Design of Embedded Based Confined Rover for Special Task Purpose in Hazardous Environment

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ABSTRACT

The hazardous environments include nuclear disaster zones, toxic chemical spills, explosive areas, mining tunnels, and space exploration missions. To address critical challenges faced in environments that are unsafe for direct human intervention. Therefore, the development of an embedded-based confined rover is proposed for special task purposes in hazardous environments. The rover is designed to operate autonomously or semi-autonomously in confined spaces while performing tasks such as exploration, environmental monitoring, inspection, and rescue operations, without exposing human operators to extreme risk. This work focuses on the integration of embedded systems, combining hardware and software components to enable remote control, real-time data processing, and decision-making in real time. The rover is equipped with an array of sensors, including MQ-135 gas sensors, DHT11sensors, an HC-12 module, an ESP32 microcontroller, and a camera module, enabling it to gather critical data, detect hazards, and navigate complex terrains autonomously. These sensors transmit data in real-time to a cloud-based system via IoT technology, allowing for remote monitoring, diagnostics, and predictive maintenance. Its ability to operate in dangerous environments makes it an invaluable tool for reducing human exposure to hazardous conditions while performing critical tasks efficiently. Overall, this system promises to improve safety, increase operational efficiency, and open new possibilities for the future of autonomous systems in extreme environments.

Keywords: ESP32 Microcontroller, IoT, MQ-135 gas sensor, DHT11 sensor, Servo Motor and HC-12 Module.

1. Introduction

A hazardous environment refers to any setting or situation that presents a danger or risk to the health, safety, or well-being of individuals. These environments arise due to various factors such as physical, chemical, biological, or ergonomic hazards. It is typically characterized by conditions or elements that lead to accidents, injuries, or illnesses if proper precautions are not taken. Monitoring vital parameters is essential for determining an individual's health status, tracking their level of physical or mental activity, and preventing the emergence or worsening of harmful conditions [1]. Because of the high complexity of the unstructured working area and the existence of hazardous components, hazardous workplaces are harmful to human health. Environments where toxic chemicals, gases, or substances are present. These are found in industries like manufacturing, agriculture, and laboratories. These environments are prone to the presence of harmful microorganisms. Healthcare settings, laboratories, and waste management facilities are common examples. Planetary rovers depend on safe navigation to function, especially when dealing with the difficult and uncertain terrains seen in space environments [2-4]. It is crucial to recognize possible risks when navigating these types of terrains since they frequently contain features like loose dirt, steep slopes, and craters. These days, robotics systems are widely used in search and rescue operations, which are extremely risky if carried out by people alone. Teleoperated mobile robots have garnered significant interest in a number of fields, including space exploration, military operations, and industrial automation [5]. These robots are carry out intricate operations in dangerous situations while maintaining human safety since they are set up to be controlled remotely by human operators. Mobile robot teleoperation entails the operator sending control orders to the robot over a communication link and the robot returning ambient sensory data to the operator. In these situations, rovers frequently encounter longitudinal slippage brought on by wheel-terrain interactions in the distant setting, which is challenging for operators to detect with just video feedback [6-7]. However, situational awareness and, by extension, command-tracking performance are seriously jeopardized when this slippage information is not communicated. Given that many companies and researchers have been investing in the design and development of advanced rovers for planetary exploration, human-assistance rovers offer a wide range of potential in the field of space robotics. The development of sensor technologies and the availability of affordable and efficient rovers have expanded the importance of mobile robots. Mobile robotics' adaptability to diverse settings through the use of heterogeneous sensors is the primary factor that has made it one of the most popular fields for both home and commercial applications [8-10]. Today, rovers are employed in both household and commercial settings for a variety of human aid tasks. Mobile robots is now a crucial component of many industrial processes, including those that need great accuracy and precision and may be dangerous for human workers. Many industrial facilities require robots due to their efficiency, accuracy, and durability [11]. The servo motor, which regulates the robot's rated load and rotation angle accuracy, is one of its main components. Servo motors in particular are commonly used in industrial robots due to their high torque, small size, and accurate control [12-13]. However, many robot failures are caused by high torque, transformation stress, cyclic load, and impact load. In order to recover from the aforementioned drawbacks, an IoT-enabled robot is necessary for prompt analysis and decision-making. The IoT enables continuous and real-time rover condition monitoring by linking various sensors and devices throughout the rover [14]. These sensors provide data to the robot and cloud-based platforms for analysis, facilitating prompt decision-making and improving inspection accuracy [15]. Hence, this works as an embedded, confined rover is developed for special task purposes in hazardous environments.

