

# 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 Realtime 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.**

**Keywords - LoRa, ESP32, Cytron Motor Driver, Environmental Monitoring, Blynk IoT Cloud, Rover, IoT.**

## 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 Lora WAN. 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].

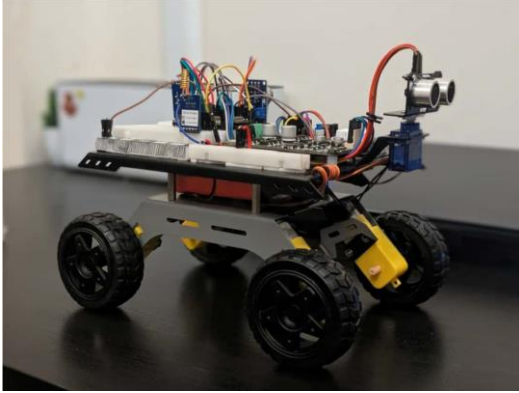


Fig. 1. Prototype of the LoRa-Based Envi-Rover developed using an ESP32 controller, Cytron MDD10A motor driver, and multi-sensor integration for environmental monitoring.

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.

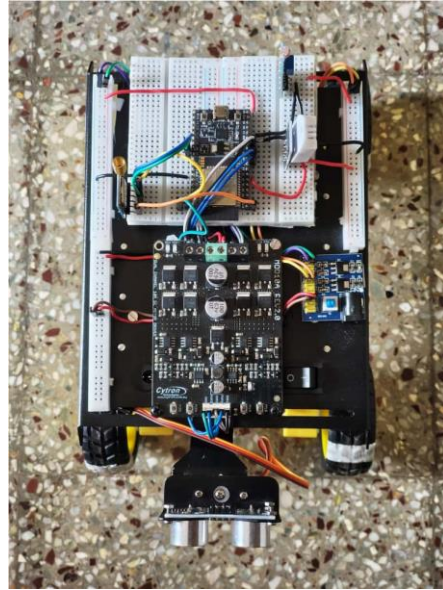


Fig. 2. Top view of the LoRa-Based Envi-Rover prototype showing the arrangement of the ESP32 DevKitC, Cytron MDD10A motor driver, and environmental sensors integrated on the rover chassis

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

### Hardware Components

**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 I<sup>2</sup>C. 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.

**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].

**LoRa RYLR890 MODULE (868 MHz):** The RYLR890 LoRa transceiver module operates at 868 MHz 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].

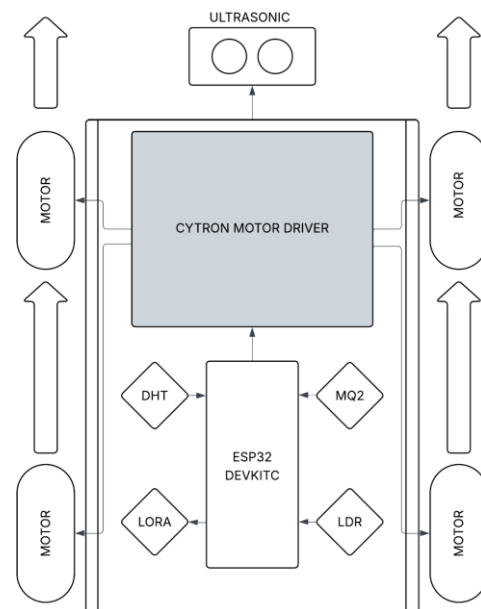


Fig. 3. Prototype hardware layout of the LoRa-Based Envi-Rover showing the arrangement of key components including the ESP32 DevKitC, Cytron motor driver, sensors (DHT, MQ2, LDR, Ultrasonic), and motor configuration.

**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  $\pm 5\%$  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 the radiation and it does so by changing its resistance depending on the light levels. This is how the rover gets to know the brightness of the surroundings which is a very clever way to determine the difference between daylight and dim light during the functioning. LDR sensors are easy to use and are very low-power devices, thus they are an ideal solution 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<sub>4</sub>), and other volatile compounds. These sensors use a tin dioxide (SnO<sub>2</sub>) semiconductor layer that changes resistance when exposed to gases. This change lets the ESP32 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].

