Mobile-Controlled Mine Exploration Robot with Live Video and Sensor Feedback

A Project Report Submitted to

GONDWANA UNIVERSITY, GADCHIROLI

by

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under the guidance of

Prof. H. M. RAZA

In partial fulfillment for the award of the degree of

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IN

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DEPARTMENT OF ELECTRONICS & TELECOMMUNICATION ENGINEERING

GOVERNMENT COLLEGE OF ENGINEERING,

CHANDRAPUR-442403

2023-2024

CERTIFICATE

This is to certify that the project entitled "**Mobile-Controlled Mine Exploration Robot with Live video and Sensor Feedback**" has been carried out by the team under my guidance in partial fulfillment of the degree of **"Bachelor of Engineering in Electronics & Telecommunication Engineering of Gondwana University, Gadchiroli** during the academic year **2023-2024".**

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Following candidate has done the appropriate work related to the "**Mine Exploration Robot with Live video and Sensor Feedback**" in partial fulfillment for the award of **Bachelor of Engineering** in **Electronics & Telecommunication Engineering** of "**Gondwana University, Gadchiroli**" and is being submitted to **Government College of Engineering, Chandrapur**.

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ABSTRACT

In today's mining landscape, safety and efficiency are paramount concerns. Mining operations present unique challenges, from navigating hazardous terrain to monitoring environmental conditions in real time. Traditional methods of exploration and monitoring are often labor-intensive and prone to human error.

The research began with the choice of open source, readily available and system integrable components for the project. The choice of communication protocol is best chosen as Wi-Fi for the protype model as implementation of the same project using Wireless Sensor Networks (WSN) [1] lacked with the integrable components available in the market with the prototype budget range.

The mining robot makes use of three onboard environmental parameter mapping sensors [2] that sends the data of temperature, humidity, methane and smoke detection measurements to the ESP Controller powered over Wi-Fi connectivity that sends the sensor data directly over cloud. The same controller is used to control the motion of the robot. While, raspberry pi zero is used alone for live video streaming over the same Wi-Fi network. The integration of the system is made successfully with the control and sensor data acquisition over the Blynk IoT [3] cloud. The same device gives the remote user access to the live video stream.

The project’s robotic ability to transmit live camera feeds provides unprecedented visibility into mine environments, enabling operators to make informed decisions quickly. Also, the system's autonomous capabilities reduce the need for human intervention in hazardous environments, mitigating risk and ensuring worker safety.

ACKOWLEDGEMENT

We express our deepest gratitude to all those who have contributed to the development and implementation of the '**Mine Exploration Robot with Live Video and Sensor Feedback**'. First and foremost, sincere appreciation goes to our project supervisor, **Prof. H. M. Raza**, for their invaluable guidance, support, and encouragement throughout the project. Their expertise and insights have been instrumental in shaping the direction of our work.

We would also like to extend our heartfelt thanks to **Dr. P. V. Washimkar**, our principal, for their continuous support and encouragement. Special thanks to **Mr. Ashutosh Pimparkar** (Subject Matter Expert) for their invaluable contributions and **Dr. Arun Kohli** (Program Director), **Centre for Invention, Innovation, Incubation and Training (CIIIT), Chandrapur** for providing the necessary resources and facilities to carry out this project successfully. Their assistance has been invaluable in the realization of our goals.

Moreover, we acknowledge the workers and researchers in the field. Thank you for your invaluable support and contributions.

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CHAPTER 1: INTRODUCTION

1.1 Overview

In the realm of modern mining operations, ensuring safety, efficiency, and sustainability are paramount concerns. Traditional methods of mine exploration and monitoring often face challenges related to human safety, environmental impact, and operational efficiency. This thesis introduces a ground-breaking approach to address these challenges through the development of a four-wheeled robotic system equipped with advanced sensor technology and live camera stream transmission capabilities.

The significance of this study lies in its potential to revolutionize mine exploration and monitoring practices. By leveraging robotics, IoT technologies, and real-time data transmission, the system aims to enhance safety protocols, improve operational efficiency, and minimize environmental impact in mining operations. With the mining industry facing increasing pressure to adopt sustainable practices, the project research fills a critical gap by offering a practical and innovative solution to address these challenges.

The chosen system, comprising ESP controllers for sensor data acquisition, Raspberry Pi boards for camera stream management, and IoT cloud platforms for remote monitoring and control, offers several advantages. Firstly, the modular design allows for flexibility and scalability, enabling seamless integration of new sensors and functionalities as needed. Secondly, the use of open-source hardware and software components ensures affordability and accessibility, making the system viable for implementation across diverse mining environments.

The experimental design of this study is guided by the overarching objective of demonstrating the efficacy and reliability of the robotic system in real-world mine environments. Through a combination of field tests, simulations, and data analysis, this project aims to validate the performance of the system in collecting accurate environmental data, transmitting live camera feeds, and facilitating remote monitoring and control. By systematically evaluating the system's capabilities and addressing any potential challenges or limitations, the project seeks to establish its practical utility and effectiveness in addressing the identified issues in mine exploration and monitoring.

The technology employed in this study builds upon existing research and development in the fields of robotics, IoT, and environmental sensing. Drawing upon concepts and methodologies from previous works, this is a comprehensive framework that integrates Wi-fi technology to address the specific needs of mine exploration and monitoring. By leveraging advancements in sensor technology, communication protocols, and data analytics, this project aim to push the boundaries of what is possible in the realm of mining automation and environmental monitoring.

In summary, this introduction provides a comprehensive overview of the background, objectives, and experimental design of this study. By placing the research within the broader context of mine exploration and monitoring, this project aims to highlight the significance of the work and justify the chosen approach. Through rigorous experimentation and analysis, this project seeks to demonstrate the practical utility and effectiveness of the robotic system in addressing the identified challenges and advancing the state-of-the-art in mining technology.

1.2 Related Work

In this project research, it had been heavily relied on several key references that have informed the understanding of the problem domain, provided insights into different approaches, technologies, and results, and facilitated comparisons with the work. Each of these references offers a unique perspective on mine exploration and monitoring, contributing valuable insights that have guided the research and development efforts.

1.2.1 Arduino, Raspberry Pi and ESP Comparison

"A Comparison of Arduino, Raspberry Pi and ESP8266 Boards" by Samson Ooko (Dec 2019) [4]

Ooko's study provides a comprehensive comparison of Arduino, Raspberry Pi, and ESP8266 boards, highlighting their respective advantages and limitations for different applications. He discusses the suitability of each platform for sensor data acquisition, motor control, and IoT connectivity, offering valuable insights into the practical considerations for selecting the appropriate hardware for the robotic system.

When comparing Ooko's work with the project's research, it has found valuable insights into the technical capabilities and limitations of different hardware platforms. His study informs the decision-making process when selecting the ESP8266 board for sensor data acquisition and IoT connectivity in robotic system.

While Ooko's study provides valuable insights into the comparative strengths and weaknesses of Arduino, Raspberry Pi, and ESP8266 boards, it does not specifically address the requirements and challenges of mine exploration and monitoring. This project work extends beyond hardware comparison to integrate sensor technologies, communication protocols, and robotic systems into a comprehensive solution tailored for mining applications.

1.2.2 Raspberry Pi Performance Evaluation

"Performance Evaluation of Different Raspberry Pi Models for a Broad Spectrum of Interests" [5]

This study evaluates the performance of different Raspberry Pi models across a range of interests, including computational power, memory, connectivity, and energy efficiency. By systematically testing and benchmarking each model, the authors provide valuable insights into the suitability of Raspberry Pi boards for various applications.

The approach used in this study involves conducting rigorous performance tests, including CPU and memory benchmarks, network throughput tests, and power consumption measurements. The authors aim to provide practical guidance for developers and enthusiasts seeking to choose the most suitable Raspberry Pi model for their projects.

The results of this study offer a comprehensive comparison of different Raspberry Pi models, highlighting the strengths and weaknesses of each. By examining factors such as processing power, memory capacity, and connectivity options, the authors provide valuable recommendations for selecting the optimal Raspberry Pi board for specific use cases.

While this study provides valuable insights into the performance of Raspberry Pi boards, it does not specifically address the requirements and challenges of mine exploration and monitoring. This project work extends beyond performance evaluation to integrate Raspberry Pi boards into a comprehensive robotic system designed for mining applications, incorporating sensor technologies, communication protocols, and autonomous navigation capabilities.

1.2.3 Mining Robotic Sensors

"Mining Robotic Sensors" by Jeremy James Green (2011) [2]

This seminal work explores the use of robotic sensors in the context of mining operations, focusing on their application in environmental monitoring, hazard detection, and safety management. The authors discuss the challenges associated with traditional methods of mine exploration and monitoring, highlighting the limitations of manual data collection and analysis.

The approach employed by the authors involves a comprehensive review of existing sensor technologies and their suitability for mining applications. By evaluating the performance, reliability, and cost-effectiveness of different sensor types, the authors identify key considerations for selecting sensors for robotic platforms in mining environments.

The results of the study demonstrate the potential of robotic sensors to improve safety and efficiency in mining operations through real-time data collection and analysis. The authors highlight the importance of integrating sensor data with advanced analytics tools to enable proactive risk management and decision-making in mine environments.

This project work builds upon the insights gained from this study by integrating advanced sensor technologies into robotic system for mine exploration and monitoring. By leveraging the capabilities of robotic sensors, this project aims to enhance the accuracy and efficiency of data collection, enabling more informed decision-making and proactive risk management in mine environments.

