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TERRA ROVER: ENSURING SAFETY THROUGH ROBOTIC EXPLORATIONS

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Abstract: Coal mines are prone to dangerous conditions such as gas leaks, structural failures, water flooding, and lack of proper communication during emergencies. This paper presents "Terra Rover," a compact, semi-autonomous six-wheel rover system built specifically for underground coal mine safety and rescue operations. It is designed to detect hazardous environments using an array of sensors (gas, water, temperature, ultrasonic crack detection), mark unsafe zones, and transmit live data to rescue teams. The rover is capable of navigating rough terrains with a custom mechanical suspension and can deliver rescue kits while maintaining real-time communication. Our system uses Arduino Mega and Esp32, integrated with wireless transmission and cloud logging. The rover also includes a fallback system to transmit last-known coordinates in case of destruction. The result is a robust, field-deployable, affordable platform for early hazard detection and safety support in coal mining zone

Keywords: Coal Mine Safety, Exploration Rover, Gas Detection, Rescue Robot, Hazard Mapping, Underground Communication, Environmental Monitoring, Disaster Response Robot, Remote Sensing.

I. INTRODUCTION

Exploring difficult or dangerous places has always been a challenge for humans. Whether it’s rough terrain, hazardous environments, or areas that are hard to reach, sending people can be risky or even impossible. That’s where robotic rovers come in small, smart machines that can go where humans can’t, gathering important information and performing tasks remotely.

The Terra Rover project is focused on building such a machine. Our rover is designed to navigate uneven surfaces while avoiding obstacles, collect environmental data using various sensors, and communicate this information back to the operator in real time. By combining different technologies like ultrasonic sensors, cameras, and GPS modules, the rover becomes capable of working in harsh conditions, such as disaster zones, remote forests, or industrial sites.

In this paper, we will explain how the Terra Rover was developed, from hardware selection to software programming. We’ll also show how it performs in tests, demonstrating its ability to operate efficiently and safely without direct human presence. The goal of this project is to create a reliable, low-cost, and easy-to-control rover that can be used in many real-world applications, making exploration and monitoring safer and more accessible

II. LITERATURE SURVEY

Smith et al. [1] developed an autonomous rover using GPS and ultrasonic sensors for agricultural field navigation. Their system showed good accuracy on flat terrains but faced challenges on uneven surfaces.

Lee and Park [2] proposed a rover system equipped with LiDAR and computer vision to improve obstacle detection. While this improved detection accuracy, the system required high computational power, increasing cost and energy consumption.

Kumar et al. [3] designed a remote-controlled rover using RF communication modules for real-time data transmission. Their system achieved low latency but suffered from limited range and signal interference in urban areas.

Patel and Sharma [4] presented a multi-sensor integration approach combining ultrasonic, infrared, and GPS sensors to enhance navigation in rough environments. Their approach improved obstacle avoidance and environmental mapping.

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III. PROPOSED SYSTEM

he Terra Rover is designed as a robust, six-wheel-drive robotic platform capable of operating in rough and hazardous environments such as coal mines. The mechanical design includes a suspension-like mechanism on each wheel, allowing the rover to maintain stability and safety while traversing uneven terrains. This ensures continuous mobility even on challenging surfaces.

