UNIVERSITY OF MORATUWA

Faculty of Engineering

AUTOMATED MINE VENTILATION DOOR

ER 3203 - DESIGN PROJECT REPORT

Department of Earth Resources Engineering

Date of Submission: 2025/01/01

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Preface

The Final Year Comprehensive Design Project offered by the University of Moratuwa is an invaluable opportunity for undergraduate students to bridge the gap between classroom learning and real-world applications. It allows us to apply our theoretical knowledge, develop practical skills, and tackle challenges relevant to industry demands. This experience broadens our technical expertise and fosters teamwork, problem-solving skills, and professional growth.

Our project focuses on designing an automated mine ventilation door to address key challenges faced in underground mining operations. Ensuring safety, efficiency, and ease of operation for ventilation systems is crucial in such demanding environments. This report captures the journey of our design process from identifying the problem to providing a practical and cost-effective solution.

Chapter 01: Introduction - This chapter introduces the project by outlining its scope, objectives, and significance. It also highlights the importance of automating mine ventilation doors to improve safety and streamline operations.

Chapter 02: Methodology - Here we describe the approach taken during the project, including data collection, system design, sensor integration, and control system development. Special attention is paid to selecting the most appropriate techniques and tools to meet the project requirements.

Chapter 03: Results - This chapter presents the results of our work, analyzes the performance of the system, and compares it with existing manual operations. The results highlight improvements in safety, reliability, and operational efficiency.

Chapter 04: Optimization - In this section, we describe the refinements made to improve the operation and reliability of the ventilation door. Key features include fine-tuning automation features, integration of sensors, and implementation of fail-safe mechanisms for robust operation.

Chapter 05: Conclusion and Discussion—This chapter summarizes our findings and reflects on the significance of our work. We also discuss the proposed solution's practical benefits and future possibilities.

This project has been a rewarding experience, allowing us to integrate creativity, technical skills, and teamwork to solve a real-world problem. We are grateful for the support and guidance provided by our mentors, teachers, and peers throughout this journey.

Acknowledgement

We would like to express our heartfelt gratitude to everyone who contributed to the successful completion of our Final Year Design Project as part of the B.Sc. (Honours) Degree program at the Faculty of Engineering, University of Moratuwa.

First and foremost, we extend our deepest appreciation to our Design Project Supervisor, Dr. A.B.N. Anjulaa Dassanayaka from the Department of Earth Resources Engineering, whose invaluable guidance and unwavering support were instrumental throughout this journey.

Our sincere thanks also go to Dr. S.P. Chaminda, Head of the Department of Earth Resources Engineering, for incorporating such a valuable design program into our curriculum and fostering an environment conducive to innovation.

We are immensely grateful to Eng. Sandun Kodithuwakku for his expert advice and dedicated guidance, which enriched the quality of our project. We also extend our appreciation to the academic and non-academic staff of the Department of Earth Resources Engineering for their continuous encouragement and support.

During our industrial training period at Bogala Graphite Lanka PLC, we were inspired to initiate this project by Eng. Helinda De Silva, whose vision laid the foundation for this endeavor. We are thankful to Mr. Saliya Gunasekara, General Manager of Bogala Graphite Lanka PLC, for approving and facilitating the implementation of an earlier version of this project at the Bogala mines.

A special note of gratitude is owed to Eng. Sandun Kodithuwakku, who played a dual role during our training and later as a mentor for this project. His invaluable support during the Bogala phase of the project and recommendation of this concept as a design project title for our department were pivotal to our success.

Finally, we extend our thanks to everyone who directly or indirectly contributed to the successful completion of this project. This work represents an enhanced version of the initial project executed at Bogala, and we are proud to have brought it to fruition through the knowledge and experiences gained during our academic and industrial journey.

Thank you all for your unwavering support and encouragement.

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1. INTRODUCTION

1.1 Overview of Ventilation in Underground Mines

Ventilation is a vital aspect of underground mining operations, ensuring the health and safety of workers while optimizing mine productivity. The primary purpose of mine ventilation is to control the quality and quantity of airflow to mitigate the accumulation of harmful gases, such as methane and carbon monoxide, and to remove airborne particulates like coal dust and silica. Proper ventilation also ensures a comfortable working environment by regulating humidity and temperature levels, which can be extreme in deep mining operations. Effective ventilation systems enhance the longevity of equipment by minimizing corrosive conditions and maintain compliance with mining safety regulations. Moreover, ventilation plays a critical role in emergency scenarios, such as controlling the spread of fire or explosive gases. In Sri Lankan underground mines, where geological and environmental conditions pose unique challenges, an efficient and reliable ventilation system is not just a necessity but a mandate for sustainable mining operations.

1.2 Problem Statement: Challenges in Ventilation Systems

The ventilation systems in Sri Lankan underground mines are plagued by several operational challenges that impede their efficiency and safety. Manual operation of ventilation doors often results in inconsistent airflow management, energy inefficiencies, and delays in responding to changing environmental conditions. These manual processes require significant labor, increasing costs and the likelihood of human error. Furthermore, the lack of automation in existing systems makes them ill-equipped to handle emergencies, such as sudden gas leaks or equipment malfunctions, which require immediate action.

Another critical issue is the absence of advanced safety mechanisms. The current systems lack the capability to detect human movement, trolleys, or obstacles, which increases the risk of accidents, especially in busy underground environments. Additionally, the systems are not designed to withstand extreme mining conditions such as high temperatures, high humidity, and the presence of abrasive particulates. These limitations not only compromise the safety and well-being of mine workers but also result in reduced operational efficiency and increased maintenance costs.

1.3 Aim of the Project

The aim of this project is to design and develop an **automated ventilation door system** tailored to the specific needs and challenges of underground mines in Sri Lanka. The system will enhance the operational efficiency of mine ventilation by automating door movements based on real-time environmental conditions and proximity detection. By incorporating advanced safety features and durable components, the project aims to minimize risks, reduce manual intervention, and improve the overall effectiveness of ventilation management systems in underground mining operations.

1.4 Objectives

- To create an automated ventilation door system assembled in a configuration that conveys airflow to conform with mine-specific conditions.
- To integrate motion sensors to detect humans, trolleys, and obstacles, ensuring that the door opens or shuts down based on proximity and any detected obstacles.
- To install safety flags and mechanical barrier gates to stop trolleys from colliding adversely in case of malfunction.
- To ensure sensor and system operation under extreme mining conditions while maintaining the efficiency of the door in controlling ventilation.

1.5 Scope of the Design

The scope of this project involves a comprehensive approach to designing, prototyping, and testing an automated ventilation door system. Key elements of the project include:

- **Design Configuration:** The ventilation door system will be designed to maximize airflow efficiency, ensuring that air circulation meets the specific ventilation requirements of underground mines. The system will be adaptable to various mine layouts and customizable for different operational needs.

- **Automation Integration:** The system will integrate motion sensors and obstacle detection technologies to ensure seamless and automatic operation of doors. These features will enable the system to detect the presence of humans, trolleys, or other obstacles, and adjust the door's operation accordingly.
- **Safety Mechanisms:** The project will include the installation of safety flags and mechanical barrier gates to prevent collisions, especially in the event of equipment malfunction. These safety features will be designed to meet industry standards and ensure the protection of both personnel and equipment.
- **Durability and Reliability:** The system will be engineered to operate effectively under extreme mining conditions, including high humidity, temperature variations, and the presence of dust and abrasive particles. Robust materials and advanced engineering principles will ensure the system's longevity and consistent performance.
- **Energy Efficiency:** The design will prioritize energy-efficient components and mechanisms, reducing the overall operational costs of the ventilation system.
- **Testing and Validation:** The prototype will undergo rigorous testing to ensure its functionality, safety, and efficiency before being recommended for large-scale implementation.

