread Spectrum (CSS) modulation technique [5], [17]. The average current draw during motion was approximately 320 mA, whereas the telemetry idle current averaged 180 mA. To sustain continuous operation for over seven hours, a 2500 mAh Li-ion battery was used, demonstrating the energy-efficient design of LoRa-powered mobile robotic systems [5], [7].

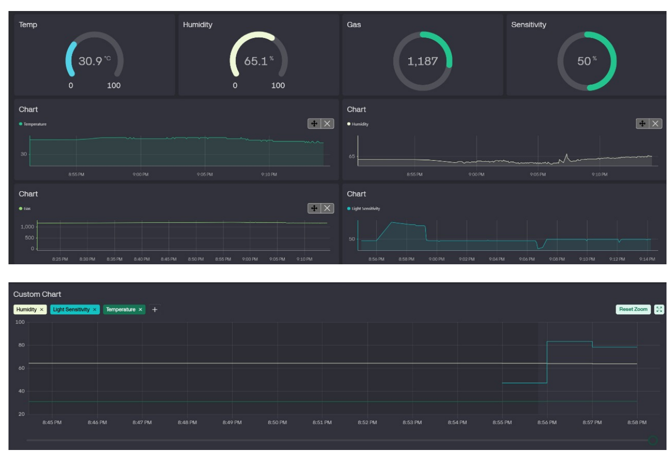

Fig. 8. Blynk IoT web dashboard visualizations showing (top) a real-time custom chart displaying humidity, light sensitivity, and temperature, and (bottom) a multi-parameter interface with gauge indicators and trend graphs for environmental data.

The Blynk IoT platform provided a user-friendly visualization interface that displayed up-to-the-minute data via gauges and time-series graphs. Data latency was kept to a minimum, approximately one second. This allowed users to monitor temperature, humidity, gas levels, and light trends simultaneously. Additionally, the cloud dashboard recorded data for future analysis and trend prediction, consistent with previously reported IoT cloud systems [13], [19]. Integration with the platform enhanced situational awareness by providing rapid access to sensor inputs, thereby enabling efficient decision-making during on-field operations.

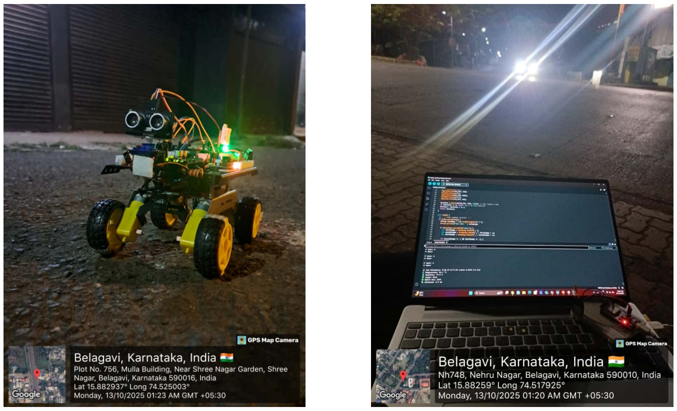

Fig. 9. Final field testing of the LoRa-Based Envi-Rover showing (left) outdoor operation in Belagavi, Karnataka, and (right) live data monitoring via the ESP32 interface during the field test.

Overall, the experimental results validate that the Envi-Rover is a reliable, cost-effective, and energy-efficient platform for remote environmental monitoring. Its applications can extend to precision agriculture, pollution monitoring, and disaster response due to the integration of LoRa-based long-range communication, ESP32 processing, and multi-sensor capabilities. The system's stability, scalability, and autonomy make it a versatile model for practical IoT deployments in regions with limited communication infrastructure [5], [7], [13], [17]–[19].

III. Comparison with Existing Solutions

The majority of existing environmental monitoring systems based on Wi-Fi or Bluetooth have limited transmission ranges, high power consumption, and require continuous network availability. Therefore, these systems are unsuitable for outdoor or remote areas. Although stationary LoRa-based monitoring systems extend range and improve energy efficiency, they are restricted to fixed sensing points and cannot adapt to changes in terrain or hazardous zones.

The innovative concept of the LoRa-Based Envi-Rover integrates LoRa long-range communication with a mobile rover platform. This configuration enables multi-location sensing, remote navigation, and dependable data transfer even in areas lacking conventional network infrastructure. Its mobility, combined with LoRa's long-range radio capability, allows users to expand sensing coverage simply by deploying intermediate LoRa nodes as repeaters or checkpoints, thereby establishing a hop-by-hop communication network.

Along with extended range and flexibility, the rover's onboard obstacle detection and servo-assisted scanning mechanisms enable safe movement across uneven or cluttered terrain—something not feasible with stationary sensor nodes. Furthermore, the system provides live visualization and data logging through the Blynk IoT platform, allowing users to remotely monitor environmental conditions without being physically present at the location. The modular design also permits easy addition of new sensors or computational modules with minimal redesign, improving scalability for long-term use. Overall, the Envi-Rover offers wider operational range, mobile data acquisition capability, and higher reliability in remote locations compared to short-range Wi-Fi or Bluetooth-based systems and fixed LoRa node configurations.