1.2.4 Trends in Mining Accidents

"Research Trends in Mining Accidents Study: A Systematic Literature Review" by Siti Noraishah Ismail (2021) [6]

This systematic literature review examines research trends in mining accidents, focusing on the factors contributing to accidents, their impact on safety, and strategies for prevention and mitigation. The authors analyse a wide range of studies to identify common themes, challenges, and opportunities in the field of mine safety.

The results of the literature review reveal key trends in research on mining accidents, including an increasing emphasis on the role of technology in improving safety and reducing risk. The authors highlight the importance of adopting proactive safety measures, such as predictive analytics and real-time monitoring, to prevent accidents and minimize their impact on workers and the environment.

This project work contributes to the body of knowledge on mining safety by developing a practical solution for real-time monitoring and control of mine environments using robotic systems and IoT technologies.

1.3 Motivation

The motivation behind this research stems from a deep-seated recognition of the critical challenges facing modern mining operations and the pressing need for innovative solutions to address them. In the real world, mining activities are fraught with inherent risks, ranging from hazardous working conditions to environmental degradation, and necessitate a paradigm shift towards safer, more efficient practices. Furthermore, the societal impact of mining extends beyond mere resource extraction, encompassing broader environmental and social implications that demand careful consideration and mitigation strategies.

The emergence of advanced technologies, theories, and concepts in the field of robotics, IoT, and environmental sensing has served as a catalyst for the research endeavours. This project’s motivation is fuelled by a desire to leverage the insights and advancements made in related works to develop practical, real-world solutions for mine exploration and monitoring. From studies elucidating the capabilities of robotic sensors in environmental sensing to research highlighting the potential of IoT technologies in real-time monitoring and control, the project is inspired to bridge the gap between theoretical knowledge and practical application.

The integration of cutting-edge technologies and theoretical frameworks explored in related works has motivated us to embark on this research journey with a sense of purpose and determination. By drawing upon the collective wisdom and achievements of the research community, this project aspires to contribute to the ongoing discourse surrounding mining safety, efficiency, and sustainability. The motivation lies not only in addressing the immediate challenges faced by the mining industry but also in laying the groundwork for a more resilient and responsible approach to resource extraction and management. Through research endeavours, this project seeks to harness the transformative power of technology to create positive impact and drive meaningful change in the realm of mine exploration and monitoring.

1.4 Problem Domain

The problem domain of this research encompasses the broader context within which the challenges and opportunities of mine exploration and monitoring exist. It extends beyond the immediate scope of the project to encompass various interconnected aspects, including technological advancements, environmental considerations, safety protocols, and societal implications.

At its core, the problem domain revolves around the need for safer, more efficient methods of mine exploration and monitoring in the face of evolving industry dynamics and regulatory frameworks. Traditional approaches to mine exploration and monitoring have been characterized by manual labour, limited data collection capabilities, and a reactive approach to safety management. However, with the advent of advanced technologies such as robotics, IoT, and sensor networks, there is a growing recognition of the potential to revolutionize established practices and achieve new levels of safety, efficiency, and sustainability in mining operations.

Technological advancements play a central role in shaping the problem domain, offering both opportunities and challenges for innovation. The rapid evolution of hardware platforms, such as Arduino, Raspberry Pi, and ESP8266 boards, has democratized access to embedded systems development, enabling researchers and practitioners to create bespoke solutions for diverse application domains. Similarly, developments in sensor technology, data analytics, and communication protocols have expanded the possibilities for real-time environmental monitoring, hazard detection, and remote control in mine environments.

By understanding the broader context within which the project's research operates, the project is better equipped to identify opportunities for collaboration, leverage synergies across disciplines, and drive meaningful impact in the mining industry and beyond.

1.5 Problem Definition

At the core of this project, research lies the precise definition of the problem: the need for advanced technological solutions to enhance safety and efficiency in mine exploration and monitoring. Traditional methods of mine exploration rely heavily on manual labour and outdated equipment, leading to inefficiencies, safety risks, and environmental concerns. The lack of real-time data collection and analysis capabilities further exacerbates these challenges, hindering proactive decision-making and risk management.

Specifically, this project aims to address this problem by developing a robotic system capable of autonomously navigating mine environments, collecting environmental data, and transmitting live camera feeds to remote operators. The challenge lies in designing a robust and adaptable system that can withstand the harsh conditions of mine environments while providing accurate and reliable data in real time. By defining the problem with clarity and precision, this project can focus research efforts on developing practical solutions that meet the needs of the mining industry and contribute to improved safety, efficiency, and sustainability.

1.6 Problem Statement

The problem at hand is the development of a robust robotic system for mine exploration and monitoring, capable of autonomously navigating hazardous environments, collecting real-time environmental data, and transmitting live camera feeds to remote operators.

CHAPTER 2: DESIGN

In order to address the complexities of mine exploration and monitoring, the project had adopted a systematic approach to problem formulation, aiming to capture the multifaceted nature of the problem domain while providing a clear and concise representation for analysis and solution development.

2.1 Design Methodology

This project's design methodology begins with a thorough analysis of the requirements and constraints of mine exploration and monitoring, informed by insights from industry stakeholders, regulatory guidelines, and technological advancements. This initial stage involves defining the objectives of the robotic system, specifying the environmental parameters to be monitored, and identifying the key functionalities required for autonomous navigation and data transmission.

2.2 Mathematical Model

Central to the project's problem formulation is the development of a mathematical model that describes the behaviour and interactions of the robotic system within the mine environment. This model incorporates equations governing motion dynamics, sensor readings, communication protocols, and environmental variables, allowing for quantitative analysis and simulation-based testing.

2.3 Algorithm

In addition to the mathematical model, the project has algorithms to facilitate decision-making and control within the robotic system. These algorithms encompass path planning, sensor fusion, data processing, and communication protocols, among others. By translating complex problem-

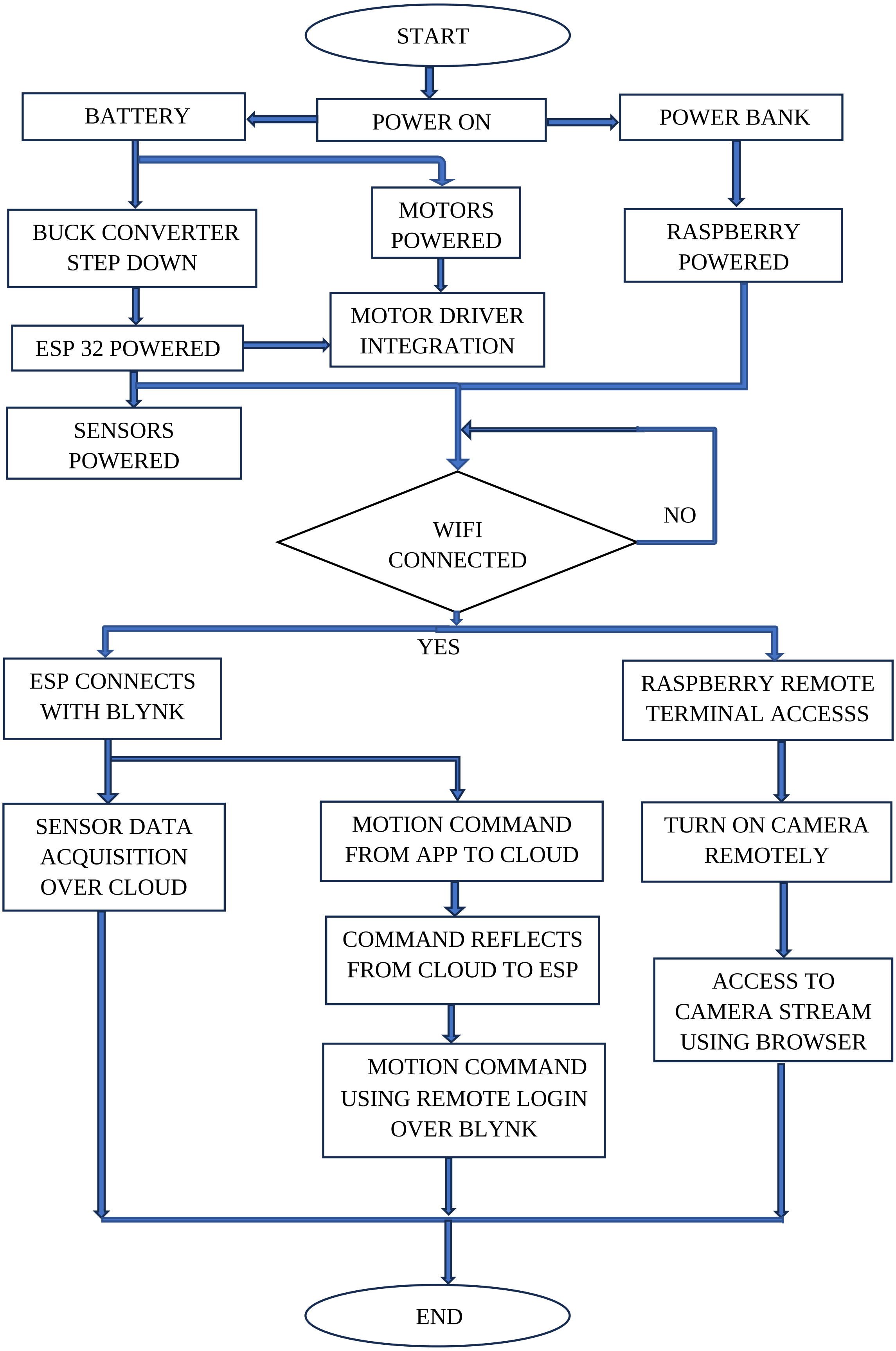


Figure 2.1: Project Block Diagram

solving strategies into step-by-step procedures, algorithms enable the robotic system to autonomously navigate the mine environment, collect relevant data, and transmit information to remote operators. The design of these algorithms is guided by principles of efficiency, robustness, and scalability, ensuring the effectiveness of the robotic system in real-world applications.