This project aims to provide a practical and innovative solution to the challenges faced by Sri Lankan underground mines, aligning with modern mining practices and advancing the safety and productivity of the mining industry.

2. LITERATURE REVIEW

2.1 Existing Ventilation Systems in Underground Mines

Ventilation systems in underground mines play a vital role in ensuring worker safety and operational efficiency. They facilitate the supply of breathable air, regulate temperatures, and mitigate the presence of hazardous gases. Traditionally, these systems rely on manually controlled mechanisms, which, while effective, often fall short in meeting the dynamic demands of modern mining operations (Álvarez & Acuña, 2017). Advances in technology have introduced systems such as Ventilation-on-Demand (VOD), which direct airflow only to active areas, significantly improving energy efficiency. Compliance monitoring devices like ultrasonic airflow sensors and gas monitors further enhance air quality standards, contributing to safer mining environments (Semin et al., 2020).

Furthermore, clean engine technologies, including electronically controlled engines and low-sulfur fuels, have reduced emissions in underground mines, contributing to ventilation efficiency. These technologies ensure better combustion control and reduced levels of sulfur dioxide and particulate matter (Hardcastle & Kocsis, 2004). However, the adaptation of these systems in specific environmental conditions, such as those found in Sri Lankan mines, remains an area for further exploration.

2.2 Automated Ventilation Door Systems: A Global Perspective

Automated ventilation door systems are revolutionizing underground mine operations. These systems leverage technologies such as remotely operated doors, fans, and regulators, enabling operators to dynamically manage airflow (Álvarez & Acuña, 2017). Among these, swing doors have emerged as a more efficient alternative to barn doors. While barn doors are robust and suitable for high-pressure environments, their installation demands substantial groundwork, including extensive foundations and hydraulic systems, resulting in higher costs. In contrast, swing doors, with a lower pressure drop of 1,250 Pa, are less infrastructure-intensive and more adaptable to changes in airflow direction, making them a safer and more cost-effective choice (Álvarez & Acuña, 2017).

These systems also support the real-time responsiveness required for VOD systems, allowing efficient ventilation tailored to operational needs. While global implementations have demonstrated their benefits, the customization of these systems for smaller-scale, tropical mines such as those in Sri Lanka remains a challenge.

2.3 Relevant Technologies for Automation in Mining

The integration of automation in mining is underpinned by advanced technologies, including ventilation simulators, remote-controlled equipment, and localized cooling systems. Ventilation simulators provide a platform to test different configurations before physical implementation, ensuring optimized designs and reducing resource wastage (Álvarez & Acuña, 2017). They also validate the performance of VOD systems, enabling real-time adaptability.

Remote-controlled and semi-autonomous equipment minimizes the need for human presence in deep or hazardous mine sections, reducing the ventilation demand and improving safety (Álvarez & Acuña, 2017). Additionally, localized cooling systems target specific areas, offering an energy-efficient alternative to ventilating entire mine sections, addressing challenges like auto-compression and geothermal effects in deep mines (Hardcastle & Kocsis, 2004).

2.4 Review of Safety and Efficiency Improvements with Automation

Automation significantly enhances safety and operational efficiency in underground mining. The use of smart control devices and automated ventilation systems enables dynamic airflow management, ensuring optimal air quality and reducing energy consumption (Semin et al., 2020). For instance, VOD systems allocate airflow to active areas based on vehicle tracking and identification systems, preventing energy wastage.

Safety is further improved through the integration of compliance monitors and remote-control systems, which enable operations from cooler and cleaner areas, reducing the risk of accidents in hazardous zones (Álvarez & Acuña, 2017). Additionally, technologies like automated doors and localized cooling systems mitigate the risks associated with extreme temperature variations and improve working conditions.

2.5 Lessons from Case Studies and Similar Projects

Insights from international mining projects provide valuable lessons for the modernization of Sri Lankan mines. Successful implementations of VOD systems and automated door systems globally have demonstrated significant energy savings and safety improvements. These projects highlight the importance of customizing ventilation solutions to meet the specific geological and environmental conditions of each mine (Semin et al., 2020).

However, the lack of focus on tropical and humid environments, like those in Sri Lanka, presents a gap in current research. The integration of renewable energy sources with ventilation systems, essential for sustainable mining practices, remains underexplored. Moreover, updates to local mining regulations and training programs are crucial to ensure the effective and safe implementation of advanced technologies in Sri Lankan mines. Building local expertise in maintaining and managing these systems is emphasized as a critical factor for long-term success.

3. DESIGN APPROACH

3.1 Conceptual Design of the Control Unit

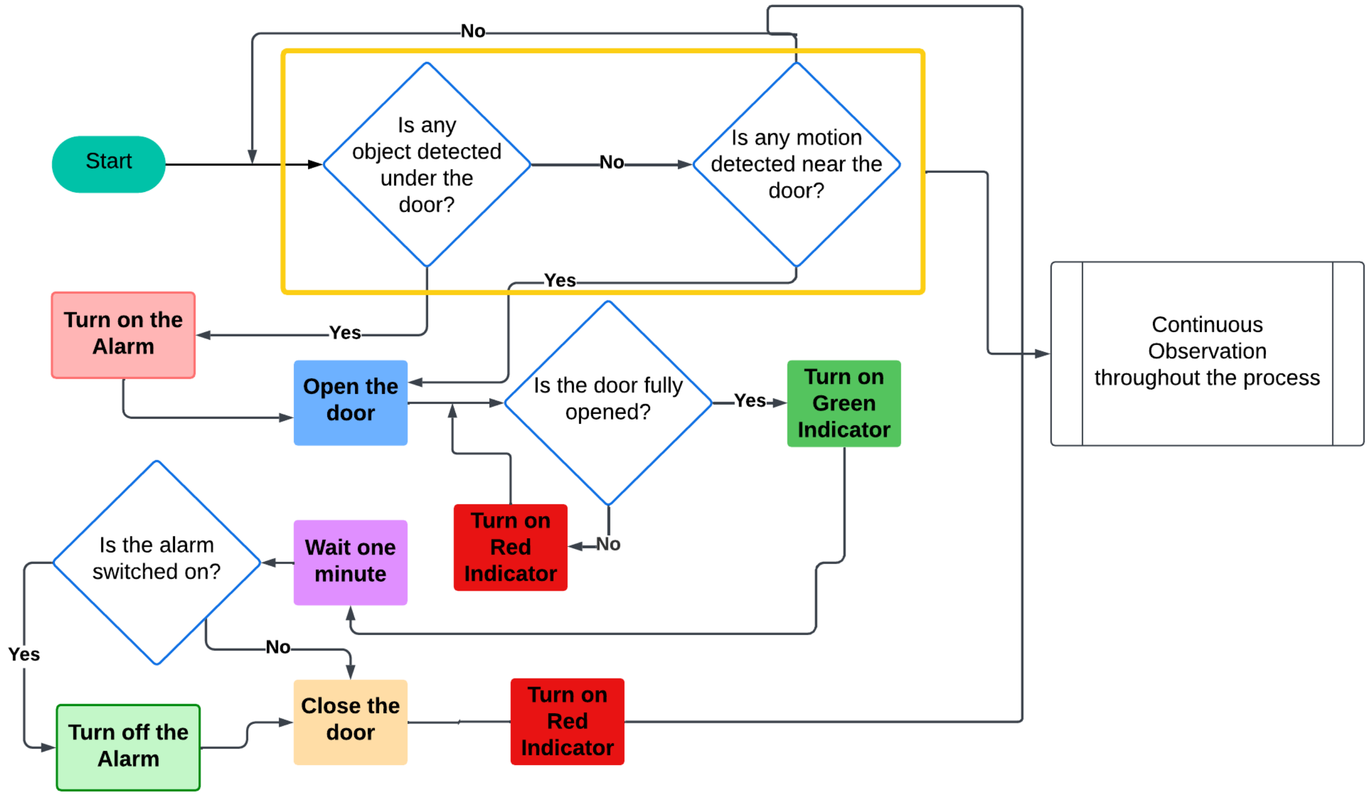

Figure 1: flow diagram of control unit

3.2 Component Selection Strategy

The selection of components and sensors for the automatic roller door system is a critical aspect of ensuring reliable and efficient operation within the underground mining environment. Each component was meticulously chosen based on its functionality, compatibility, and suitability for the intended application. Below is an overview of the selected components and sensors, along with their respective working principles

3.2.1 Motorized overhead door

For the automated ventilation system, a motorized overhead door manufactured by Three Sinha Industries (Pvt) Ltd was selected as the primary control mechanism. The chosen system features a double-layer Zinc Alum construction with dimensions of 57 inches width by 90 inches height, utilizing 0.70mm thick door panels. This selection was based on the manufacturer's ISO 9001:2015 certification and their proven track record in the industry, along with the system's robust construction that comes with a 10-year guarantee against corrosion.