TABLE I
Hardware Configuration

Sl. No.	Module	Specifications	Purpose
1	ESP32	Dual-core 240 MHz, integrated Wi-Fi and Bluetooth connectivity	Central processing and control unit
2	Cytron MDD10A	Dual-channel motor driver, 10 A per channel PWM output	Controls DC motor speed and direction
3	RYLR890	LoRa module operating at 868 MHz using Chirp Spread Spectrum modulation	Long-range, low-power communication link
4	DHT11	Temperature: 0–50 °C, Humidity: 20–90 % RH	Measures temperature and humidity for environmental analysis
5	HC-SR04 + Servo	Ultrasonic range: 2–400 cm, Servo rotation: 180°	Detects obstacles and performs environmental scanning
6	LDR Module	Analog light-dependent resistor sensor	Measures illumination and light intensity
7	MQ Series Gas Sensor	Detects CO, CH_4, and other gases within 0–1000 ppm range	Monitors air quality and hazardous gas presence

Most current environment-focused IoT systems rely on short-range local wireless technologies such as Wi-Fi, Bluetooth, or ZigBee, which limit their operation to areas with stable connectivity and small coverage zones. Although stationary LoRa sensor nodes can extend range and reduce energy consumption, they remain fixed in place and cannot dynamically collect data across large or rugged areas.

The proposed LoRa-Based Envi-Rover addresses this limitation by merging long-range LoRa communication with a mobile rover platform, enabling dynamic, real-time environmental monitoring across multiple locations. The system incorporates multi-sensor integration, servo-assisted obstacle detection, and Blynk IoT cloud connectivity to achieve mobility, safety, and remote visualization. As a mobile platform, the Envi-Rover provides enhanced scalability, adaptability, and extended operational range for outdoor applications compared to conventional static monitoring systems.

A. Advantages of the Proposed System

Compared to existing IoT-based monitoring systems, the proposed Envi-Rover offers the following advantages:

1) **Long-Range Communication:** LoRa connectivity achieves more than 1 km of reliable coverage, outperforming Wi-Fi, Bluetooth, and ZigBee networks.
2) **Mobility:** The rover platform enables dynamic data collection from multiple locations without requiring fixed sensor deployment.
3) **Low Power Operation:** LoRa and optimized motor duty-cycle control reduce energy consumption and extend operating time.
4) **Multi-Sensor and Cloud Integration:** Simultaneous measurement of temperature, humidity, gas, and light data with real-time Blynk IoT visualization.
5) **Scalable and Cost-Effective:** Minimal infrastructure requirements and easy system expansion with additional rovers or relay nodes.

TABLE II
COMPARISON OF EXISTING SOLUTIONS AND OUR PROPOSED ENVI-ROVER

Parameter	**Wi-Fi / Bluetooth IoT**	**Static LoRa Nodes**	**Proposed Envi-Rover**
Communication Range	10–100 m, affected by obstacles	1–10 km, fixed coverage	**1+ km mobility; range can be extended further using LoRa repeaters / hop-based relay**
Power Consumption	High (continuous radio)	Low	**Low (LoRa + optimized motor control duty cycle)**
Node Mobility	Cannot move; data only from fixed point	Fixed once deployed	**Mobile rover collects data across multiple terrain points**
Data Coverage	Very limited area	Limited to sensor placement locations	**Wide area coverage through rover traversal and waypoint-based movement**
Reliability in Remote / Hazardous Areas	Poor (requires network availability)	Moderate (static sensing)	**Highly reliable — LoRa unaffected by terrain obstructions, rover reaches inaccessible regions**
Deployment Flexibility	Needs stable infrastructure	Requires planned placement	**Can be deployed quickly in unknown / changing environments**
Scalability	Difficult; each node needs configuration	Good; can add more nodes	**Excellent — rover + optional LoRa mesh repeater nodes allow network range expansion**

IV. CONCLUSION

The LoRa-Based Envi-Rover demonstrates how low-power long-range communication and robotic mobility can be integrated into a scalable environmental monitoring platform. Built around an ESP32 microcontroller, Cytron MDD10A motor driver, and RYLR890 LoRa module, the system delivers energy-efficient data transmission over distances exceeding one kilometer.

The rover collects key environmental parameters such as temperature, humidity, air quality, and light intensity using sensors including DHT11, MQ-series gas sensors, and LDR modules. An ultrasonic sensor with servo-assisted scanning enables effective obstacle detection and safe navigation. Real-time monitoring and control are provided through the Blynk IoT platform, supporting remote visualization and data logging.

Experimental results confirm stable LoRa communication and reliable multi-sensor data acquisition with minimal delay. The modular design allows easy customization for applications such as smart agriculture, industrial safety, and environmental research. Compared to Wi-Fi-based systems, the Envi-Rover offers significantly lower power consumption, extended range, and mobile data collection in hard-to-reach or hazardous areas.

Future enhancements may include solar power integration, autonomous navigation, AI-based data analysis, and LoRa mesh networking. These upgrades would improve endurance, intelligence, and scalability, enabling long-term autonomous deployment for smart cities, precision agriculture, and disaster management.

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DECLARATIONS

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Authors' Contributions: Prof. Kiran Nandi supervised the project and guided the system architecture. Harish B Patil and Murali Vijay Vhanmani developed the hardware and communication modules. Narendra R Giriyappanavar (corresponding author) led the integration, testing, and manuscript preparation. Netravati M Murari contributed to software development, data collection, and validation. All authors reviewed and approved the final manuscript.

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