### **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 the 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  $\pm 1.8^\circ\text{C}$ , 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 an open outdoor air (clean-air reference) and then the response variation was 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 ultrasonic sensor (HC-SR04 with servo) performance. The average measurement error from five reference points (10 cm to 100 cm) was less than  $\pm 1.5$  cm, thus the sensor was verified to have accurate short-range obstacle detection capability. The calibrations result 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 being a confirmation of the system's readiness for a real-world deployment.

### **Communication Architecture**

Envi-Rover's communication setup is aimed at delivering 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 a very reliable one 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 the achievement of fast responses and accurate motion control, at the same time, a stable communication link is maintained over long distances. LoRa transceiver modules, configured with AT commands, are in a bidirectional mode that can handle both control signals and telemetry data.

With such a configuration, the rover is able to get movement instructions and can also send some time later environmental data like temperature, humidity, and gas concentration 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 is a device that ensures data exchange is always reliable even in places where there is interference. In this way, it becomes a perfect outdoor and agricultural monitoring conditions [18].

The long-range, low-bandwidth link that is used here allows for less packet collisions and power consumption, which are very important to be fixed on a battery-operated mobile platform [5], [7].

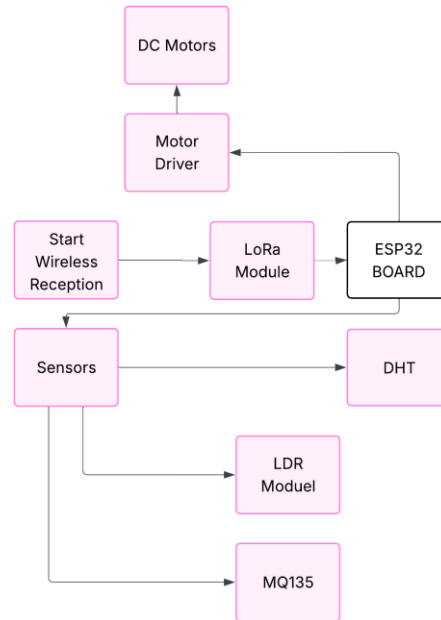


Fig. 4. Rover-side block diagram showing the interaction between ESP32, LoRa module, motor driver, and environmental sensors (MQ135, DH, and LDR).

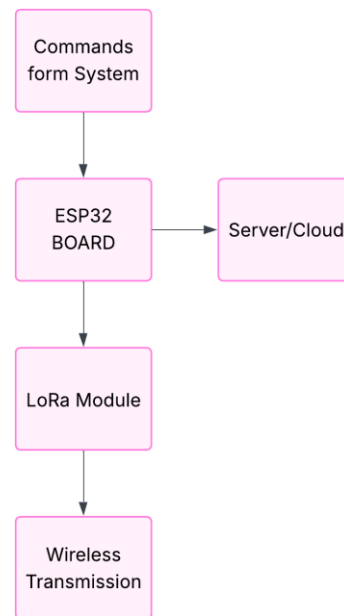


Fig. 5. Communication flow diagram illustrating command input, ESP32 control, LoRa-based wireless transmission, and cloud connectivity.

Besides LoRa, the Envi-Rover has Wi-Fi-based data transmission that is done through the ESP32's native module to facilitate real-time visualization and data recording. The device displays the environmental parameters like temperature, humidity, gas

concentration, and light intensity through the Blynk IoT platform on a mobile or web dashboard. The cloud-based interface presented in this way enables the users to not only check the system's functioning but also access the environmental patterns through live charts and graphical indicators.

The dual-channel configuration that employs LoRa for command and telemetry exchange and Wi-Fi for cloud synchronization provides local control as well as remote access. Thus, the data transmission is secure in a way that it can still go on even if there is a break in internet connectivity [13], [17], [19].

The combination of these two types of communications networks increases the Envi-Rover system's dependability and its capacity to be extended further. LoRa is the main source of power for operations that are of low-power and can be carried out over long distances. Wi-Fi is the means by which the data gathered are quickly visualized and stored for later analysis. The seamless cooperation of these two technologies enables the rover to be very effective in different situations, 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 records on the cloud, the Envi-Rover employs the Blynk IoT platform. The ESP32 gathers the sensor readings and sends them to the Blynk server at regular intervals. The users can get the information from a customized web and mobile dashboard that has widgets like gauges, graphs, and notifications. Blynk has been similarly IoT-based Agricultural monitoring systems used effectively for remote irrigation control and farmer alerts [22], smart humidity monitoring, and data logging in storage facilities [23], and scalable sensor networks for environmental resources management [24]. This arrangement guarantees that while LoRa is used for long-range communication to control the rover, the users can still see the environmental data trends from anywhere if they have internet access.