2. Proposed Methodology

The paper develops an embedded based confined rover using IoT for special task purposes in hazardous environments. The developed block diagram is presented in Figure 1.

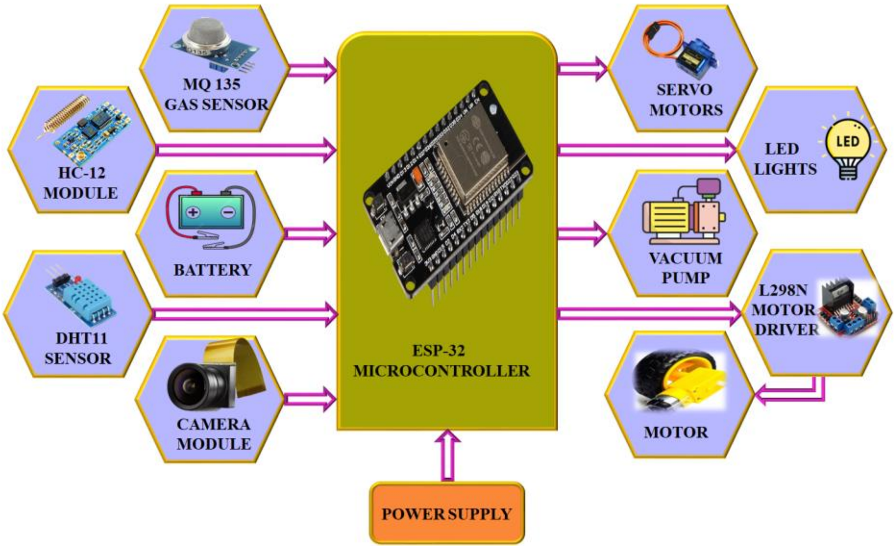

Figure 1 Developed Block Diagram

The DHT11 and MQ135 gas sensors, servo motor, HC-12 module, battery, DC gear motor, vacuum pump, and ESP32 microcontroller are included in the system. First, the ESP32 microcontroller receives power. All of the functions are primarily operated by the microcontroller. The microcontroller is then attached to the sensors, servo motor, NodeMCU, and drivers. The DHT 11 is employed to measure the temperature and humidity of its surrounding environment. Further, the MQ-135 helps the rover assess the air quality in the environment by detecting harmful gases or pollutants. Additionally, the camera module helps the rover detect obstacles in its path by capturing images or videos of the surroundings. A servo motor is used to rotate to a specific position with high accuracy. The relay is powered by a 12V battery for charging. In order to operate the switch and its contacts when an electrical current passes through its control circuit and creates an electromagnetic field, the motor driver is connected to a motor. Electrical energy is transformed into mechanical energy by the DC gear motor. Wi-Fi is used to upload all of the gathered data to the IoT device for monitoring and analysis. Lastly, the Blynk app displays the results of the IoT.

2.1 ESP32 Microcontroller

The ESP32 is a 32-bit microcontroller with a dual-core processor designed by embedded systems, offering integrated Wi-Fi, Bluetooth and other connectivity features. It's known for being highly versatile, low power, and cost-effective for a wide range of IoT and wireless applications. The ESP32 is used in many embedded systems, wearables, home automation, and sensor networks. The ESP32 microcontroller is displayed in Figure 2.

Figure 2 ESP32 microcontroller

It supports both Data RAM and Instruction RAM to help ensure smooth execution of code and tasks. The large amount of RAM also makes it capable of handling relatively complex programs, especially for embedded systems. It performs complex tasks and manage multiple processes simultaneously, which is essential for resource-demanding applications.

2.2 MQ 135 Gas Sensor

The MQ-135 gas sensor is a widely used air quality sensor that detects various harmful gases in the environment. It is part of a series of gas sensors known as the MQ series, which are designed to detect different gases such as ammonia (NH_3), nitrogen oxides (NOx), alcohol, benzene, smoke, and other Volatile Organic Compounds (VOCs). It is commonly used in air quality monitoring systems to detect pollutants in indoor air, such as in homes, offices, factories, or public spaces. Figure 3 is presented in the MQ 135 Gas Sensor.

Figure 3 MQ 135 Gas Sensor

It plays a crucial role in creating safe work environments by monitoring for gases such as ammonia or benzene, which are toxic if inhaled in high concentrations. Moreover, it helps in identifying sources of pollution and taking corrective actions to reduce harmful emissions.

2.3 DHT11 Sensor

The DHT11 sensor is a widely used temperature and humidity sensor that provides a simple and cost-effective way to measure environmental conditions. It measures the amount of moisture in the air. This component works by using a capacitive sensor that changes its electrical properties as the humidity level changes. It is a simple, affordable, and easy-to-use sensor for measuring temperature and humidity in a variety of applications. The DHT11 sensor is shown in Figure 4.