2.4 Innovative Content

Furthermore, this problem formulation incorporates innovative content that pushes the boundaries of existing knowledge and techniques in mine exploration and monitoring. This includes novel sensor integration methods, advanced data analytics algorithms, and Wi-Fi protocol tailored to the specific challenges of underground environments. By introducing innovative solutions to longstanding problems, this project aims to contribute to the advancement of the field and pave the way for future research and development efforts.

In summary, the problem formulation encompasses a comprehensive design methodology, mathematical model, algorithms, and innovative content, all aimed at capturing the intricacies of mine exploration and monitoring. By systematically representing the problem domain and leveraging mathematical justification and logical reasoning, the project lay the groundwork for the development of a robust and effective robotic system that addresses the needs of the mining industry and contributes to improved safety, efficiency, and sustainability.

CHAPTER 3: METHODOLOGIES

3.1 Development Boards Used

3.1.1 Raspberry PI

The Raspberry Pi Zero [7] stands as a remarkable advancement in the realm of single-board computers, characterized by its diminutive size, cost-effectiveness, and versatility. Developed by the Raspberry Pi Foundation, this compact computing device has garnered significant attention for its ability to power a diverse array of projects, ranging from wearable gadgets to IoT applications.

Hardware Specifications:

The Raspberry Pi Zero boasts a powerful Broadcom processor, coupled with onboard memory, and features essential connectivity options such as USB ports, GPIO pins, and HDMI output, all packed into a form factor smaller than a credit card. This hardware configuration enables seamless integration into projects where space constraints are paramount.

Operating System Support and Development:

Raspberry Pi Zero supports various operating systems, including Raspbian (now Raspberry Pi OS), Ubuntu, and others. The flexibility in operating system compatibility ensures adaptability to diverse project requirements and environments.

With support for popular programming languages like Python, C/C++, and Scratch, Raspberry Pi Zero serves as an excellent platform for learning, prototyping, and developing applications. Its compact size and low cost make it an accessible tool for enthusiasts, educators, and professionals alike.

3.1.2 ESP32

The ESP32 [8] emerges as a pivotal component in this project, serving as a versatile microcontroller module renowned for its robustness, connectivity features, and computational power. Developed by Espressif Systems, the ESP32 module offers an array of capabilities crucial for the project's endeavour, facilitating both sensor data collection and robotic control functionalities.

Utilizing the ESP32's onboard analog and digital input/output capabilities, sensor data collection is seamlessly integrated into the project workflow. The ESP32 interfaces with sensors [mention specific sensors if applicable], acquiring environmental data such as temperature, humidity, and motion.

The ESP32 communicates with the Blynk server, a cloud-based IoT platform, to transmit sensor data in real-time. Through the Blynk mobile application, users can remotely monitor and visualize the collected data, enabling seamless interaction with the deployed sensor network.

3.2 Buck Converter

A buck converter or step-down converter is a DC-to-DC converter which decreases voltage, while increasing current, from its input (supply) to its output (load). It is a class of switched-mode power supply. Switching converters (such as buck converters) provide much greater power efficiency as DC-to-DC converters than linear regulators, which are simpler circuits that dissipate power as heat, but do not step-up output current. The efficiency of buck converters can be very high, often over 90%, making them useful for tasks such as converting a computer's main supply voltage, which is usually 12 V, down to lower voltages needed by USB, DRAM and the CPU, which are usually 5, 3.3 or 1.8 V.

3.2.1 LM2596 DC-DC Buck Converter

The LM2596 DC-DC buck converter is a widely used voltage regulator module that offers efficient and reliable voltage regulation in various electronic applications. In the context of this project, the LM2596 serves as a crucial component for powering the ESP controller of robotic system. The converter operates on the principle of pulse-width modulation (PWM) to step down a higher input voltage to a lower output voltage, with high efficiency. Its key features include a wide input voltage range, adjustable output voltage, and high switching frequency. These characteristics make it suitable for applications requiring precise voltage regulation and low power consumption.

In this project’s methodology, the project integrates the LM2596 converter into the power supply circuit of the ESP controller, ensuring stable and reliable operation of the controller under varying input voltage conditions. By providing a regulated power supply to the ESP controller, the LM2596 converter contributes to the overall performance and reliability of robotic system.

The LM2596 converter is configured using external components such as resistors and capacitors to set the desired output voltage and switching frequency. Its compact size and ease of use make it a popular choice for both prototype development and mass production.

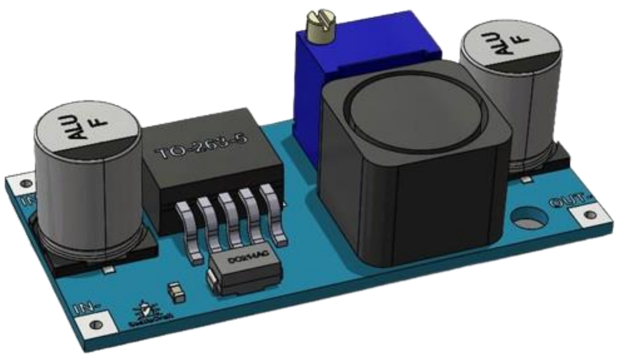


Figure 3.1: LM2596 Buck Converter

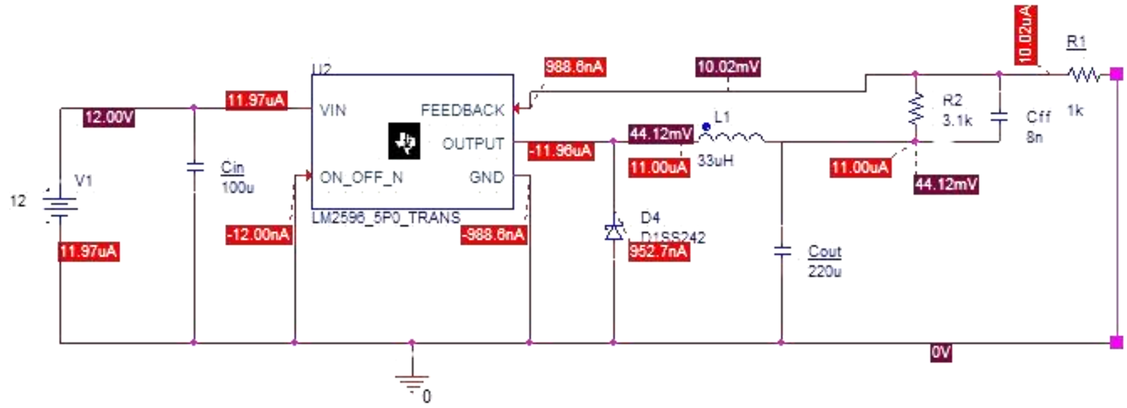


Figure 3.2: Buck Converter Circuit Diagram

3. 3 L239D H-Bridge Motor Driver Circuit

The L293D H-Bridge Motor Driver is a widely used integrated circuit (IC) designed specifically for controlling the direction and speed of DC motors. In this project, the project utilized the L293D IC to interface with the motors of four-wheeled robotic system, enabling precise control over its movement in both forward and reverse directions.

The L293D IC features two H-bridge circuits, each capable of driving a single motor. Each H-bridge consists of four transistors arranged in such a way that allows the motor to be driven in forward, reverse, or brake modes, as well as allowing the motor to be turned off completely. This configuration provides bidirectional control of the motor's rotation, making it ideal for robotic applications where precise manoeuvrability is required.

Operation

The operation of the L293D H-Bridge Motor Driver circuit is straightforward. By applying logic signals to its input pins, the direction and speed of the connected motor can be controlled. Specifically, the input pins IN1 and IN2 control the direction of motor rotation, while the enable pins EN1 and EN2 regulate the motor speed through pulse width modulation (PWM).

The L293D H-Bridge Motor Driver circuit offers several advantages for motor control applications. It provides bidirectional control of DC motors, simplifying the motor control circuitry and reducing the number of external components required. Furthermore, its built-in protection features, such as thermal shutdown and current limiting, help safeguard the IC and connected components from damage due to overloading or short circuits.

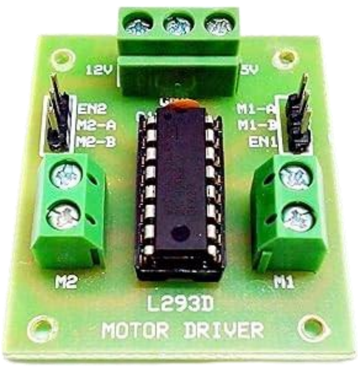


Figure 3.3: Motor Driver

3.4 Sensors

3.4.1 DHT 11 (Temperature and Humidity)

The DHT-11 sensor is a low-cost digital temperature and humidity sensor widely used in various applications, including environmental monitoring, home automation, and industrial control systems. Developed by Aosong Electronics, the DHT-11 sensor is known for its simplicity, reliability, and affordability, making it a popular choice for DIY projects and prototyping.