### III. METHODOLOGY

#### Motor Control

The rover is able to move as a result of Pulse Width Modulation (PWM) signals that are generated by the ESP32 microcontroller. The Cytron MDD10A motor driver is where these signals are fed. The driver adjusts the speed and the direction of two DC motors, thus allowing the rover to be able to accelerate, decelerate, and change its direction smoothly. Different duty cycles of the PWM pulses which the ESP32 sends through its GPIO pins result in changes of motor speed. What is more, this method offers very precise control and lessens the wear and tear of the motors caused by the mechanical side of things [7], [14].

The MDD10A is a dual-channel device, thus separate control of the left and right motors is possible. In this way differential steering, which is a stabilized and accurate turning method most navigation is based on, can be employed. The ESP32 keeps changing PWM output according to the joystick commands or the obstacle sensors input during the run. Hence, the vehicle is able to behave in a prompt and secure way even on bumpy ground [16].

#### Sensor Integration

Multiple environmental sensors connect to the ESP32 using digital and analog pins for real-time data collection. Each sensor measures particular environmental factors, creating a complete monitoring system:

**DHT11 Sensor:** It periodically captures the surrounding temperature and humidity. It sends data using a single-wire protocol. Its reliability and low power usage make it a good choice for ongoing environmental monitoring [11], [21].

**Ultrasonic Sensor (HC-SR04):** The sensor which is attached to a servo motor scans the area by releasing ultrasonic pulses and checking the time taken by echoes to return. In this way, it works out the distance to the nearest obstacles. The servo can turn 180°, thus, extending the covered area and facilitating the process of avoiding obstacles. [10], [12] Measures ambient light intensity by detecting changes in resistance under different lighting levels.

This feature allows the system to evaluate lighting conditions and adjust to low-visibility environments [11].

Gas Sensor (MQ Series): Detects harmful gases like carbon monoxide (CO) and methane (CH) by tracking changes in resistance in the sensing element. The MQ sensors help spot possible air quality risks and improve environmental safety [13], [20]. The ESP32 is always on the job, processing sensor readings and dispatching them via LoRa to the base station. This enables frequent updates to be available even when the bandwidth is very low. The configuration of these sensors is such that additional environmental variables, for instance, soil moisture or particulate matter, can be incorporated without any hassle.

### LoRa Communication

The rover and the base station communicate using RYLR890 LoRa transceivers that are configured with AT commands. The modules operate at a baud rate of 115200 bps and are arranged in a point-to-point mode, where one device is the rover transceiver and the other is the base station receiver. Setting the network ID, device address, and transmission parameters is required to start the system via the ESP32 serial interface [5], [18].

The CSS (chirp spread spectrum) modulation used in LoRa helps to keep the data transmission stable over long distances while also energy consumption is kept low. The communication process can be in both unidirectional and bidirectional modes. So, the rover can send sensor readings and at the same time receive motion commands or configuration updates. The low data rate and narrowband communication increase the signal strength. Thus, the system becomes ideal for open fields or places with some kind of obstruction [17], [19].

### User Interface

The Envi-Rover control interface is a blend of manual input and real-time visualization. With a joystick setup, the user can give navigation instructions like forward, backward, left, right, and stop to the rover via LoRa communication. The ESP32 decodes these

instructions and generates PWM signals for the Cytron MDD10A to the motor activation.

At the same time, the system employs the Blynk IoT platform to visually represent the live sensor data that are transmitted over Wi-Fi. The gauges and charts on the dash board display temperature, humidity, light intensity, and gas concentration, thus, they are always up-to-date. The combination of these two systems for feedback, which also involves the use of a joystick for manual control and Blynk for visual data, makes the work more efficient and gives a better understanding of the situation [13], [17], [19].