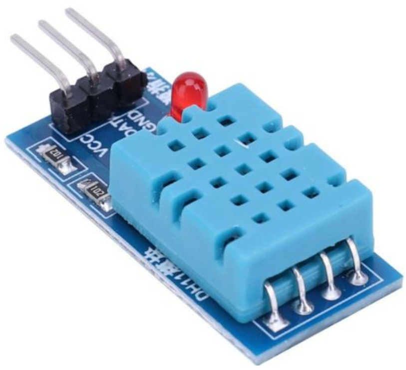

Figure 4 DHT11 Sensor

Further, it provides a simple and cost-effective way to gather environmental data and is primarily used in applications where temperature and humidity need to be tracked for controlling systems or gathering data. Then data is collected and sent to a cloud platform for analysis, storage, or remote monitoring and control.

2.4 Servo Motor

A servo motor is a type of motor that is used for precise control of angular position, speed, and acceleration. It is a highly accurate and efficient motor that is typically used in applications where controlled motion is necessary, such as in robotics, automation, and machinery. It operates on a closed-loop system where feedback is used to adjust and correct the motor's position or speed in real time. Figure 5 shows the servo motor device.

Figure 5 Servo Motor

This type of servo motor uses a DC motor along with a feedback system for precise control. These are simple and cost-effective for low-power applications.

2.5 HC-12 Module

The HC-12 module is a popular wireless communication module used in many DIY electronics projects, especially in Arduino-based applications. It's a 433 MHz Radio Frequency (RF) transceiver that allows sending and receiving data over long distances, up to 1,000 meters, depending on the power level and environment. It is designed to be energy-efficient, making it suitable for battery-powered applications. Figure 6 is presented in the HC-12 module.

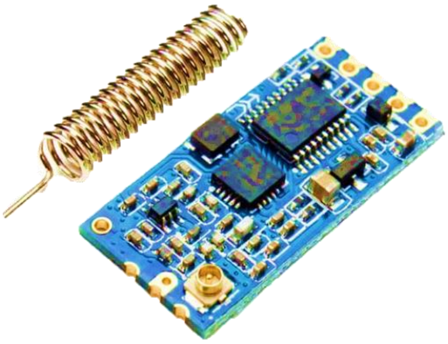

Figure 6 HC-12 module

It reduces the power consumption of the module when it's not transmitting. This is useful in battery-powered applications, where saving energy is crucial.

2.6 Camera Module

A Camera module typically refers to an electronic component that allows for image or video capture in a variety of electronic projects. These modules are often used with microcontrollers, single-board computers, or development boards to integrate imaging capabilities such as surveillance systems, robotics, or IoT devices. The camera module is displayed in Figure 7.

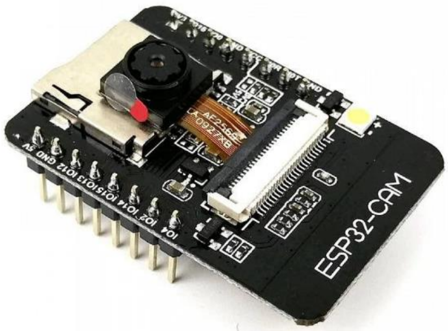

Figure 7 Camera Module

These modules are typically used for simpler applications, as Arduino doesn't have enough processing power to handle high-resolution video or images directly. The higher the resolution, the better the quality of the captured image or video. Moreover, it captures basic images or integrates with other systems for more advanced tasks.

2..7 Motor

A motor is a crucial component in many electronics and mechanical systems, converting electrical energy into mechanical motion. Motors are used in a wide variety of applications, from simple toys to complex robots, automation systems, and vehicles. Motors are divided into different types based on their design, operating principle, and the type of current. A DC gear motor is a DC motor that is coupled with a gearbox to reduce the speed of the motor while increasing its torque. This combination is useful in many applications where high torque at low speeds is required. The DC gear motor device is displayed in Figure 8.

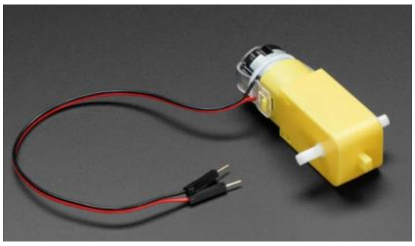

Figure 8 DC gear motor

DC gear motors are often used in mobile robots to drive the wheels, providing the necessary torque to move the robot while controlling its speed. The reduction in speed provided by the gears allows for greater control and more precise movements. It is preferred in these applications because they offer more control over acceleration and deceleration.