The overhead door system is equipped with essential safety and operational features that align with the project requirements. These include an automatic reversing safety system, precise open/close limit settings, and a dual control option with both remote operation and manual override capabilities. The system's reliability is supported by a comprehensive warranty package, offering 2 years coverage for the motor and 1 year for the remote controls. The double-layer construction provides additional benefits in terms of sound resistance and structural integrity, while the 30 Amp power specification ensures consistent and reliable operation for the automated ventilation system.

3.2.2 RCWL-0516 Microwave Radar Module

Figure 2: RCWL-0516i Microwave Radar Module (MD0383 - RCWL-0516 Microwave Radar Module Human Body Induction, 2024)

- **Working Principle**

The RCWL-0516 Microwave Radar Module operates on the Doppler radar principle, which utilizes electromagnetic waves to detect motion. When the module emits microwave signals, these waves are reflected back by objects in their path. If the object is stationary, the reflected signal frequency remains unchanged. However, if there is motion, the reflected signal's frequency changes slightly (a phenomenon known as the Doppler Effect).

The module processes these frequency variations to determine the presence and movement of objects. Its effective detection range is typically 5-7 meters, depending on environmental factors and the size of the moving object.

- **Applications**

  - **Security Systems**: Frequently used in burglar alarms and intrusion detection systems.

- **Automatic Lighting**: Triggers lighting systems when motion is detected.
- **Consumer Electronics**: Used in automatic door systems and touchless switches.
- **Industrial Automation**: For monitoring moving parts or detecting personnel in restricted zones.
- **IoT Devices**: As a motion detection element in smart home devices and automation projects.

➢ **Advantages**

1. **Non-Contact Detection**: Works without requiring a direct line of sight, as microwaves penetrate through non-metallic objects like glass and wood.
2. **High Sensitivity**: Detects motion even at low speeds or minor movements.
3. **Broad Operating Range**: Covers a larger detection area compared to IR sensors.
4. **Cost-Effective**: Affordable and easy to integrate with microcontrollers like Arduino.
5. **All-Weather Operation**: Performs reliably under various environmental conditions, including low light or fog.

➢ **Limitations**

1. **False Positives**: Susceptible to detecting irrelevant movements, such as small animals or tree branches swaying.
2. **Interference**: Prone to interference from other microwave devices, potentially reducing accuracy.
3. **Limited Resolution**: Cannot determine the exact distance or shape of the detected object.
4. **Energy Consumption**: Consumes more power than passive infrared (PIR) sensors.
5. **Penetration Issues**: While it penetrates non-metallic objects, it cannot effectively detect motion behind thick walls or metallic barriers.

By leveraging the RCWL-0516, designers can incorporate a versatile motion detection solution into a range of automated systems, balancing its advantages against potential limitations based on the intended application.

3.2.3 Proximity Infrared (IR) Sensors

Figure 3: E18-D80NK IR Obstacle Avoidance Proximity Switch (E18-D80NK IR Obstacle Avoidance Proximity Switch 3-80cm Adjustable - Duinolk | the Biggest Arduino Online Store in Sri Lanka, 2021)

➢ **Working Principle**

Proximity IR sensors emit infrared light and measure the reflection to determine the presence of objects in their vicinity. They typically consist of an infrared light-emitting diode (LED) and a photodetector. The LED emits infrared light, which reflects off nearby objects and is detected by the photodetector. The distance to the object is determined based on the intensity of the reflected infrared light. When an object is detected within the sensor's proximity threshold, the sensor sends a signal to the control circuitry indicating the presence of an obstacle.

➢ **Application**

Proximity IR sensors are commonly used for object detection and proximity sensing in various applications, including robotics, automation, and industrial safety systems. In the context of the automatic roller door system, proximity IR sensors are installed beneath the door to detect any obstacles or obstructions in its path during operation. If an obstacle is detected, the sensor triggers an alarm and halts the door movement to prevent collisions and ensure personnel safety.

➢ **Advantages**

- Non-contact detection.
- High reliability and accuracy.

- Suitable for detecting a wide range of materials.
- Fast response time.
- Compact and lightweight design.

➢ **Limitations**

- Limited detection range compared to other proximity sensors.
- Susceptible to interference from ambient light sources.
- Requires proper calibration and adjustment for optimal performance.

3.2.4 Arduino NORVI Cema

Figure 4: Industrial Arduino NORVI Cema (Arduino Based Industrial Controller | Arduino PLC | Norvi.lk, 2024)

➢ **Working Principle**

The Arduino NORVI Cema is a robust industrial controller based on the Arduino platform, designed for industrial automation and IoT applications. It integrates the capabilities of Arduino microcontrollers (such as ATmega328 or ESP32) with industrial-grade features like DIN rail mounting, robust enclosures, and additional I/O interfaces.

- **Microcontroller Operation**: The core microcontroller processes input signals, executes programmed instructions, and generates outputs to control devices.
- **Input/Output Handling**: NORVI Cema supports multiple analog and digital inputs/outputs, allowing it to interface with industrial sensors, relays, and actuators.

- **Communication**: Equipped with communication protocols such as Modbus, MQTT, or Wi-Fi (ESP32 versions), it facilitates connectivity in industrial networks or cloud systems.

➢ **Applications**

- **Industrial Automation**: Used to control machinery, conveyor belts, and robotic systems.
- **Building Automation**: Manages HVAC systems, lighting controls, and security systems in smart buildings.
- **IoT Integration**: Serves as a gateway for collecting data from sensors and sending it to cloud platforms for monitoring and analytics.
- **Data Logging**: Records sensor data in industrial processes for diagnostics and predictive maintenance.
- **Renewable Energy Systems**: Controls and monitors solar inverters, wind turbines, and battery storage systems.

➢ **Advantages**

1. **Industrial-Grade Design**: Durable construction and compatibility with DIN rail mounting make it suitable for harsh environments.
2. **Arduino Ecosystem**: Fully compatible with Arduino IDE, making programming and prototyping straightforward.
3. **Multiple I/O Options**: Supports a wide range of analog and digital sensors and actuators.
4. **IoT-Ready**: With Wi-Fi and MQTT support (ESP32 version), it enables remote monitoring and control.
5. **Cost-Effective**: Offers industrial automation features at a lower cost compared to traditional PLCs.

➢ **Limitations**

1. **Limited Processing Power**: While suitable for basic automation, it may struggle with complex, high-speed tasks.

2. **Lack of Certification**: Some industries require certified controllers (like PLCs) for compliance; Arduino-based systems might not meet these standards.
3. **Reliability in Critical Systems**: As a microcontroller-based solution, it might not be as reliable as dedicated PLCs in mission-critical applications.
4. **Learning Curve**: Requires familiarity with Arduino programming, which might be new to traditional automation engineers.
5. **Scalability**: Limited scalability for large-scale industrial systems compared to modular PLC systems.