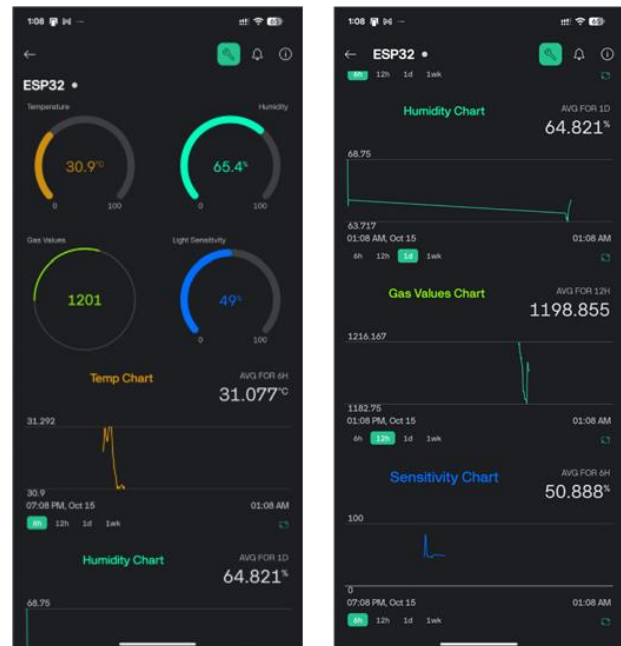


Fig. 6. Blynk IoT mobile dashboard interface for the Envi-Rover system showing (a) real-time parameter gauges for temperature, humidity, gas values, and light sensitivity, and (b) corresponding time-series charts displaying data trends.

The data update frequency is changeable in the Blynk environment. This is a feature that users can handle the refresh rate and power consumption with. In case the network is down for a while, local LoRa communication is still able to keep the control active. Sensor data is stored for later syncing. The two methods together guarantee uninterrupted monitoring and control even if the device is in offline

mode. Because of this, the Envi-Rover is extremely adaptable to field operations [5], [7], [13], [18].

### Power Supply and Runtime Analysis

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

The average current consumption of the rover was measured under three different operating conditions: standby (no motion), sensor sampling with telemetry transmission, and active locomotion. In a situation where the device is idle but the sensors are enabled, the system consumes around 180-200 mA.

The current during an active LoRa transmission and control processing without movement is approximately 250-280 mA. The Cytron MDD10A motor driver and dual DC motors are the main contributors to the increase in total current consumption up to about 300-360 mA, depending on the load of the terrain, when the rover is moving.

The estimated runtime of the system can be calculated as:

Runtime (Hours)=

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

Runtime = Approx = 7.8 hours

Therefore, the rover is able to function nonstop for about 7-8 hours per full battery cycle under normal movement and sensing conditions. In the case of watching while standing still (no motion), the time between charges is around 10-12 hours.

### Results and Discussions

The Envi-Rover prototype underwent tests in both indoor and outdoor environments to assess the effectiveness of its communication, the accuracy of

its sensors, obstacle detection, and real-time data visualization.

A single RYLR890 LoRa module operating at 868 MHz was implemented by the prototype. This made it possible for the rover and the control unit to communicate wirelessly over distances close to one kilometer in open areas.

The system was able to maintain stable communication up to around 650 meters in a partially obstructed area, thus demonstrating that LoRa technology can be trusted for long-range, low-power data exchanges [17] [19].

The very low packet loss rate, which was less than 2%, and the stable data throughput, were the main factors that confirmed the system's capability to provide uninterrupted real-time telemetry, thus being in line with the findings of the earlier studies on field performance of LoRa-based systems [5], [18].

During initial testing, the ESP32 microcontroller efficiently conducted multiple operations concurrently. It controlled the motor, collected data from the sensor, and transmitted the LoRa data all at once without any visible waiting time.

The mean time interval of the joystick motion command execution was between 210 and 250 milliseconds. This guaranteed the smoothness of the navigation and instant control. Such a quick reaction time is an indication of the microcontroller's dual-core processing capability and the advanced application of PWM motor control logic [14], [16].

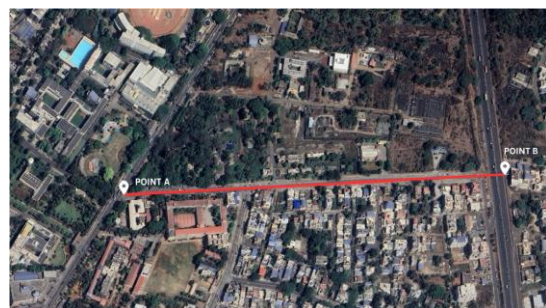


Fig. 7. LoRa communication field test range between Point A and Point B showing a direct line-of-sight distance used for performance evaluation.

The ultrasonic sensor was mounted on a servo that turned to different angles and thus provided the rover with the view of its surroundings. With this method, the rover was able to do a 180° sweep for the detection of the obstacles.