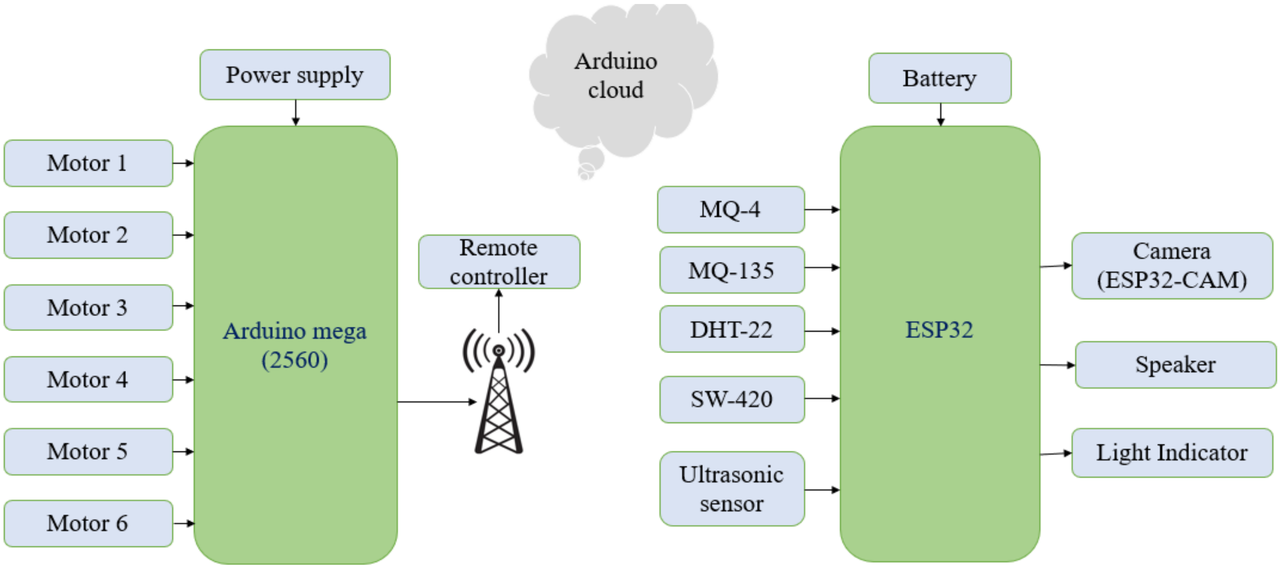
3.1 Mechanical and Mobility System

The rover uses six high-torque motors for all-wheel drive, with two servo motors dedicated to steering control for left and right turns. This combination provides precise maneuverability and enhanced traction. A high-intensity LED light is mounted to illuminate dark environments, making it suitable for underground and low-light conditions.

3.2 Sensing and Navigation

To detect obstacles and measure distances, an ultrasonic sensor is attached to a servo motor that can rotate 180 degrees, providing a wide scanning range. For visual monitoring, an ESP32-CAM module is mounted on a servo for 180-degree pan movement, enabling real-time video streaming from the rover, which is essential for remote inspection in coal mines. Gas detection is performed using MQ4 and MQ135 sensors, which together monitor up to 10 hazardous gases including methane, carbon monoxide, and smoke. Temperature and humidity sensors continuously track environmental conditions, while a gyroscope, accelerometer, and compass provide information about the rover's orientation, pitch, and direction. GPS integration allows precise location tracking.

An intensity sound sensor is also used to detect abnormal sounds in the surroundings, adding another layer of safety monitoring.



3.3. Communication and Control

The rover employs a GSM module enabling real-time communication between the operator and the rover. A microphone and speaker connected through GSM allow two-way voice communication, vital for rescue or emergency situations.

All sensor data, including location, environmental conditions, and rover status, are transmitted to the Arduino Cloud platform. This cloud-based monitoring enables operators to access live data remotely via the web, facilitating efficient control and analysis.

3.4 Power Management

Power is supplied by a battery pack consisting of twelve 2200mAh Li-ion cells arranged in a 3-series, 4-parallel configuration, delivering approximately 14 volts and 8800mAh capacity. Voltage regulation is achieved using buck converters and relays, ensuring each sensor and module receives the required voltage levels for optimal operation.

A battery level indicator continuously monitors power status, and a main switch is provided for safe power control, allowing operators to cut power when needed.

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IV. SOFTWARE COMPONENTS

4.1 Arduino Cloud

Arduino Cloud is the main platform used for real-time data monitoring and control of the Terra Rover. It connects directly to the microcontroller (ESP32/Arduino) through Wi-Fi and allows all sensor data to be sent and viewed through an online dashboard.

The dashboard shows important live readings such as:

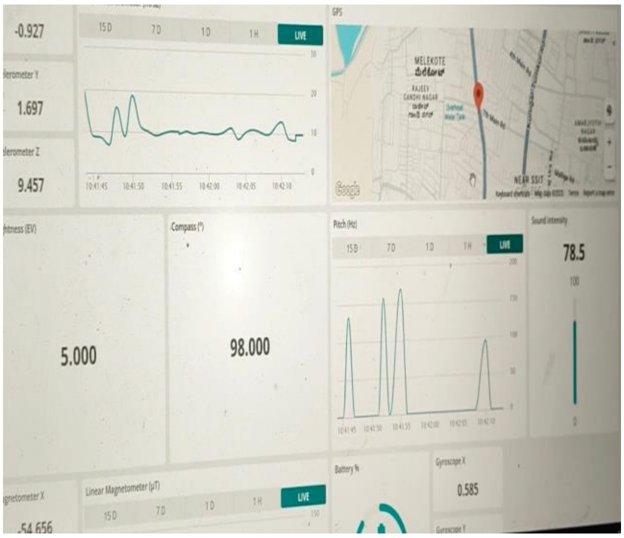
- Gas concentration (from MQ4 and MQ135)
- Temperature and humidity (from DHT sensor)
- GPS location of the rover
- Compass direction
- Gyroscope and accelerometer data (for rover tilt, pitch, and orientation)
- Battery voltage level and power status