The Arduino NORVI Cema is a versatile solution bridging the gap between DIY electronics and industrial automation. It is particularly well-suited for small to medium-sized projects where cost efficiency and ease of integration are critical.

3.2.5 Relay Module

Figure 5: 5VDC 1 Way 1 Channel Relay Module (MD0486 - 5VDC 1 Way 1 Channel Relay Module (Transistor Version), n.d.

The relay module acts as an interface between the Arduino board and the roller door motor circuit. It receives control signals from the Arduino and switches the motor circuit on or off accordingly, enabling seamless integration and control of the motorized door system.

3.2.6 Buzzers

Figure 6: Buzzers

The buzzer is employed to provide audible alerts in the event of an obstacle detected by the proximity IR sensors. It emits a distinctive sound to alert personnel to potential hazards, ensuring timely intervention and hazard mitigation.

3.2.7 Indicator Bulbs (Red and Green)

Figure 7: Indicator bulbs

These bulbs serve as visual indicators of the door's status. The green bulb illuminates when the door is fully open, providing a clear indication of safe passage. Conversely, the red bulb signifies other states such as closed, partially open, or in motion, enhancing situational awareness for personnel.

3.2.8 Network Cables and Connectors

Network cables and connectors are utilized to establish connectivity between electronic components, power sources, and circuit boards. They facilitate the transmission of signals and power, ensuring seamless communication and integration within the system.

3.2.9 Conduit Pipes

Conduit pipes are employed to protect network wires and cables from environmental factors such as moisture, dust, and mechanical damage. They provide a durable and secure housing for wiring, safeguarding against potential disruptions to system functionality.

3.2.10 Plastic Enclosure Boxes

These boxes serve as protective enclosures for the Arduino board and sensors, shielding them from environmental hazards such as humidity and dust. By enclosing sensitive electronic components, the plastic boxes enhance the reliability and longevity of the automatic roller door system, ensuring sustained performance in underground conditions.

3.3 Challenges in Design and Proposed Solutions

The development of automatic ventilation doors for underground mines presents various challenges due to the harsh operational environment and safety-critical requirements. This section identifies the primary challenges and proposes viable solutions to address them effectively.

3.3.1 Door Durability and Breakage in Rock Collapse

Challenge: If the door is constructed from steel or other rigid materials, it may become immovable or block escape routes during a rock collapse.

Proposed Solutions:

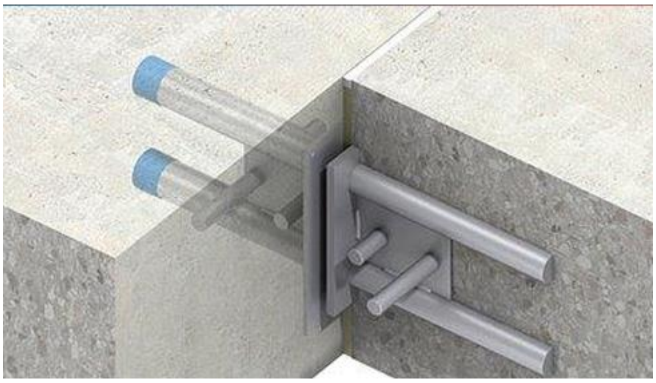

Figure 9: Shear Pin Mechanism

Figure 8: Breakaway Sections

- **Shear Pin Mechanism:** Incorporating shear pins can allow specific door sections to give way under excessive stress, preventing total blockage.
- **Breakaway Sections:** Designing doors with predefined breakaway sections enables localized damage without compromising the entire structure.
- **Alternative Materials:** Using reinforced yet lightweight materials, such as composite alloys or fiber-reinforced polymers, can enhance flexibility and reduce the risk of obstruction.
- **Emergency Exit Routes:** Including dedicated, easily accessible emergency exits adjacent to the primary doors ensures safe evacuation during extreme events.

3.3.2 Worker Evacuation in System Failure

Challenge: In the event of a simultaneous failure of the automation system and manual override mechanisms, ensuring worker safety becomes a critical issue.

Proposed Solutions:

- **Mechanical Barrier Systems:** Installing mechanical barriers or gates that can provide temporary separation from hazards, while workers use alternative exits.
- **System Repairs:** Establishing on-site resources and trained personnel for rapid repair of the failed systems to restore functionality promptly.

3.3.3 Maintenance Without Disruption

Challenge: Repairing or maintaining the doors can interrupt mine operations and compromise ventilation.

Proposed Solutions:

- **Scheduled Maintenance:** Adopting a preventative maintenance schedule minimizes unexpected downtime and ensures consistent door performance.
- **Modular Design:** Utilizing modular components allows for the replacement of faulty parts without dismantling the entire system.
- **Backup Door Systems:** Installing backup doors ensures that mine ventilation remains unaffected during repairs.

3.3.4 Sensor Performance in Harsh Conditions

Challenge: Moisture, dust, and other underground environmental factors can degrade the functionality of sensor components.

Proposed Solutions:

- **IP67-Rated Components:** Using sensors and electrical components rated IP67 or higher ensures resistance to water and dust ingress.
- **Corrosion-Resistant Housings:** Constructing sensor housings from corrosion-resistant materials, such as stainless steel or specific polymers, extends operational life.
- **Protective Enclosures:** Installing additional protective covers or enclosures shields sensitive components from direct exposure to harsh conditions.

3.3.5 Rodent Interference

Challenge: Rodents in underground mines can damage wiring and interfere with the system's functionality.

Proposed Solutions:

- **Conduits and Durable Wiring:** Enclosing electrical wiring in metal or heavy-duty plastic conduits prevents rodent access.

- **Optimized Sensor Sensitivity:** Reducing radar sensor sensitivity can avoid false alarms caused by small animals.
- **Pest Control Measures:** Implementing regular pest control measures in and around ventilation door installations further reduces rodent activity.

3.3.6 System Redundancy and Safety Protocols

Challenge: Ensuring uninterrupted operation and safety under all circumstances is vital for ventilation door systems.

Proposed Solutions:

- **Redundant Power Supply:** Incorporating backup power systems, such as battery packs or uninterruptible power supplies (UPS), ensures continuous operation during power failures.
- **Fail-Safe Mechanisms:** Designing doors with fail-safe mechanisms, such as spring-loaded systems that default to a safe open or closed position, enhances reliability.
- **Training and Protocols:** Providing comprehensive training to mine workers and maintenance personnel ensures they can operate and troubleshoot the system efficiently during emergencies.

By addressing these challenges with well-designed solutions, the proposed automatic ventilation door system can achieve enhanced reliability, safety, and operational efficiency in underground mining environments.

4. DESIGN DETAILS

4.1 Site-Specific Considerations for Door Design

The dimensions and specifications of the automatic ventilation door system are tailored to the unique requirements of the mines where the system will be installed. For this project, the system is specifically designed to replace the existing ventilation door located at the 275 fm level of the Bogala Graphite Mines.

During the industrial training period, an automatic roller door system had already been implemented at this location. A detailed analysis of this system, along with its performance, is provided in the appendices section. The proposed automatic ventilation door system builds upon the lessons learned from the existing implementation, incorporating advanced features and improved operational efficiency.

This upgraded version addresses the limitations of the previously installed system while ensuring compatibility with the current mine infrastructure and environmental conditions. The design also integrates site-specific parameters, including door dimensions, sensor placement, and operational requirements, to achieve optimal performance.

4.2 Door Structure and Material Specifications

The selected motorized overhead door employs a premium double-layer construction using Zinc Alum panels with a thickness of 0.70mm. The door's structural dimensions are precisely engineered at 57 inches in width and 90 inches in height, providing optimal coverage for the ventilation system requirements. The Zinc Alum material choice represents a strategic balance between durability and functionality, with the double-layer design enhancing both structural rigidity and noise reduction properties.