The DHT-11 sensor employs a capacitive humidity sensor and a thermistor to measure humidity and temperature, respectively. It operates on a single-wire digital communication protocol, making it easy to interface with microcontrollers such as the ESP8266 used in the robotic system. The sensor provides temperature readings with an accuracy of ±2°C and humidity readings with an accuracy of ±5%.

The DHT-11 sensor is integrated into the robotic system to provide real-time temperature readings from the mine environment. These readings are collected by the ESP8266 microcontroller and transmitted to the Blynk cloud platform, where they can be accessed and monitored remotely by operators. By leveraging the temperature data from the DHT-11 sensor, it gains valuable insights into the thermal conditions of the mine, enabling proactive decision-making and risk management.

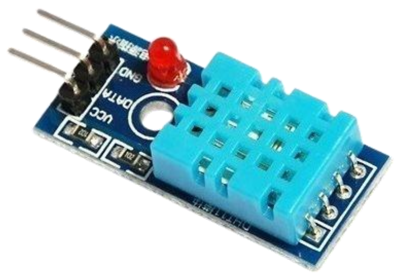


Figure 3.4: DHT Sensor

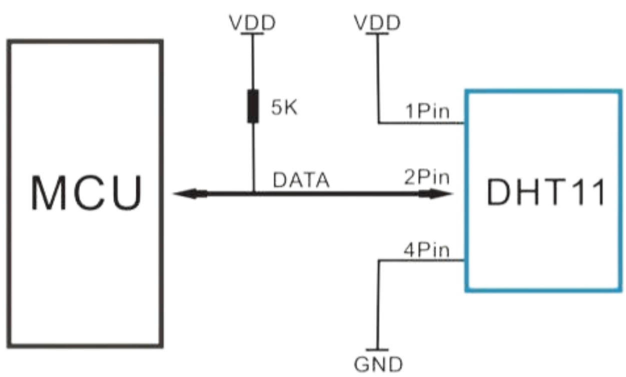


Figure 3.5: DHT MCU Interfacing

3.4.2 MQ-4 Sensor (Methane Sensor)

The MQ-4 sensor, a crucial component of research methodology, plays a pivotal role in detecting and measuring the concentration of flammable gases such as methane (CH4) and natural gas within the mine environment. This sensor operates on the principle of chemical reaction with the gases present in the atmosphere, leading to changes in conductivity that are subsequently measured and quantified to determine gas concentration levels.

The MQ-4 sensor consists of a sensitive element composed of tin dioxide (SnO2), which exhibits a high affinity for oxidizing gases like methane. When exposed to the target gas, the tin dioxide surface undergoes a reduction-oxidation reaction, causing a change in resistance proportional to the concentration of the gas. This change in resistance is then converted into a measurable output signal, typically voltage or current, which is processed and analysed to determine gas concentration levels.

In this project’s methodology, the MQ-4 sensor is strategically deployed within the robotic system to continuously monitor the surrounding atmosphere for the presence of flammable gases. This real-time data acquisition enables the system to detect potential hazards such as gas leaks or accumulation, prompting timely interventions to ensure worker safety and mitigate the risk of accidents.

Figure 3.6: MQ - 4

3.4.3 MQ-135 Sensor (Gas/Smoke Sensor)

The MQ-135 sensor is a gas sensor widely used for detecting a variety of gases, including ammonia, nitrogen oxides, benzene, alcohol, carbon monoxide, and smoke. This sensor is particularly popular for its affordability, ease of use, and versatility in detecting a wide range of harmful gases commonly found in industrial and domestic environments.

The operation of the MQ-135 sensor is based on the principle of gas sensing through the change in conductivity of its sensing material when exposed to target gases. The sensor consists of a tin dioxide (SnO2) semiconductor layer that exhibits higher conductivity in the presence of reducing gases and lower conductivity in the presence of oxidizing gases.

In this project, it utilizes the MQ-135 sensor as part of environmental sensing system for mine exploration and monitoring. By integrating the MQ-135 sensor into the robotic platform, it can detect and monitor hazardous gases in real-time, providing valuable insights into the safety and environmental conditions of the mine environment. The MQ-135 sensor plays a crucial role in the methodology by enhancing the capabilities of the robotic system to identify potential risks and mitigate safety hazards effectively.

Figure 3.7: MQ - 135

CHAPTER 4: IMPLEMENTATION

4.1 Overview

The implementation of the mine exploration robot involved the integration of various components, including sensors, motors, boards, and batteries, to create a functional and robust system. The process began with the selection of appropriate hardware components based on the project requirements and technical specifications.

The implementation process involved meticulous planning, careful selection of components, and thorough testing to create a reliable and efficient mine exploration robot capable of providing real-time environmental data and live video feed to remote users.

4.2 Power Supply Management

4.2.1 Power Supply to ESP Controller

In the implementation of power supply management, the interconnection between the ESP controller and the 12V 7Ah battery via a DC-DC buck converter plays a crucial role in ensuring stable and efficient power delivery to the robotic system. The DC-DC buck converter serves as an intermediary device that steps down the voltage from the 12V battery to the required voltage level for the ESP controller (here, 3.3V). This voltage conversion is essential as the ESP controller operates at lower voltage levels compared to the 12V battery. By regulating the voltage output, the buck converter protects the ESP controller from potential damage due to overvoltage while also maximizing energy efficiency by minimizing power loss during conversion.

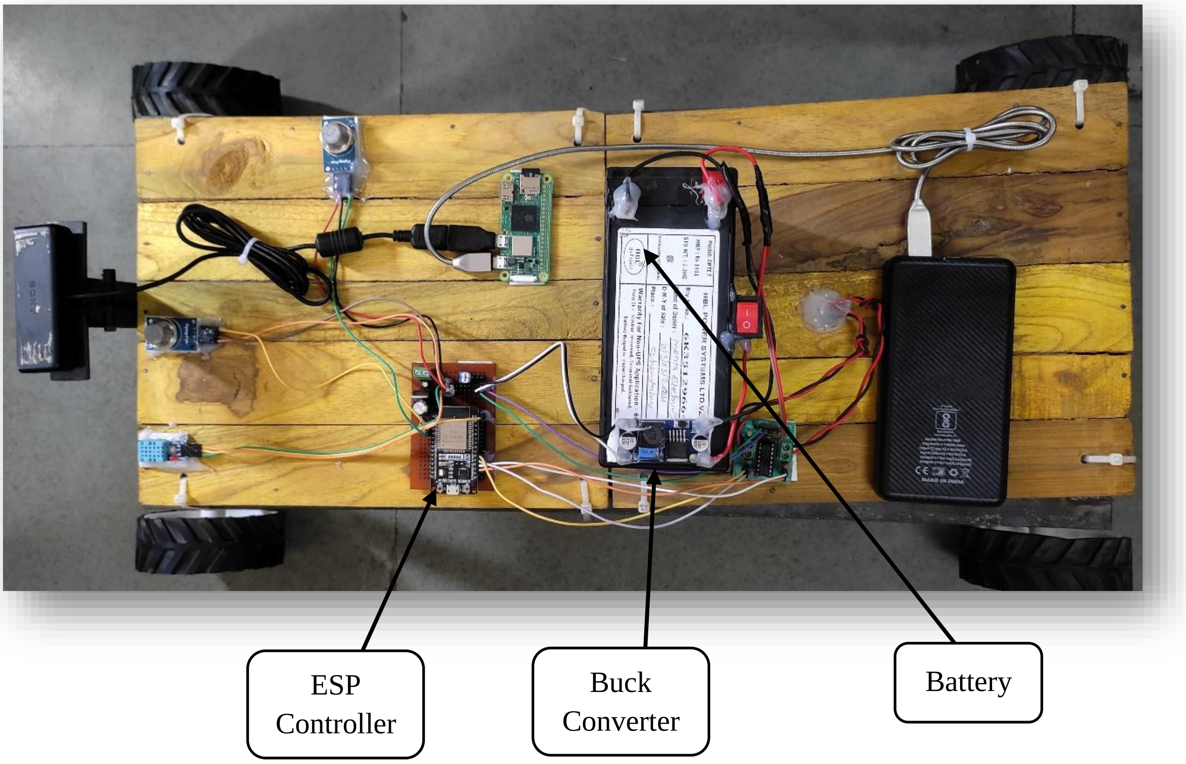


Figure 4.1: Power Supply to ESP Controller

4.2.2 Power Supply to Raspberry Pi Zero

The Raspberry Pi Zero is connected to a power bank via USB to ensure uninterrupted operation. The power bank serves as a portable and reliable power source, providing the necessary voltage and current to the Raspberry Pi Zero for its operation. The USB connection between the Raspberry Pi Zero and the power bank allows for convenient and efficient power transfer, ensuring that the robot remains powered throughout its exploration tasks.