2.8 Vacuum Pump

A vacuum pump is a device that removes gas molecules from a sealed volume, creating a vacuum or a space with lower pressure than the atmospheric pressure. Vacuum pumps are commonly used in applications where air or gas must be removed to create a vacuum environment for various processes. In Figure 9, the vacuum pump is shown.

Figure 9 Vacuum Pump

A plastic molding process where the plastic sheet is softened with heat and then vacuumed over a mold. It helps maintain the low-pressure environments required for etching and lithography during the production of integrated circuits. Additionally, its ability to remove air and create controlled environments is crucial in many processes.

3. Results and Discussions

In this work, an embedded-based confined rover using IoT is designed for special task purposes in hazardous environments. Figure 10 shows the hardware setup of the embedded-based confined rover system.

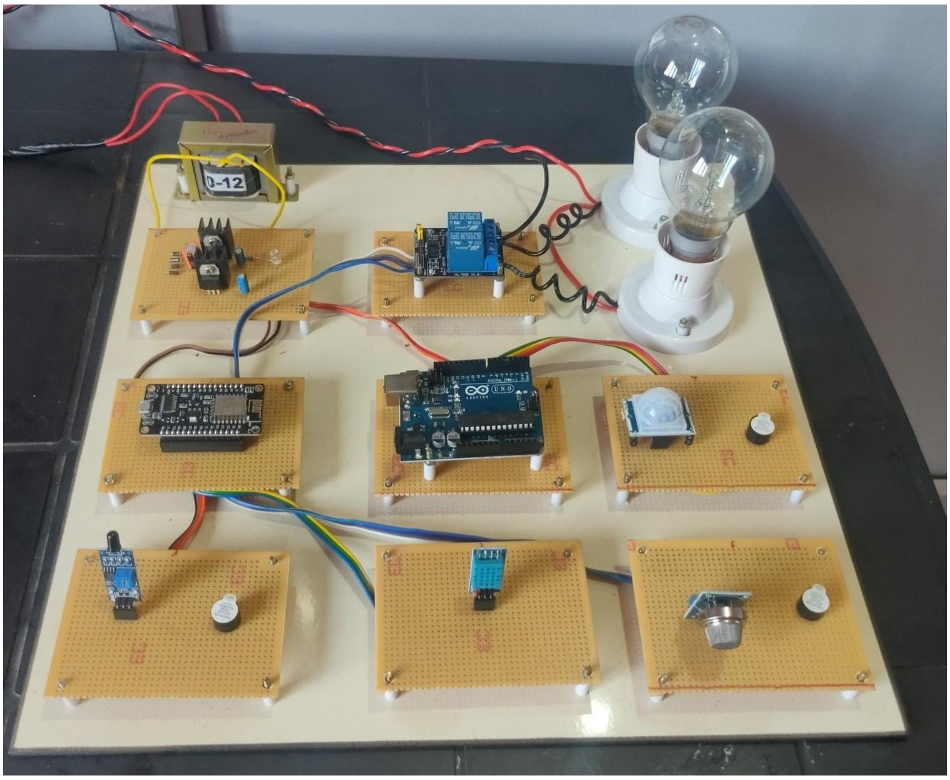

Figure 10 Hardware Setup of The Embedded-Based Confined Rover System.

The rover is equipped with an ESP32 microcontroller, which integrates the Node MCU and IoT and enables external devices like cameras. Additionally, by sending data in real time to a cloud-based system, this rover system makes remote monitoring, diagnostics, and predictive maintenance possible.