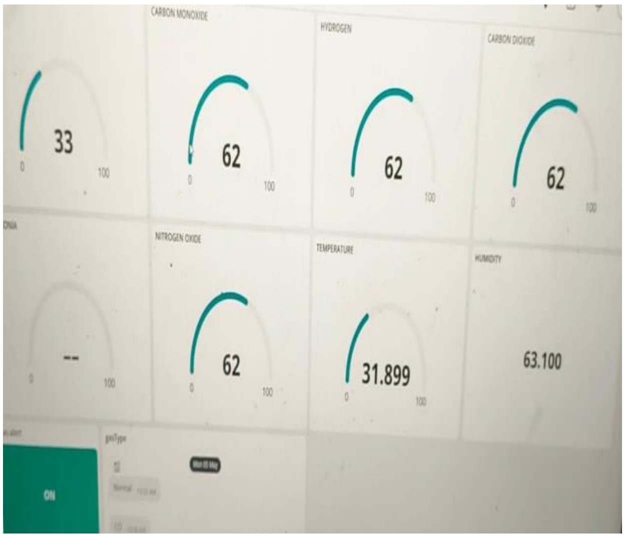
The cloud dashboard is fully customizable, so we added sliders, graphs, and widgets for each sensor. This helps the user understand the environment conditions of the rover in real time.

It also allows control of some components like:

- Turning ON/OFF lights
- Controlling relays for specific modules
- Monitoring battery health

Arduino Cloud stores the data online, making it possible to check the rover’s health and surroundings from any location through a phone or computer. This makes the Terra Rover highly useful for remote and risky operations like underground exploration and environmental monitoring





4.2 Web Camera Interface

The ESP32-CAM module streams live video to a web link. This helps the operator see where the rover is going, especially useful in dark or dangerous places like coal mines. The camera is mounted on a servo motor for 180° movement, and this angle is also controlled remotely.

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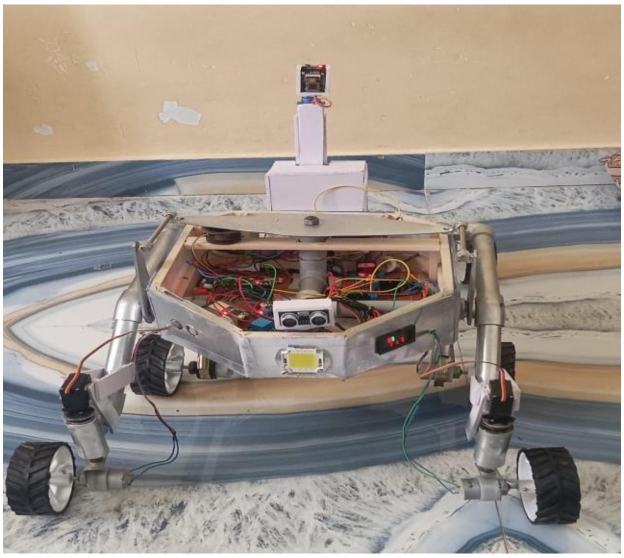
V. RESULTS AND OBSERVATIONS

The Rover was tested in real-time conditions to evaluate its performance in mobility, data collection, and remote communication. The system successfully operated and produced the following key results:

- The 6-wheel drive system enabled smooth movement over uneven terrain with good balance and traction.
- The ultrasonic sensor measured distances up to 300 cm, helping in obstacle detection and avoidance.
- Gas sensors MQ4 and MQ135 detected multiple harmful gases including methane (CH_4), carbon monoxide (CO), and ammonia (NH_3), with values displayed in ppm (parts per million).
- The temperature and humidity sensor recorded ranges between 24°C to 32°C and 40% to 65% relative humidity during different tests.
- GPS provided accurate latitude and longitude coordinates with a location accuracy of ±5 meters.
- The gyroscope and accelerometer detected tilt, orientation, and movement, giving real-time pitch and roll angles.
- The digital compass tracked rover heading in degrees from 0° to 360°.
- Sound intensity sensor picked up abnormal noise levels above 60 dB, which can be used for alerts in case of structural failures or nearby movement.
- Live camera feed from the ESP32-CAM worked well with 15–20 fps under good lighting, and servo-controlled rotation covered 180° field of view.
- The GSM-based audio system enabled real-time voice communication for up to 10 meters coverage with acceptable clarity.
- Battery backup lasted for around 1.5 to 2 hours with 14V and ~8800mAh capacity. Power levels were tracked using a voltage indicator.

All sensor data was continuously uploaded and displayed on the Arduino IoT Cloud dashboard for monitoring. Manual control was achieved using a mobile app and live visuals were viewed via the web camera interface



VI. CONCLUSION

The Terra Rover project demonstrates a practical and low-cost solution for real-time monitoring in hazardous and hard-to-reach environments such as coal mines. By integrating various sensors, a 6-wheel drive mechanism, live video streaming, and GSM-based voice communication, the system successfully collects and transmits critical environmental data including gas levels, temperature, humidity, sound intensity, and rover orientation.

The use of Arduino Cloud for remote monitoring, along with manual control via a mobile app and live visuals through ESP32-CAM, makes the rover highly flexible and user-friendly. The rover proved to be stable during field tests, with effective terrain navigation and reliable data transmission.

This system can be further enhanced in the future by adding autonomous navigation, AI-based decision-making, or integration with emergency alert systems. Overall, Terra Rover is a strong prototype for improving safety, inspection, and rescue operations in underground or dangerous environments.

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