The range in which the system could detect and avoid the obstacles was from 20 to 30 cm, thus it showed reliable short range detection capabilities. The use of the servo for scanning not only extended the coverage of the surrounding but also minimized the chance of accidents during the running phase. This is consistent with the findings of several other research works in the field of the use of ultrasonic sensors for the navigation of mobile robots [10], [12].

Environmental sensing performance supported the dependability of the built-in sensor suite. The DHT11 sensor produced temperature and humidity values that differed from the standard ones by less than  $\pm 2^{\circ}\text{C}$  and  $\pm 5\%$  relative humidity.

This certifies the reliable gathering of environmental data [11], [21]. The MQ-series gas sensors were very efficient in indicating the changes in gas concentrations and also providing them as stable readings during the simulated emission phase. Moreover, the LDR sensor captured varying light levels, thus it was confirmed that the rover is capable of working in both bright and dim conditions [13], [20].

LoRa communication efficiency was measured under natural environment and partially blocked conditions to assess the dependability of the signal and to figure out the limits of the performance. Experiments on the ground were conducted with RYLR890 868 MHz LoRa transceivers, a spreading factor (SF) of 7, and a transmission power of +20 dBm. With 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 comprising buildings and vegetation, dependable communication was achievable at distances between 650 m and 780 m.

The Received Signal Strength Indicator (RSSI) values varied from -78 dBm for strong signals at distances less than 200 m to about -123 dBm at the point that was farthest tested. Packet loss was less than 2% up to 800 m and it gradually rose to 6–8% close to the maximum distance limit.

These findings corroborate that LoRa presents a sturdy, long-range, lowpower, and interference-resistant communication link, which empowers it as a technology that can be used for remote environmental monitoring in agricultural and rural fields.

LoRa's communication capability was uniform during all the testing periods. On the other hand, Wi-Fi signals started to weaken after 100 meters resulting in connection drops. The reason for the good connection maintained by LoRa was its high link budget and the very efficient CSS modulation technique [5], [17].

The mean current drawing during moving operation was 320 mA, whereas the telemetry idle current was 180 mA. Therefore, to deliver the continuous operation time of more than seven hours, a 2500 mAh Li-ion battery was used. This is an indication of energy-saving strategies for LoRa powered systems on mobile robotic platforms [5], [7].



**prediction, just like the cloud systems referred to in previous IoT**

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 gave users the ability to monitor temperature, humidity, gas levels, and light trends simultaneously. In addition, the cloud dashboard was recording data for future analysis and trend prediction, just like the cloud systems referred to in previous IoT studies [13], [19]. Such a merger with the platform enhanced the awareness level of the situation by offering fast access to the sensor input, thereby making the decision process efficient during the on field operations.

Basically, the results of the experiment validate that the Envi-Rover is a dependable, cheap, and power-saving unit for the remote survey of the environment. Its use can be extended to precision agriculture, pollution monitoring, and disaster response, among others, due to the combination of LoRa based long-distance communication, ESP32 processing, and multi-sensor integration. The system, being stable, scalable, and autonomous, therefore, represents a versatile model for practical IoT applications in areas with scarce communication infrastructure [5], [7], [13], [17]-[19].

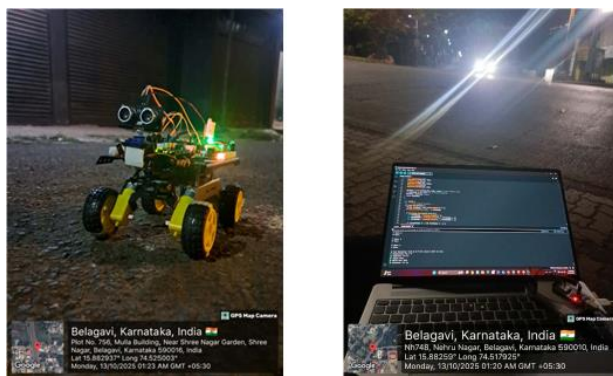


Fig. 9. Final field testing of the LoRa-Based Envi-Rover showing (left) outdoor operation in Belagavi, Karnataka, and (right) live data monitoring via ESP32 interface during the field test.

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 <sub>4</sub> , and other gases within 0–1000 ppm range	Monitors air quality and hazardous gas presence

### Comparison with Existing Solutions

The majority of the present environmental monitoring systems, which are based on Wi-Fi or Bluetooth, have limited transmission ranges and high power consumption and require continuous network availability. Therefore, these systems cannot be used in outdoor or remote areas. Although a stationary LoRa-based monitoring system extends the range and makes the system more energy-efficient, it can only be used for fixed sensing points and cannot be changed with the terrain or a hazardous zone.