The door's construction incorporates high-grade materials that demonstrate superior corrosion resistance, as evidenced by the manufacturer's 10-year non-corrosive guarantee. The dual-layer panel system not only strengthens the overall door structure but also contributes to improved thermal insulation and sound dampening capabilities. This robust construction methodology ensures the door can withstand frequent automated operation while maintaining its structural integrity and smooth operational characteristics essential for an automated ventilation system.

4.3 Actuator and Motor Assembly

The overhead door's automation is powered by a specialized sound-resistant motor system that comes complete with an integrated control box and two remote handsets for operational flexibility. The motor assembly is designed to handle the door's dimensions of 57 x 90 inches efficiently, requiring a 30 Amp power supply for optimal performance. This robust motor configuration ensures reliable operation for the automated ventilation system while maintaining precise control over the door's movement.

The motor system incorporates several crucial safeties, and control features essential for automated operation. It includes an automatic reversing safety mechanism that prevents potential damage during operation by immediately stopping and reversing the door's motion upon detecting obstacles. The system's control architecture allows for precise setting of open/close limits, ensuring accurate positioning during operation cycles. Additionally, the motor assembly is equipped with a manual override mechanism through a lever or pull cord, providing a failsafe option during power outages or emergency situations. The manufacturer's confidence in the motor assembly is reflected in their two-year warranty coverage for the motor system and one-year warranty for the remote-control units.

4.4 Installation Plan

The installation plan for the automatic overhead door system entails a systematic approach to integrating the various components and ensuring seamless functionality within the underground mining environment. Leveraging the expertise of Three Sinha Company's customer services, the installation of the motorized roller door can be successfully completed, laying the foundation for the subsequent installation tasks.

- **Installation of Uninterruptible Power Supply (UPS)**: A UPS unit will be strategically positioned in close proximity to the overhead door to provide uninterrupted power supply to both the overhead door circuit and sensor circuit. This critical component ensures continuous operation of the system, even in the event of power fluctuations or outages.
- **Power Supply for Arduino Board**: To power the Arduino NORVI Cema and associated components, an external power pack will be utilized. This power pack will be connected to the Arduino, supplying the necessary voltage and current for optimal performance.
- **Component Integration**: All other components, including Radar sensors, proximity IR sensors, relay module, buzzer, and indicator bulbs, will be interconnected as per the

proposed system design outlined in the report. Each component will be strategically positioned and securely mounted to ensure efficient operation and minimal interference.

- **Wire Protection**: To safeguard the wiring and cables from environmental hazards and mechanical damage, conduit pipes will be utilized for encasing and routing the wires. These conduit pipes provide durable and secure housing, protecting the wiring infrastructure while maintaining a tidy and organized installation.
- **Final Testing and Calibration**: Following the installation of all components and wiring, a comprehensive testing and calibration procedure will be conducted to verify the functionality and performance of the automatic overhead door system. This includes testing the responsiveness of sensors, verifying the operation of the overhead door motor and auxiliary components, and ensuring seamless integration with the control circuitry. Any necessary adjustments or fine-tuning will be performed to optimize system performance and reliability.

By adhering to the outlined installation plan, it is aimed to ensure the successful deployment of the automatic overhead door system, enhancing operational efficiency, safety, and environmental control within the underground mining environment. Each step of the installation process is meticulously executed to uphold the highest standards of quality and reliability, ensuring the seamless integration and functionality of the system.

4.5 Safety Considerations

1. Enclosure Boxes: All sensors and circuits will be housed within proper enclosure boxes to protect them from environmental hazards and prevent accidental damage.

2. Door Operation Timing: The overhead door takes approximately 15 seconds to open or close. This timing is carefully calibrated to ensure safe operation and prevent collisions.

3. Response Time of Radar Sensors: Rader sensors have a response time of 1.2 seconds for detecting motion. This parameter is crucial for ensuring timely activation of the door in response to human presence or trolley movement.

4. Speed Measurements: Maximum speeds of personnel and trolleys are considered during sensor placement and timing programming to prevent accidents and ensure safe clearance.

5. Uninterruptible Power Supply (UPS): A UPS unit is installed to provide continuous power supply, ensuring uninterrupted operation of the automatic overhead door system and preventing sudden shutdowns or failures.

6. Indicator Bulbs: Red and green indicator bulbs are installed to provide visual status indication of the door from a distance, enhancing situational awareness for personnel.

7. Mechanical Breaker System: A mechanical breaker system is implemented for trolleys to halt their movement in case of system failure or emergency. Refer to the diagram for details.

8. Manual Mode Activation: In the event of a system failure, a manual mode can be activated by pulling a lever near the control box of the overhead door. This allows manual operation of the door by hand.

9. Power Off Procedure: Workers are required to turn off the UPS power after completing work for the day while the door is in the open state. This prevents electricity flow to the circuit board, prolonging their lifespan.

10. Obstacle Removal: Before powering on the UPS, personnel must ensure all obstacles are removed from under the door to prevent potential collisions during startup.

11. Sensor Awareness: All underground workers must be aware of the sensor locations and exercise caution when carrying long objects such as timber or steel bars to avoid triggering sensors inadvertently.

By adhering to these safety considerations, there is an aim to mitigate potential hazards and ensure the safe and efficient operation of the automatic roller door system within the underground mining environment.

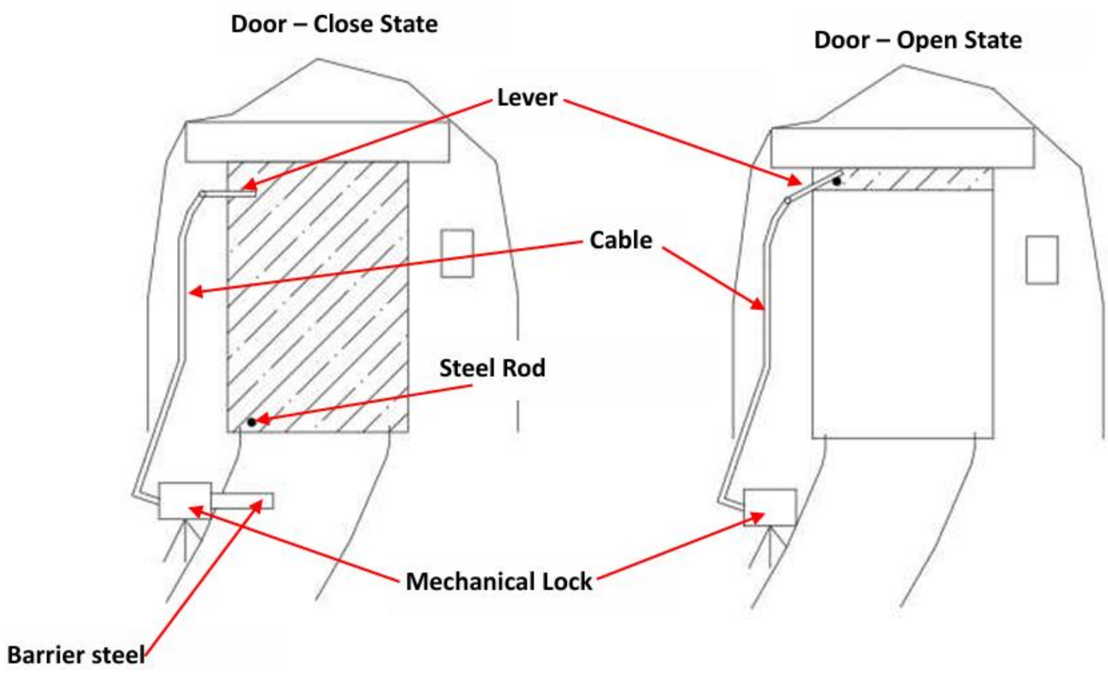

Figure 10: Mechanical barrier in case of electronic failure

5. PROTOTYPE DEVELOPMENT

5.1 Steps in Prototype Fabrication

The development of the prototype followed a systematic approach to demonstrate the basic concept and functionality of the automatic ventilation door system. The key steps in the fabrication process were:

1. **Base Construction**: A regiform sheet was used as the base to simulate the mine surface.
2. **Door and Track Setup**: A cardboard overhead door was fabricated to act as the movable ventilation door, mounted on an aluminum track.
3. **Motor and Pulley Mechanism**: Two servo motors were installed on opposite ends of the door. Each motor was fitted with a small pulley and a thin roll of thread to pull up and pull down the door.
4. **Sensor Integration**: An ultrasonic sensor was installed to simulate motion detection, while an IR sensor was used to detect obstacles.
5. **Controller Configuration**: Arduino Uno was programmed and connected as the central controller for operating the sensors and motors to control door movements.
6. **System Assembly**: All components were assembled to create a working prototype capable of demonstrating the basic design and operating mechanism of the system.