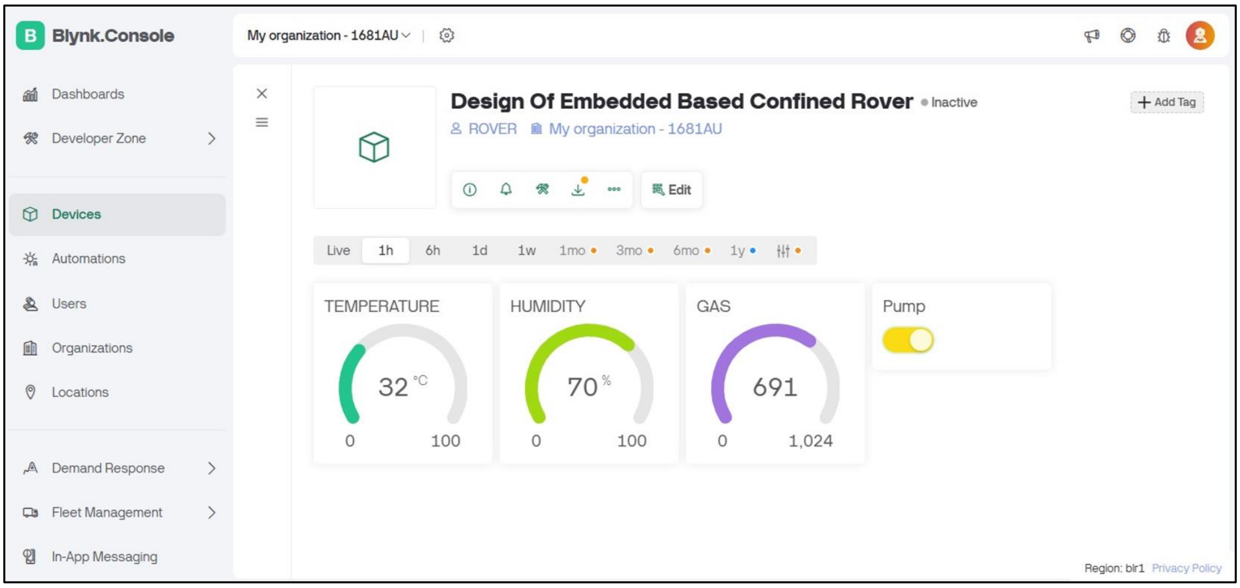

Figure 11 Outcome Page of the BLYNK App

The BLYNK app outcome page is presented in Figure 11. In this figure, the temperature of 320°C and humidity of 79% are measured using a DH11 sensor, and the gas of 691 cf is measured using a gas sensor. Further, it was monitored and demonstrated in this system.

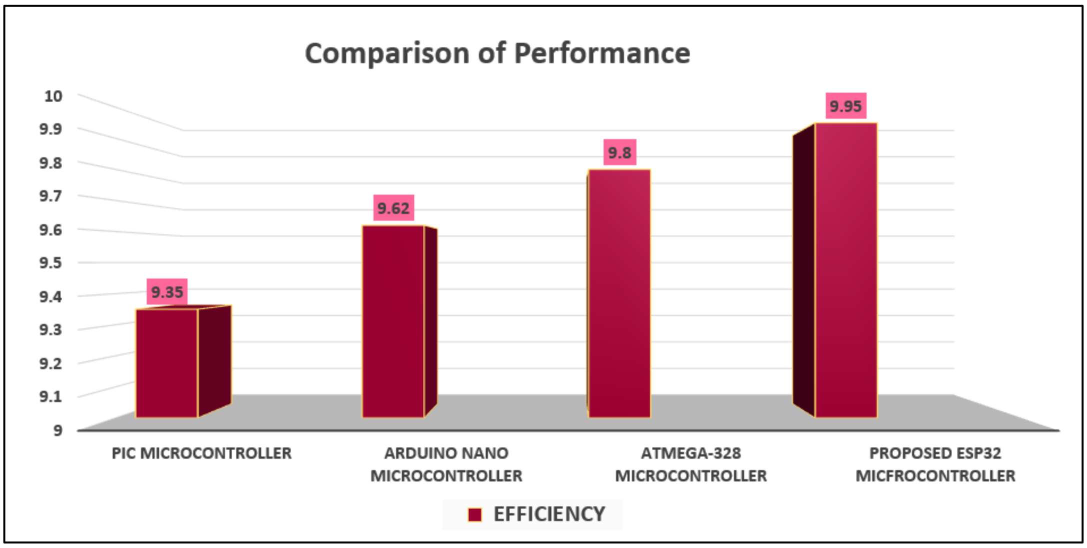

Figure 12 Comparison of Performance

A comparison of several microcontrollers' levels of efficiency is shown in Figure 12. The proposed ESP32 microcontroller of 9.95% is reached in the graph. Based on efficiency, previous controllers of the Arduino Nano microcontroller (9.62%), ATMega-328 microcontroller (9.8%), and Peripheral Interface Controller (PIC) (9.35%) are achieved.

4. Conclusion

This work develops an embedded-based confined rover for special task purposes in hazardous environments. This work minimizes human exposure to hazardous conditions such as toxic gases, high radiation levels, extreme temperatures, and unstable terrains. This rover system is capable of performing complex tasks in environments where human intervention is dangerous or infeasible. Further, sensors and cameras are providing real-time data, allowing for prompt IoT device real-time monitoring purposes. This work demonstrates the high efficiency of 98.55%; a temperature of 320°C and humidity of 79% are achieved experimentally. Overall, this system offers a promising solution to a wide range of special-purpose tasks in hazardous environments, ensuring increased operational safety, efficiency, and adaptability.

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