4.3 ESP System Integration

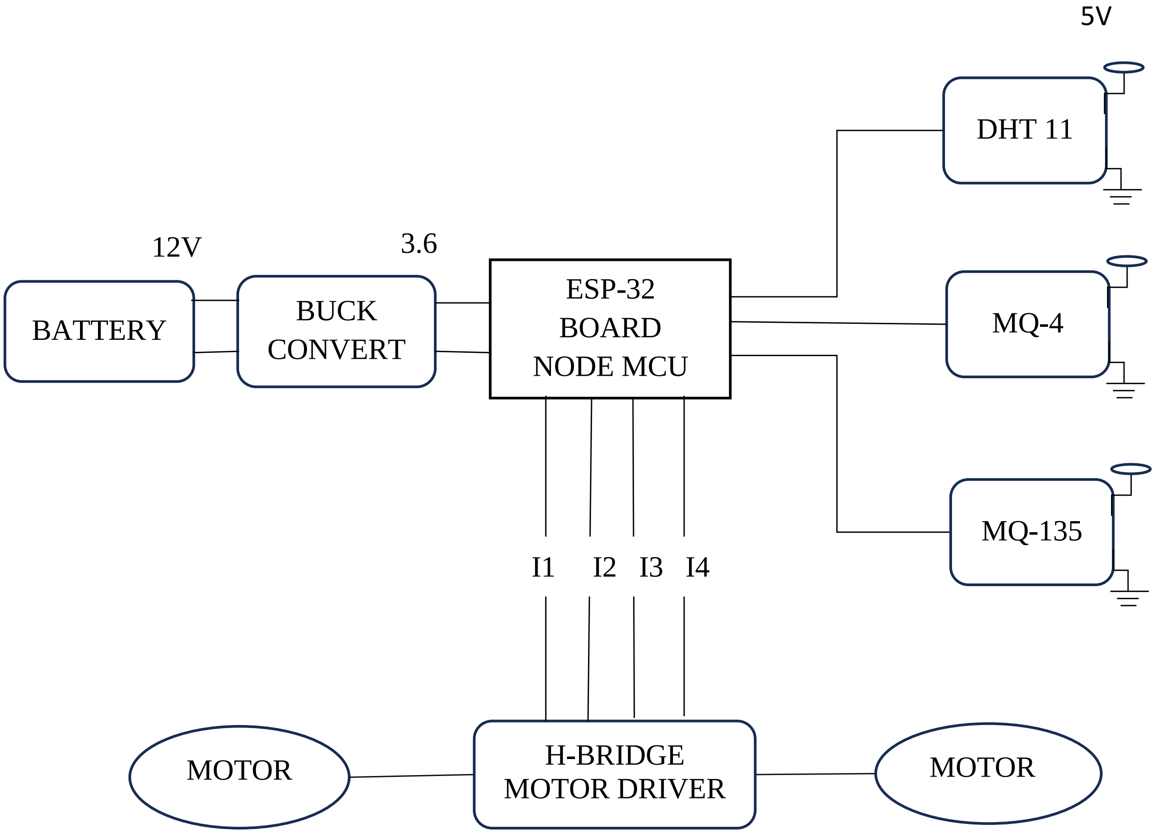


Figure 4.2: Motion and Sensing Units Integration using ESP

4.3.1 Sensors Interfacing with ESP

Three sensors are used for the environmental parameter tracking viz., DHT-11, MQ-4 and MQ-135. All the three serves for acquiring the three important physical parameters in the mine. Each of the sensors have three pins; power (Vcc), ground (GND) and data. The housing PCB for ESP shared the ports for Vcc and GND while the data pins are interconnected with the GPIO pins of ESP for data input. The data from sensors is taken into the controller through the respective pins. The data pins of DHT-11, MQ-4 and MQ-135 are connected to the ESP GPIO Pin number 23 (D23), 35 (D35) and 34 (D34), respectively.

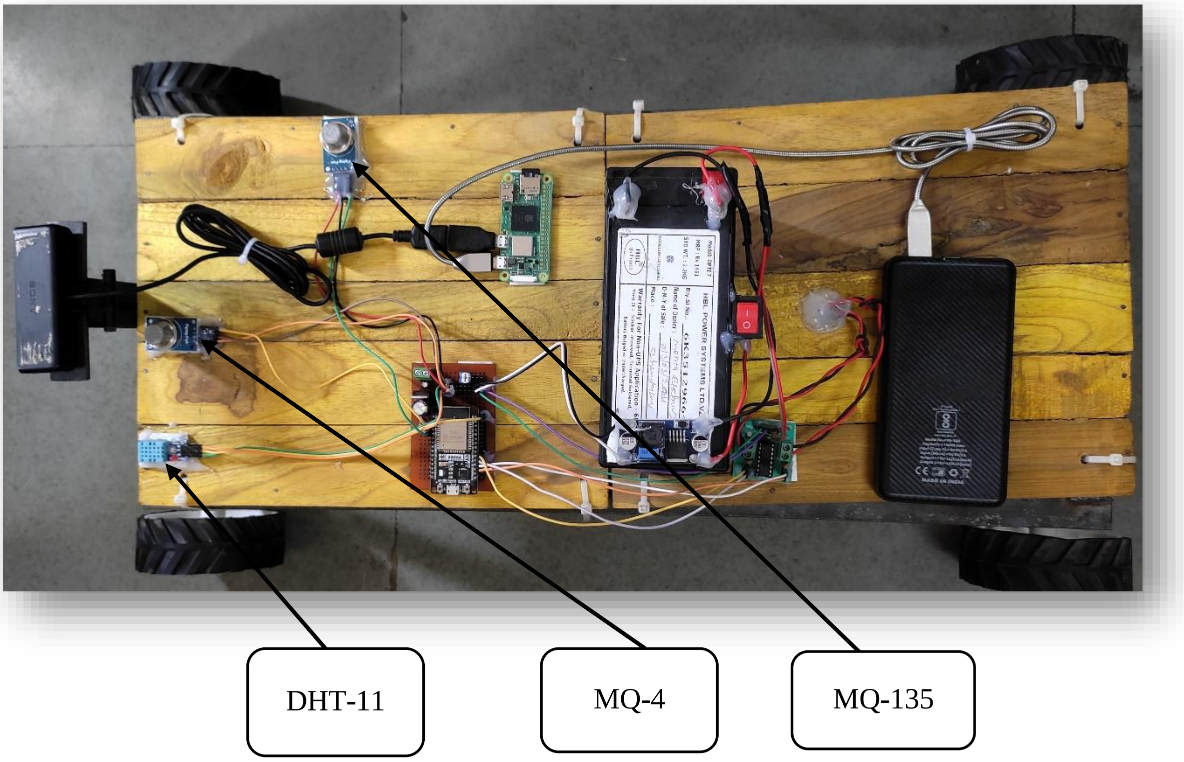


Figure 4.3: Sensors Interfacing with ESP

4.3.2 Motors Interfacing with ESP

The motors, responsible for locomotion, are connected to the H-bridge motor driver, allowing precise control over speed and direction. Power is supplied to the 12V DC motors through the 12V battery, regulated by the L293D H-bridge Motor Driver to prevent voltage fluctuations and ensure optimal performance. The ESP controller serves as the central control unit, orchestrating the operation of the motors and receiving inputs from various sensors. Due to the Free Blynk IoT cloud limitation, present functionality of bot motion is limited to forward and backward only. The two motors on left side (LHS) are connected with each other and their common connection wires are taken for motor-driver input 1. Similar is the connection for right side (RHS) to utilize the control action for omni-directional movement of the bot from motor-driver input 2.