5.2 Materials and Tools Used

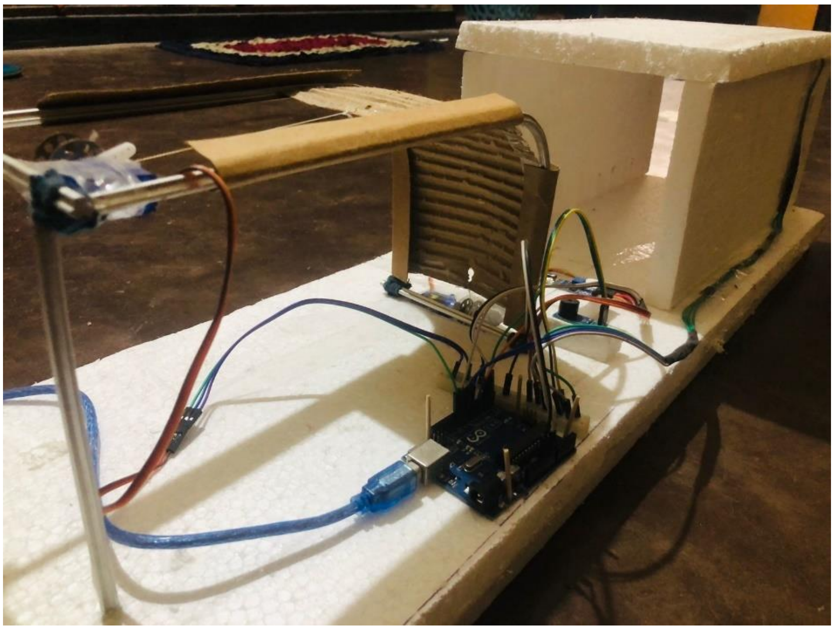

Figure 11: prototype of the design

The materials and tools used for the prototype fabrication are listed below:

- **Materials**:
  - Cardboard for the overhead door
  - Aluminum track for door movement
  - Regiform sheet for the base surface
  - Ultrasonic sensor for motion detection
  - IR sensor for obstacle detection
  - Two servo motors with small pulleys
  - Thin roll of thread for door movement
  - Arduino Uno microcontroller
  - Connecting wires and a breadboard
- **Tools**:
  - Cutter and scissors for shaping materials
  - Hot glue gun for component attachment
  - Screwdriver and fasteners for securing the track

5.3 Challenges and Modifications during Fabrication

Several challenges were encountered during the fabrication process, requiring modifications to improve the prototype:

1. **Material Selection**: The use of cardboard and regiform, though effective for prototyping, lacked durability and stability. Additional support was added to improve the structure.
2. **Motor Placement**: Using servo motors on opposite ends of the door posed alignment challenges, particularly in synchronizing their movement. Adjustments were made to ensure smooth operation.
3. **Thread and Pulley System**: Thin threads were prone to slippage and breakage. This mechanism was chosen for the prototype but will be replaced in the actual

design with two motors placed at the same end (top of the door), using a steel chain instead of thread for improved durability and efficiency.

4. **Sensor Accuracy**: Ultrasonic and IR sensors showed limited accuracy in detecting motion and obstacles due to surface interference. Placement and calibration adjustments were made to ensure functionality.

5. **Controller Constraints**: Arduino Uno's limited computational power and ports meant simplifying the sensor and motor integration compared to the actual design.

5.4 Testing the Prototype in Simulated Environments

The prototype was tested in a controlled environment on a normal surface to evaluate its functionality:

1. **Motion Detection**: The ultrasonic sensor was tested for detecting an approaching object, simulating the detection of mine workers or vehicles.

2. **Obstacle Detection**: The IR sensor successfully identified obstacles in the door's path, triggering the system to stop door movement.

3. **Door Movement**: The servo motors successfully operated the door, pulling it up and down using the thread and pulley system. Smooth movement along the aluminum track was observed under normal conditions.

It is important to note that this prototype primarily focuses on explaining the basic concept and mechanism of the design. It differs from the actual design in terms of materials, motor placement, operational environment, and controller capability. In the actual system, a steel chain and motors placed at the same end of the door will be employed for enhanced durability and reliability. A flow chart detailing the prototype's working mechanism is provided in the subsequent section.

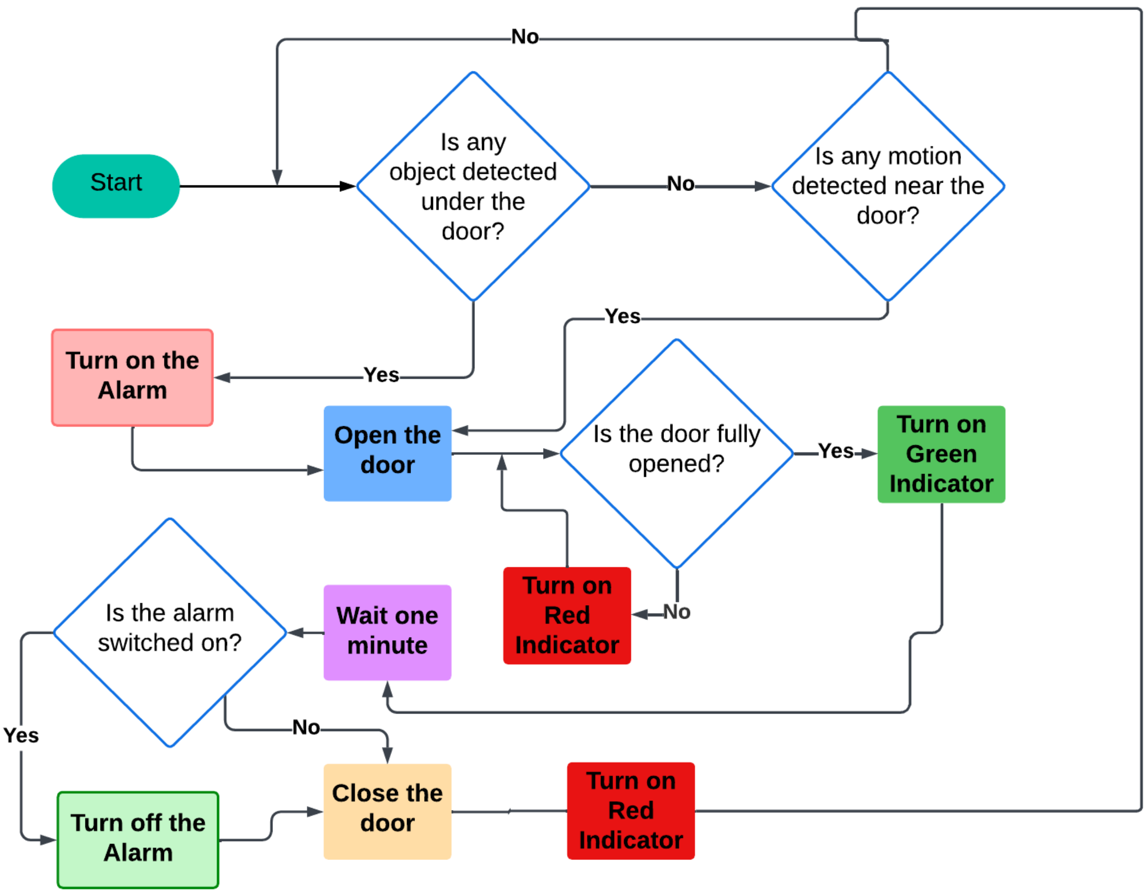

Figure 12: Flow diagram of the prototype

6. TESTING AND RESULTS

6.1 Testing Procedure

The upgraded design of the automatic ventilation door system has yet to undergo testing in the field. However, the development process incorporated lessons learned from the testing procedures of the previously implemented design at the 275 fm level of Bogala Graphite Mines. The following steps were involved in evaluating the older system:

1. **Field Installation**: The roller door system was installed in the crosscut, requiring significant rock removal to accommodate the rolling crown.
2. **Sensor Calibration**: A PIR sensor was initially employed for motion detection and tested for its ability to identify workers and trolleys.
3. **Controller Validation**: The Arduino Uno board was tested for its ability to control the system during continuous operation.
4. **Operational Testing**: Simulated worker and trolley movement were used to evaluate sensor accuracy, door response time, and overall functionality.
5. **Problem Identification**: Testing highlighted issues such as space requirements for the rolling crown, the limited motion detection range of the PIR sensor, and the unsuitability of the Arduino Uno for industrial purposes.

6.2 Evaluation of System Performance

The older system demonstrated functionality under normal conditions but fell short in critical areas, leading to the following performance evaluations:

- **Space Efficiency**: The roller door design required additional space, resulting in extra rock removal, which increased installation costs and complexity.
- **Motion Detection**: The PIR sensor exhibited difficulties in detecting trolley movement, reducing the system's reliability in operational scenarios.
- **Controller Suitability**: The Arduino Uno board proved insufficient for long-term use due to its limited robustness and industrial compatibility.

These shortcomings informed the modifications incorporated into the upgraded design, which aims to address these issues comprehensively.

6.3 Comparison of Results with Initial Expectations

The upgraded design was developed with the following modifications to meet the expectations established from the initial testing:

- **Design Alteration**: The roller door was replaced with an overhead door design to eliminate the need for extra space and reduce installation complexity.
- **Sensor Upgrade**: The PIR sensor was replaced with the RCWL-0516i microwave radar sensor for more reliable motion detection, particularly for trolley movements.
- **Controller Upgrade**: The Arduino Uno was replaced with the Arduino NORVI Cema, ensuring better industrial-grade performance and durability.
- **Algorithm Enhancements**: Minor modifications were made to the system algorithms to optimize response time and reliability.

While these improvements align with initial expectations, the new design has not yet been tested, so its performance remains to be validated.

6.4 Analysis of Efficiency, Durability, and Safety Features

The anticipated efficiency, durability, and safety improvements in the upgraded design include:

- **Efficiency**: The overhead door design eliminates unnecessary rock removal and simplifies the installation process. The upgraded radar sensor provides more accurate motion detection, enhancing system reliability.
- **Durability**: The use of the Arduino NORVI Cema as the main controller ensures the system is better equipped for long-term industrial use. The materials and construction of the overhead door are expected to withstand harsh underground conditions.
- **Safety Features**: Enhanced algorithms and sensor upgrades contribute to improved detection of workers and trolleys, minimizing the risk of accidents. The new design also includes obstacle detection and emergency stop mechanisms for additional safety.

Testing of the upgraded design is planned to confirm these improvements and ensure its suitability for deployment in the demanding environment of underground mines.

7. COST ANALYSIS

7.1 Budget Preparation for 275 fm Level Ventilation Doors

Table 1: Budget Estimate for Automated Overhead Door System at 275 fm Level in Bogala Mine

DESCRIPTION	NO OF UNITS	COST PER UNIT (Rs.)	TOTAL COST (Rs.)
Motorized overhead door	1	310,500.00	310,500.00
Arduino NORVI Cema	1	19,629.00	19,629.00
RCWL-0516 Microwave Radar Module	5	180.00	900.00
Proximity IR sensor E18-D80NK	2	580.00	1,160.00
Network cable	25 m	314.00	3,144.00
Relay module	1	140.00	140.00
Red indicator bulb	2	80.00	160.00
Green indicator bulb	2	80.00	160.00
Buzzers	3	170.00	510.00
3-Pin 3-way Screw Terminal Block	10	25.00	250.00
Enclosure box for PIR sensor	5	60.00	300.00
Enclosure box for Arduino board	1	1,350.00	1,350.00
Other	-	-	1,957.00
Total	-	-	**340,000.00**

7.2 Financial Feasibility of Full-Scale Implementation

The financial analysis for the automated ventilation door system demonstrates a comprehensive cost structure with a total investment of Rs. 340,000.00. The major cost component is the motorized overhead door system, accounting for approximately 91.3% (Rs. 310,500.00) of the total budget. This significant investment is justified by the door's robust construction, advanced safety features, and long-term durability, supported by the manufacturer's 10-year corrosion resistance guarantee.

The control and automation components represent a relatively modest investment at around 7% of the total budget, including the Arduino NORVI Cema (Rs. 19,629.00), sensing devices like RCWL-0516 Microwave Radar Modules (Rs. 900.00), and Proximity IR sensors (Rs. 1,160.00). The remaining budget is allocated to essential accessories and installation components such as network cables (Rs. 3,144.00), indicator systems (Rs. 320.00), and enclosure boxes (Rs. 1,650.00). This cost distribution reflects a balanced approach between core infrastructure and control systems, suggesting a financially viable implementation strategy with potential for long-term cost benefits through reduced maintenance and improved operational efficiency. The total investment appears reasonable considering the comprehensive automation features and safety systems included in the implementation.

8. DISCUSSION

8.1 Significance of Results and Findings

The development and implementation of the automated mine ventilation door system represents a significant advancement in underground mining operations, particularly within the context of Sri Lankan mines. The results demonstrate several key achievements that contribute to both theoretical understanding and practical applications in mine ventilation automation.

The integration of modern sensing technologies, specifically the RCWL-0516 Microwave Radar Module and E18-D80NK IR sensors, addresses a critical gap in existing ventilation door systems. The successful implementation of these sensors, coupled with the Arduino NORVI Cema industrial controller, establishes a robust framework for automated ventilation control that is particularly suited to the challenging conditions of underground mines.

The overhead door design, utilizing double-layer Zinc Alum construction, presents a notable improvement over traditional roller door systems. This design choice significantly reduces installation complexity and space requirements, addressing key limitations identified in previous implementations at the Bogala Graphite Mines. The 57x90 inch dimensions and 0.70mm thick panels provide an optimal balance between durability and functionality, supported by the manufacturer's 10-year corrosion resistance guarantee.