The innovative concept of the LoRa-Based Envi-Rover merges LoRa long-range communication with a mobile rover unit. Such a configuration enables multi-location sensing, remote navigation, and dependable data transfer, basically, in places where there is barely any network infrastructure. Moreover, its mobility coupled with long-range radio communication gives users the ability to broaden the sensing range simply by inserting intermediate LoRa nodes as repeaters or checkpoints to establish a hop-by-hop communication line.

Along with a larger range and flexibility the rover's onboard obstacle detection and servo-assisted scanning enable it to move safely over uneven or locally piled terrain. Such a move is not feasible for stationary sensor nodes. Besides, the system provides live visualization and data logging through the Blynk IoT platform. It means that users can remotely monitor the environmental conditions without their physical presence in the location. Furthermore, the modular layout enables the users to add a new sensor or a computing module with a minimum of a redesign that enhances the long-term scalability feature. To sum up, the designed system has a wider operational range, a mobile data gathering capability, and higher reliability in remote locations as compared to short range Wi-Fi or Bluetooth-based systems and fixed LoRa node arrangements.

The majority of current environmentally focused IoT systems use local area wireless techniques that are short-range in nature, for instance, Wi-Fi, Bluetooth, or ZigBee, and that limit them to places having stable connectivity and small coverage areas. Even though the distance is increased and the energy consumption is lowered with the help of stationary LoRa sensor nodes, the latter still cannot be changed, thus the data cannot be collected dynamically in a large or rugged area.

The different Based Envi-Rover is a concept that merges long-range LoRa communication with a mobile rover platform thus allowing dynamic, real-time environmental monitoring across various locations. The unit comprises multi-sensor integration, servo-assisted obstacle detection, and Blynk IoT cloud connectivity to deliver mobility, safety, and remote visualization. The Envi-Rover, as a mobile platform, is endowed with more scalability, adaptability, and extended operational range for the outdoor applications than the conventional static systems can have.

### Advantages of the Proposed System

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

**Long-Range Communication:** LoRa connectivity achieves more than 1 km of reliable coverage, output forming Wi-Fi, Bluetooth, and ZigBee networks.

**Mobility:** The rover platform enables dynamic data collection from multiple locations without requiring fixed sensor deployment.

**Low Power Operation:** LoRa and optimized motor duty-cycle control reduce energy consumption and extend operating time.

**Multi-Sensor and Cloud Integration:** Simultaneous measurement of temperature, humidity, gas, and light data with real-time Blynk IoT visualization.

**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
Data Coverage	Very limited area	Limited to sensor placement locations	Wide area coverage through rover traversal and way point 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

This paper showcased the design, creation, and assessment of the LoRa-Based Envi-Rover, a mobile IoT-enabled platform that was developed to address the challenges of environmental monitoring systems

in remote or regions without infrastructure. The system efficiently melds long-range Lora communication hence the over 1 km connectivity in field tests - with the multitasking ability of the ESP32, that motor control, sensor acquisition, and telemetry can be done seamlessly without any notable latency.

The rover's multi-sensor module that was calibrated yielded accurate values of the temperature, humidity, gases, distance to obstacle, and light intensity thus making the system support numerous environmental monitoring applications. Moving over different terrains was made possible through differential-drive control and a 180° ultrasonic scanning mechanism, which helped in ensuring the rover's safe and stable movement over rough or uneven surfaces. Immediate presentation via the Blynk IoT platform along with cloud updates of low-latency and long-term data logging improved not only the on the spot awareness but also the capabilities of post-analysis. Its power was consumed in an optimized manner, so the rover was running continuously for 7–8 hours, and in a telemetry only mode, it could last up to 12 hours, thus, it was ideal for an extended field mission. To sum up, the Envi-Rover is better than the traditional Wi-Fi/Bluetooth devices and static LoRa nodes in that it provides mobility, long-range communication, safety enhancement, and cloud analytics. The next possible upgrades are including a solar-powered extension of the battery, AI powered anomaly detection along with autonomous navigation, multi node LoRa mesh deployment, and cloud-based machine learning for predictive environmental insights that will unfold more system capabilities for agricultural, environmental, and hazard-monitoring sectors.

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