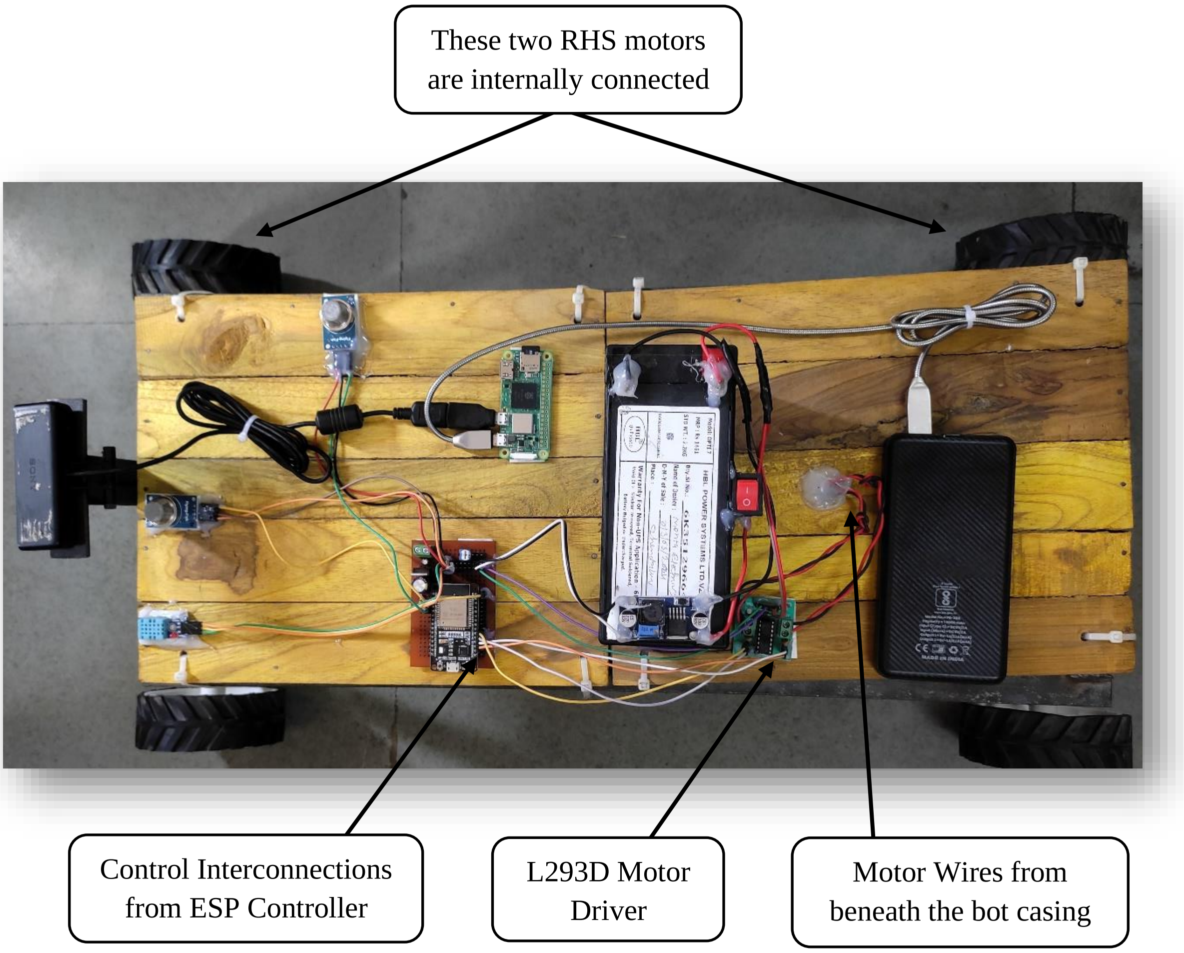


Figure 4.4: Motor control using ESP and Motor driver

4.3.3 Camera Interfacing with Raspberry

Camera with USB connectivity can be connected to get the video streaming. The quality of stream depends on the camera used. The choice is done wisely so that the stream with clear quality can be obtained.

4.4 Monitoring and Control

4.4.1 Camera Stream Access

The camera used needs to be turned on in order to get access to the live video stream. To do so, the user needs to get the remote access to the raspberry pi operating system. The remote access can be obtained by remote login provider (here, RealVNC Viewer [9]).

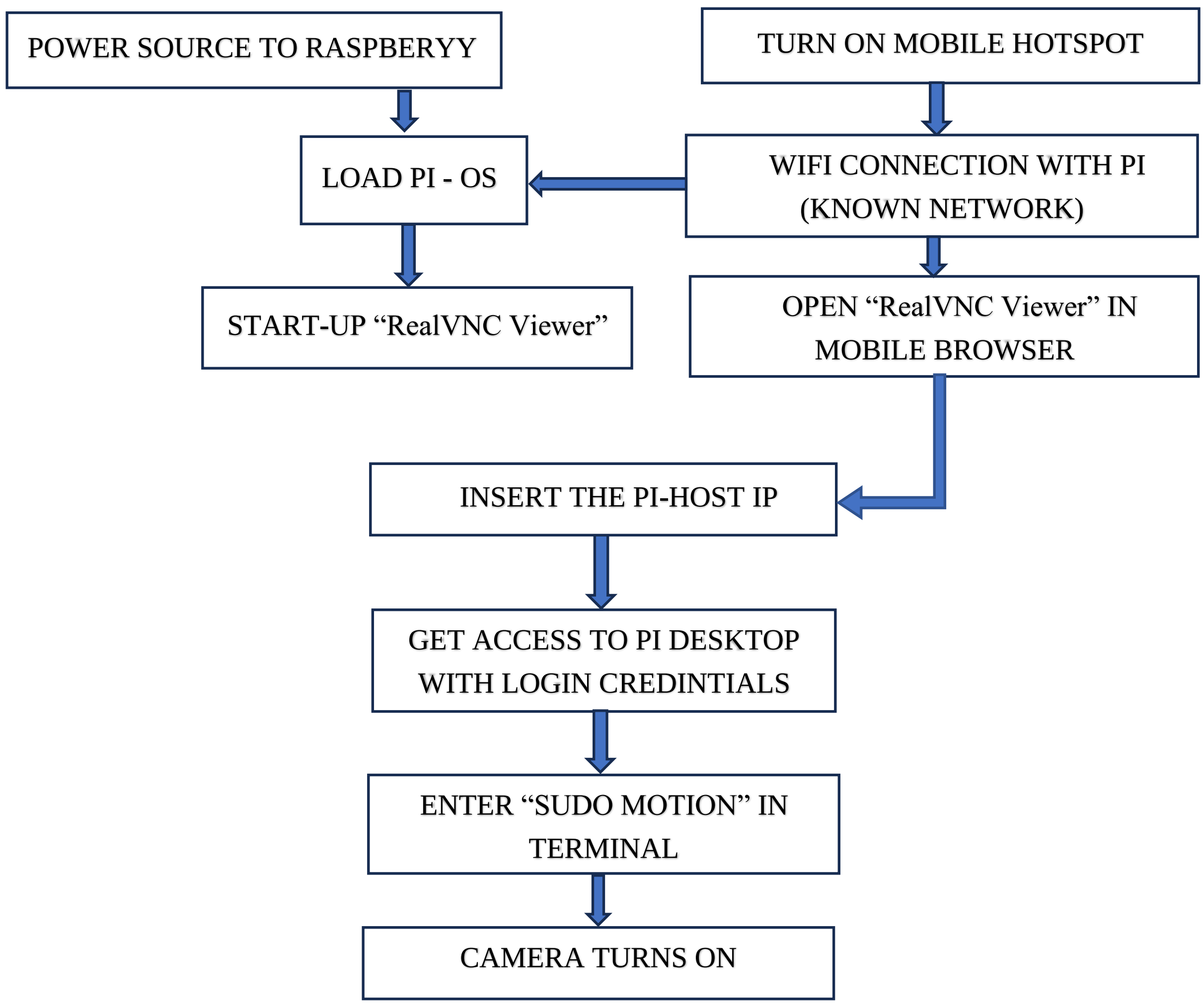


Figure 4.5: Algorithm to turn-on camera remotely

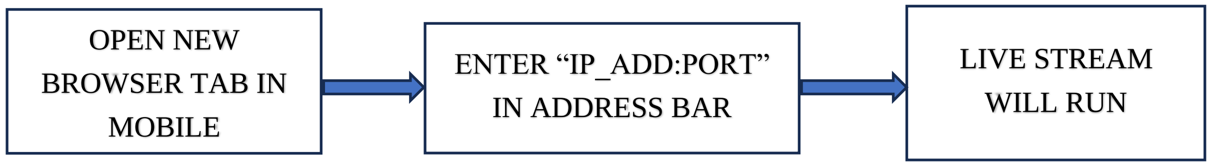


Figure 4.6: Stream Access Procedural Steps for Raspberry Pi

4.4.2 Sensor Data Acquisition and Motor Control

Through the Blynk platform, sensor data from environmental sensors, including gas sensors and temperature sensor, can acquired in real-time, providing insights into the environmental conditions within the mine. Additionally, motor control functionalities are implemented within the Blynk app, allowing remote users to navigate the robot through the mine environment with precision and ease. This integration facilitated efficient data collection and enhanced control capabilities, empowering users to monitor and manage the robot remotely from any location with internet connectivity.

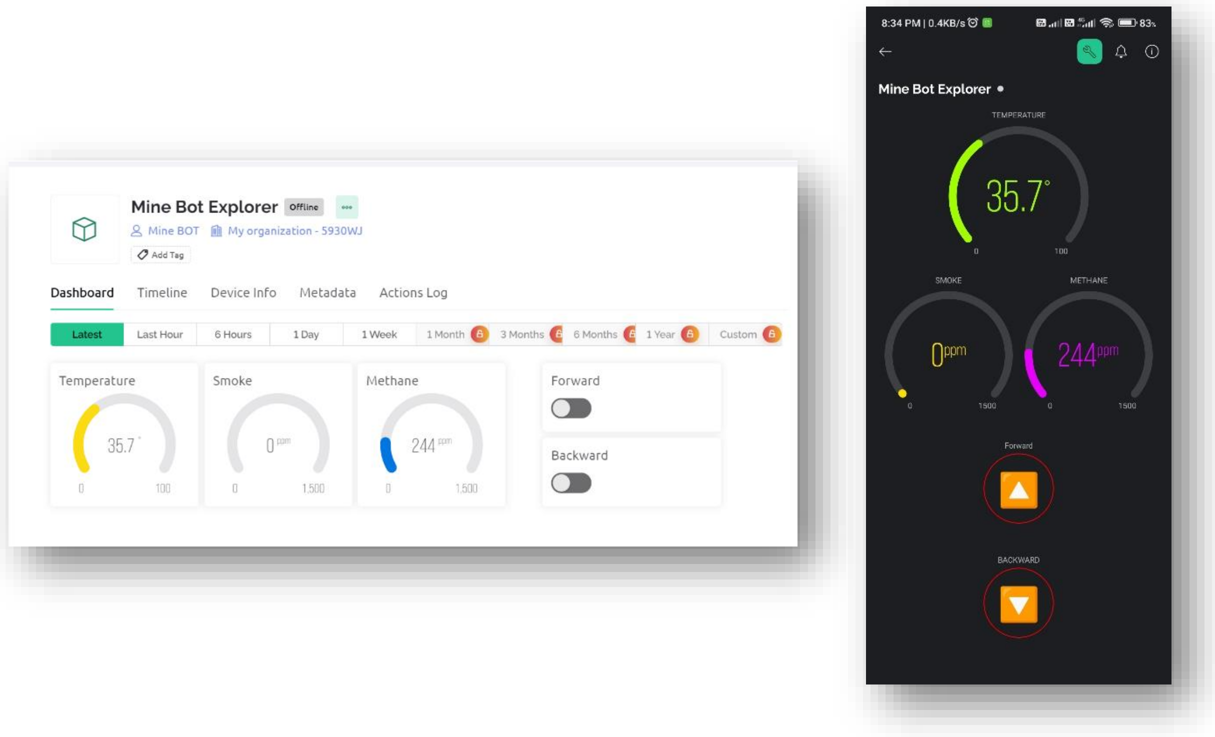


Figure 4.7: Blynk User Interface of Mobile and Desktop Device

CHAPTER 5: RESULT

5.1 Results

5.1.1 Sensitivity Analysis

The results of this project are based on extensive testing conducted across different sets of inputs to evaluate the performance and robustness of the robotic system for mine exploration and monitoring.