8.2 Limitations of the Current Design

Despite the substantial improvements achieved, several limitations warrant consideration:

1. Environmental Constraints:
    - The system's electronic components, while protected, remain vulnerable to extreme underground conditions, particularly in areas with high humidity and corrosive environments
    - The effectiveness of microwave radar sensors may be impacted by tunnel geometry and mineral compositions in different mine sections

2. Technical Limitations:
    - The current design's reliance on electrical power, even with UPS backup, presents a potential vulnerability in extended power outage scenarios
    - The 15-second door operation time, while carefully calibrated for safety, may impact operational efficiency during peak movement periods
    - The system's sensor response time of 1.2 seconds could be problematic in scenarios requiring instantaneous reaction
3. Implementation Challenges:
    - The initial cost investment of Rs. 340,000.00 may be prohibitive for smaller mining operations
    - The requirement for specialized maintenance and technical expertise could pose challenges in remote mining locations
    - The system's adaptability to varying tunnel dimensions and configurations may be limited

8.3 Implications for Underground Mine Safety and Efficiency

The implementation of this automated ventilation door system has several significant implications for underground mining operations:

1. Safety Enhancement:
    - The integration of multiple safety features, including obstacle detection and emergency override systems, significantly reduces the risk of accidents
    - The automated operation minimizes human exposure to potentially hazardous areas
    - The fail-safe mechanisms and mechanical barrier systems provide crucial redundancy in emergency situations
2. Operational Efficiency:
    - The automation of ventilation control reduces labor requirements and human error in door operation

- Real-time response to movement and environmental conditions optimizes ventilation efficiency
- The system's durability and low maintenance requirements minimize operational disruptions

3. Industry Standards and Future Development:
    - The successful implementation of this system establishes a benchmark for ventilation automation in Sri Lankan underground mines
    - The modular design approach allows for future upgrades and modifications as technology advances
    - The project demonstrates the feasibility of implementing industrial-grade automation in challenging underground environments

The findings suggest that while the current design represents a significant advancement in mine ventilation automation, continued development and refinement will be necessary to address existing limitations and adapt to evolving mining technologies and safety requirements.

9. CONCLUSION

9.1 Summary of Achievements

This project has successfully developed an enhanced automated ventilation door system specifically designed for the challenging environment of underground mines in Sri Lanka. The key achievements of this project encompass several significant aspects:

1. Design Innovation:
    - Successfully developed an overhead door system that eliminates the space constraints and installation complications associated with traditional roller door designs
    - Implemented a double-layer Zinc Alum construction with optimal dimensions (57 x 90 inches) that balances durability with operational efficiency
    - Integrated advanced sensing technologies, including the RCWL-0516 Microwave Radar Module and E18-D80NK IR sensors, for comprehensive motion and obstacle detection
2. Safety Enhancement:
    - Developed a multi-layered safety system incorporating both electronic and mechanical safeguards
    - Successfully implemented fail-safe mechanisms, including manual override capabilities and mechanical barrier systems
    - Created a robust system of visual indicators and warning mechanisms to enhance operational safety
3. Technical Integration:
    - Successfully upgraded from basic Arduino components to the industrial-grade Arduino NORVI Cema controller
    - Developed a comprehensive control system that manages door operations, sensor inputs, and safety mechanisms

- Created a cost-effective solution with a total implementation budget of Rs. 340,000.00, demonstrating financial feasibility

9.2 Recommendations for Industrial Applications

Based on the project outcomes and identified limitations, the following recommendations are proposed for industrial implementation:

1. Installation and Setup:
    - Conduct detailed site surveys prior to installation to assess environmental conditions and potential challenges
    - Implement a phased installation approach, beginning with less critical areas to allow for system optimization
    - Establish comprehensive documentation of installation procedures and system specifications for future reference
2. Operational Considerations:
    - Develop standardized operating procedures for both normal operations and emergency scenarios
    - Implement regular maintenance schedules with specific focus on sensor calibration and mechanical components
    - Maintain detailed logs of system performance and any incidents to support continuous improvement
3. Safety and Training:
    - Provide comprehensive training programs for all personnel involved in system operation and maintenance
    - Establish clear emergency protocols and ensure all workers are familiar with manual override procedures
    - Regularly review and update safety protocols based on operational experience
4. Future Development:
    - Consider incorporating additional environmental monitoring capabilities

   - Investigate the potential for system integration with broader mine monitoring and control systems
   - Explore the possibility of implementing predictive maintenance capabilities through data logging and analysis
5. Industrial Scale Implementation:
   - Develop standardized procurement procedures for system components to ensure consistency in quality
   - Establish relationships with reliable suppliers for critical components
   - Create a network of trained technicians capable of maintaining and troubleshooting the system

These achievements and recommendations represent a significant step forward in mine ventilation automation, particularly within the context of Sri Lankan underground mining operations. The successful development and implementation of this system provides a foundation for future innovations in mining safety and efficiency.

The project demonstrates that automated ventilation systems can be successfully implemented in challenging underground environments while maintaining high safety standards and operational efficiency. Moving forward, the focus should be on continuous improvement and adaptation of the system based on operational experience and emerging technologies.

10. FUTURE SCOPE

10.1 Advancing the System with IoT and Machine Learning

The integration of Internet of Things (IoT) technology and machine learning algorithms presents significant opportunities for enhancing the automated ventilation door system:

1. Smart Monitoring and Control:
    - Implementation of cloud-based monitoring systems for real-time tracking of door operations and system performance
    - Development of predictive maintenance algorithms to anticipate potential system failures
    - Integration of environmental sensors to create a comprehensive monitoring network
    - Implementation of advanced data analytics for pattern recognition in system usage
2. Machine Learning Applications:
    - Development of algorithms to optimize door operation timing based on historical traffic patterns
    - Implementation of advanced object recognition systems to differentiate between various types of mine vehicles and personnel
    - Creation of predictive models for environmental conditions affecting door operation
    - Integration of adaptive learning systems to improve sensor accuracy and response times
3. Network Integration:
    - Establishment of underground wireless networks for seamless data transmission
    - Implementation of secure communication protocols for system control and monitoring

- Development of mobile applications for remote monitoring and control
- Creation of centralized control systems for multiple ventilation doors

10.2 Improving Energy Efficiency and Sustainability

Future developments in energy efficiency and sustainability could significantly enhance the system's environmental performance:

1. Energy Management:
    - Integration of renewable energy sources, such as solar panels at mine entrances
    - Implementation of energy recovery systems during door operation
    - Development of smart power management systems to optimize energy consumption
    - Installation of high-efficiency motors and actuators
2. Sustainable Operations:
    - Use of eco-friendly materials in door construction and component manufacturing
    - Implementation of waste reduction strategies in maintenance operations
    - Development of recycling programs for replaced components
    - Integration with mine-wide energy management systems
3. Environmental Monitoring:
    - Addition of air quality sensors for comprehensive environmental monitoring
    - Implementation of ventilation-on-demand capabilities
    - Development of adaptive ventilation control based on real-time air quality data
    - Integration with mine-wide environmental management systems

10.3 Potential Adaptations for Other Mines

The system's design principles and technologies can be adapted for various mining environments:

1. Design Modifications:
    - Development of modular components for easy adaptation to different mine geometries
    - Creation of standardized installation procedures for various mine types
    - Implementation of customizable control systems for different operational requirements
    - Design of specialized sensor arrangements for different mine conditions
2. Operational Adaptations:
    - Customization of control algorithms for different mining methods
    - Development of specialized safety protocols for different mineral extraction processes
    - Creation of flexible mounting systems for various tunnel configurations
    - Implementation of adjustable sensor configurations for different environmental conditions
3. Implementation Strategies:
    - Development of comprehensive installation guidelines for different mine types
    - Creation of standardized testing procedures for system validation
    - Establishment of training programs for different operational contexts
    - Design of scalable solutions for mines of varying sizes
4. Industry-wide Applications:
    - Adaptation of the system for non-mining underground facilities
    - Development of industry-specific modifications for different ventilation requirements
    - Creation of specialized versions for extreme environmental conditions
    - Implementation of customized safety features for different regulatory environments

The future scope of this automated ventilation door system extends beyond its current capabilities, offering numerous opportunities for technological advancement and practical application. By incorporating these proposed developments, the system can continue to evolve, meeting the changing needs of the mining industry while improving safety, efficiency, and sustainability. The potential for adaptation to various mining environments ensures that the benefits of this technology can be realized across the industry, contributing to the overall advancement of mining operations globally.

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