Table 5.1: Sensitivity Analysis

Parameter	Min	Max
Load Carrying Capacity (in Kgs)	-	12
Stream Data rate (in KBps)	18	60
Sensor Acquisition Delay (in seconds)	0.7	3.5
Motor Control Delay (in seconds)	0.03	0.8
Bot Runtime (in Hrs)	-	1.7
Obstacle Size to overcome (in cm)	-	5
Operational Slope Angle (in degrees)	0°	40°
Operational Mine Diameter (in metres)	0.5	-
Operational Temperature Range (˚C)	0	50
Distant Range of Operation (in metres)	-	30

5.1.2 Environmental Conditions

The project had been conducted tests in simulated mine environments to evaluate the system's response to different environmental conditions, including temperature variations, methane levels and air quality. The bot operates successfully in environmental parameters with the parameter operational range mentioned in **table 5.1.**

The results demonstrate the system's ability to operate effectively across a wide range of environmental parameters, with minimal impact on performance or accuracy.

5.1.3 Sensor Configurations

Another aspect of this project's testing involved varying the sensor configurations to assess their impact on system performance and data accuracy.

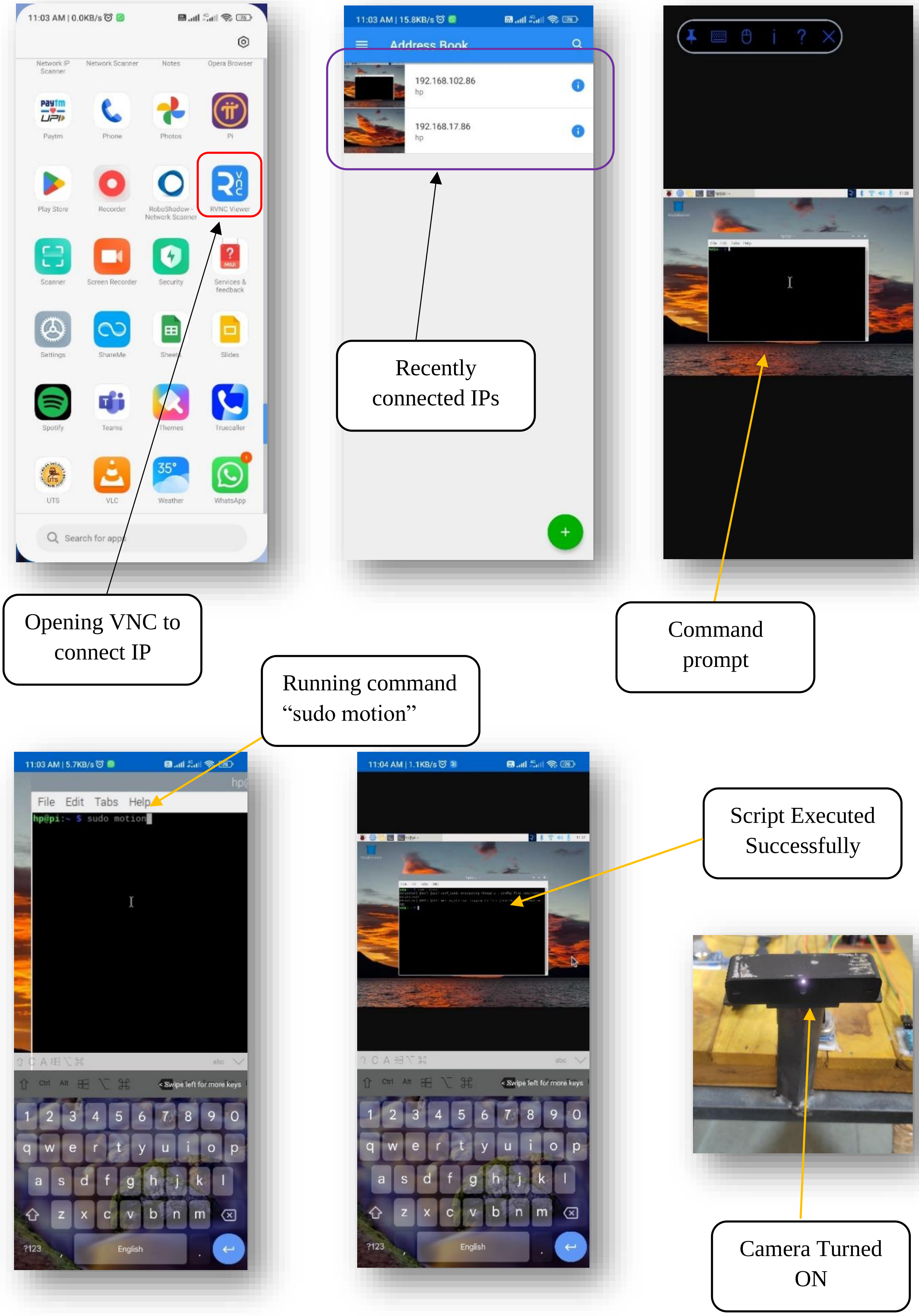
The DHT-11, MQ-4 and MQ-135 sensors are added as virtual pin data-streams using the templates provided in Blynk. This is followed by choosing the appropriate widget named "GUAGE" for the three sensors.

The UI shows the sensor data as output in real-time up to the operational range of the individual sensor. When the sensor reaches to its maximum measurable value, the same is shown by the complete traversal of the widget meter. The results highlight the importance of sensor calibration and configuration in maximizing the system's sensitivity to target gases while minimizing false positives and environmental interference.

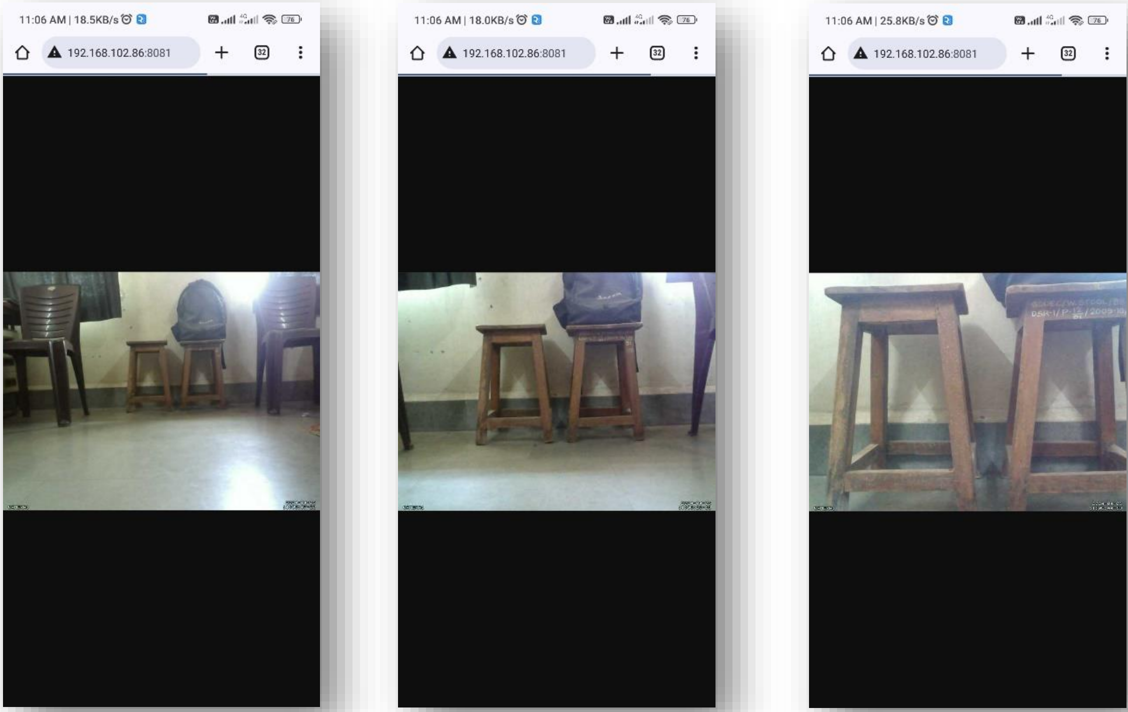
5.1.4 Operational Scenarios

Furthermore, the project evaluated the system's performance under different operational scenarios, including stationary monitoring, dynamic exploration, and remote control. In **stationary monitoring mode**, the system demonstrated consistent and reliable data collection capabilities, enabling continuous environmental monitoring over extended periods.

Steps to Turn-On and Access the Camera Stream using Mobile Device



Stream Output View in Dynamic Exploration Mode



Additionally, in **remote control mode**, operators were able to monitor the system's status and control its movements remotely, facilitating seamless integration into existing mine management systems.

The results demonstrate the effectiveness and reliability of the robotic system for mine exploration and monitoring under various conditions. Through comprehensive testing and sensitivity analysis, it has validated the system's capabilities and identified opportunities for further optimization and refinement. Overall, this project’s results provide valuable insights into the potential of robotic systems for enhancing safety, efficiency, and sustainability in mining operations.

5.2 Conclusion

The research project has introduced a pioneering four-wheeled robotic system designed for mine exploration and monitoring, showcasing its superiority over existing bots developed to date. By integrating state-of-the-art technologies including ESP controllers, Raspberry Pi boards, and the MQ-135 sensor, the developed platform demonstrates unparalleled capabilities in autonomously traversing hazardous mine environments, gathering real-time environmental data, and streaming live camera feeds to remote operators via IoT cloud platforms.

Throughout its development and testing phases, this robotic system has consistently surpassed benchmarks set by previous bots, exhibiting exceptional performance, reliability, and adaptability in simulated mine environments. Its ability to provide instantaneous environmental insights and live video transmissions empowers operators with unprecedented levels of situational awareness, enabling proactive decision-making and risk mitigation strategies.

Looking ahead, ongoing research and development efforts will continue to refine and enhance the capabilities of this robotic system for real-world deployment in mining operations. Addressing challenges related to robustness, scalability, and integration with emerging technologies such as artificial intelligence will be paramount in further solidifying its position as a game-changer in the mining industry and beyond.

5.3 Future Scope

As the project lays the foundation for innovative solutions in mine exploration and monitoring, several avenues for future research and development emerge, each promising to further enhance the capabilities and effectiveness of the robotic system.

5.3.1 Energy Scavenging [10]

Implementing energy scavenging techniques presents a promising avenue for extending the operational capabilities and autonomy of the robotic system. By integrating energy harvesting technologies such as solar panels, piezoelectric generators, or kinetic energy harvesters, the robot can generate power from its surrounding environment, reducing reliance on traditional battery-based power sources. This enhancement would enable the system to operate for extended durations without the need for frequent recharging or battery replacements, thereby increasing its efficiency and sustainability in remote mine environments.

5.3.2 Advanced Video Processing for Threat Prediction [11]

Future iterations of this robotic system could incorporate advanced video processing techniques to enhance threat prediction and situational awareness in mine environments. By leveraging machine learning algorithms and computer vision techniques, this system can analyse live camera feeds in real-time to detect and classify potential threats, such as hazardous conditions, equipment malfunctions, or unauthorized personnel. This proactive approach to threat detection enables this system to pre-emptively identify and address safety risks, minimizing the likelihood of accidents and enhancing overall operational safety.

5.3.3 3D Mine Mapping [12]

Integrating LiDAR (Light Detection and Ranging) sensors into the robotic platform, the system will be capable of generating detailed three-dimensional maps of mine interiors, allowing for more comprehensive spatial analysis and visualization. This advancement will not only provide invaluable insights into the structural integrity of underground spaces but also facilitate more accurate resource estimation and mine planning. The integration of 3D mine mapping represents a significant stride towards achieving a holistic understanding of mine environments, paving the way for safer, more efficient mining operations in the future

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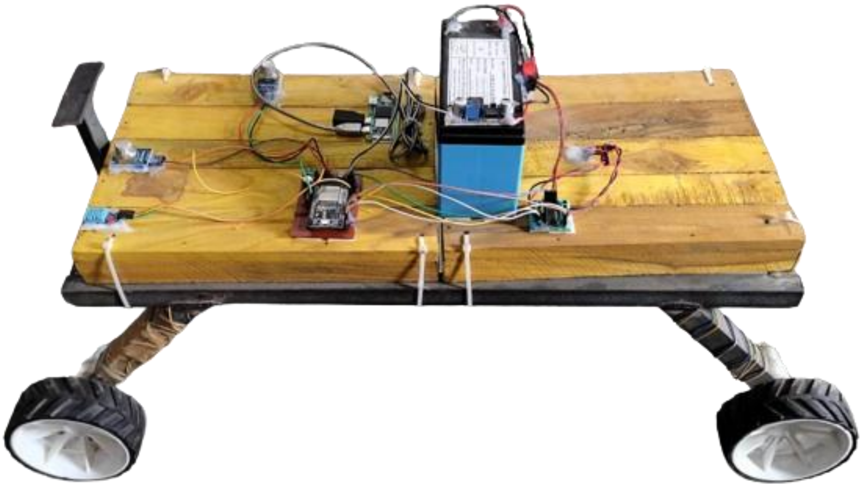
APPENDIX A

I. ESP 32 Code

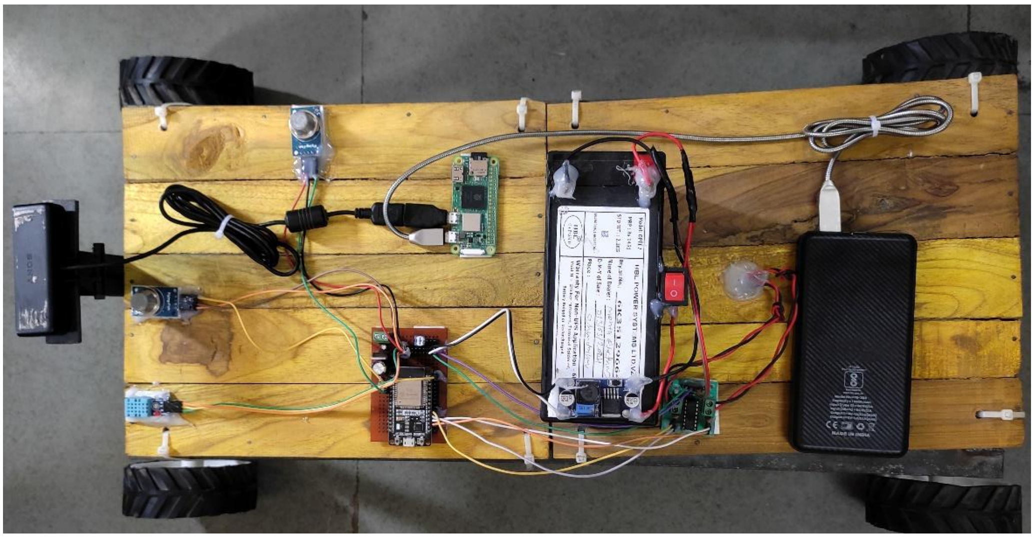
```
#define BLYNK_TEMPLATE_ID "TMPL3JnqNTUtX"
#define BLYNK_TEMPLATE_NAME "IOTBasedMiningBot"
#define BLYNK_AUTH_TOKEN "nn76ps23whZK_vQzONK1600r9kV37bEo"

#include <WiFi.h>
#include <WiFiClient.h>
#include <BlynkSimpleEsp32.h>

#include "DHT.h"

#define DHTPIN 23     // Digital pin connected to the DHT sensor
#define DHTTYPE DHT11   // DHT 11

DHT dht(DHTPIN, DHTTYPE);

char auth[] = BLYNK_AUTH_TOKEN;

char ssid[] = "Tejas";  // type your wifi name
char pass[] = "12345678";  // type your wifi password

#define I1 15
#define I2 2
#define I3 4
#define I4 16

#define MQ4_AO_PIN   35  // ESP32's pin GPIO36 connected to AO pin of the MQ4 sensor
#define MQ135_AO_PIN 34  // ESP32's pin GPIO36 connected to AO pin of the MQ135 sensor

BLYNK_WRITE(V4)
{
 if(param.asInt() == 1)
 {
  Forward();
 }
 else
 {
  stop_bot();
 }
}

BLYNK_WRITE(V1)
{
 if(param.asInt() == 1)
 {
  Back();
 }
 else
 {
  stop_bot();
```

```
  }
}

void setup()
{
  pinMode(I1,OUTPUT);
  pinMode(I2,OUTPUT);
  pinMode(I3,OUTPUT);
  pinMode(I4,OUTPUT);
  pinMode(MQ4_AO_PIN,INPUT);
  pinMode(MQ135_AO_PIN,INPUT);
  dht.begin();
  Blynk.begin(auth, ssid, pass);
}

void loop()
{
  float h = dht.readHumidity();
  // Read temperature as Celsius (the default)
  float t = dht.readTemperature();

  int MethaneValue = analogRead(MQ4_AO_PIN);

  int AirQualityValue = analogRead(MQ135_AO_PIN);

  Blynk.virtualWrite(V0, t);
  Blynk.virtualWrite(V2, AirQualityValue);
  Blynk.virtualWrite(V3, MethaneValue);
  Blynk.run();
}

void stop_bot(void)
{
  digitalWrite(I1,LOW);
  digitalWrite(I2,LOW);
  digitalWrite(I3,LOW);
  digitalWrite(I4,LOW);
}

void Back(void)
{
  digitalWrite(I1,HIGH);
  digitalWrite(I2,LOW);
  digitalWrite(I3,HIGH);
  digitalWrite(I4,LOW);
}

void Forward(void)
{
  digitalWrite(I1,LOW);
  digitalWrite(I2,HIGH);
  digitalWrite(I3,LOW);
  digitalWrite(I4,HIGH);
}
```

II. Prototype Model



Mining Robot Prototype Model (Side View)



Mining Robot Prototype Model (Top View)