UNIVERSITY of RWANDA
COLLEGE OF SCIENCE AND TECHNOLOGY

ACEIoT
Website: www.aceiot.ur.ac.rw
Mail: aceiot@ur.ac.rw

AFRICAN CENTRE OF EXCELLENCE IN INTERNET OF THINGS

SMART MINER HELMET AND MONITORING SYSTEM IN RWANDA

A CASE OF RUTONGO MINES, GASABO DISTRICT

MASTER DISSERTATION

Submitted for partial fulfillment for the requirements for the award of

MASTER OF SCIENCE IN INTERNET OF THINGS

WIRELESS INTELLIGENT SENSOR NETWORKING

(MSC in IoT-WISENET)

Submitted by

UWANTEGE STELLAH PROSSY: Ref No: 220014218

January 2022

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Under the Supervision of;
Main Supervisor
Dr. Alfred UWITONZE
and
Co-Supervisor
Dr. Jean Baptiste MBANZABUGABO

January 2022

DECLARATION

I, UWANTEGE Stellah Prossy, hereby declare that this dissertation report is my original work and has not been submitted before for any other academic award in the either the University of Rwanda or other higher learning institutions for publication for other academic purposes.

UWANTEGE Stellah Prossy

December 2021

BONAFIDE Certificate

This is to certify that the dissertation report titled "SMART MINER HELMET AND MONITORING SYSTEM IN RWANDA" is the original work of UWANTEGE Stellah Prossy with Refn 20014218 for partial fulfillment of the requirement of the ward of a Master's degree in Internet of Things in Wireless Intelligent Sensor Networking (MSc in IoT-WISENET) from College of Science and Technology in Rwanda University.

Main Supervisor:

Dr. Alfred UWITONZE

Signature: …………………

Date: ……………………….

Co-Supervisor:

Dr. Jean Baptiste MBANZABUGABO

Signature: ………………………….

Date: ……………………………….

Head of Masters Studies and Trainings:

Dr. James RWIGEMA

Signature: ……………………….

Date: ……………………………

DEDICATION

This dissertation would have not been completed if not for the support from;

Both my husband and the baby boy who was very young by then!

My both parents, who supported me through my education!

My supervisors, lecturers, colleagues, and close friends, who supported me greatly during my master's studies!

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Finally, to my loving, supportive, and caring husband, am truly grateful, Thanks for great encouragement when times get hard all that is appreciated and greatly noticed, it has been a comfort and relief that you are always there for our entire household as we completed my studies and this research work. Thanks, from the bottom of my heart.

ABSTRACT

The use of technology within the mining industry in Rwanda has grown to be difficult to avoid deaths in mines; it's for this reason that the protection of the miner is an essential aspect from risks outside and inside the mining tunnels. The process of digging minerals in the underground has many dangerous factors such as concentration level of gases such as carbon monoxide, sulfur dioxide, nitrous gases, carbon dioxide, change in temperature, moisture and airflow, and other hazards like falling of caves, leakage of dangerous gases, humidity and temperature change which can lead to death due to failure to report their prevalence on time; The development of an IoT solution called Smart miner helmet and monitoring system provides real-time communication and monitoring between miners in the underground site and control room administrator for all level of substances from the underground by getting real-time data probed by sensors on microcontroller deployed within the miner's helmet. This whole system proposed to develop a SMART MINER HELMET AND MONITORING SYSTEM using technologies such as Internet of Things (IoT), wireless network networks, cloud computing, the data processing server to help miners improve the way mines are safely used using sensors to monitor different levels of gas, humidity, temperature, and hazards. The proposed system will provide information about the miner conditions specifically on measuring gas levels, humidity, and temperature, and help miners and supervisors to take precise decisions. logistic regression, decision tree classifier, and k-nearest classifier were used to measure the gas levels, and the best model was Decision Tree 84% accurate, Precision of 61%, and Recall 62%.

Keywords: Smart System, IOT4Mining, Data visualization, Technology convergence

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LIST OF ACRONYMS

AI: Artificial Intelligence

CDMA: Code Division Multiple Access

EEPROM: Electrically Erasable Programmable Read-Only Memory

GPRS: General Packet Radio Services

GSM: Global System for Mobile Communication

IIoT: Industrial Internet of Things

IoT: Internet of Things

KNN: K-Nearest Neighbors

LPG: Liquefied Petroleum Gas

OLED: Organic Light Emitting Diode

PPE: Personal Protective Equipment

RMB: Rwanda Mines, Petroleum and Gas Board

SDM: System Development Method

SMHMS: Smart Miner Helmet and Monitoring System

TCP: Transmission Control Protocol

TDMA: Time Division Multiple Access

UDP: User Datagram Protocol

ULP: Ultra-Low Power

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Chapter 1 : INTRODUCTION

1.1Introduction of Mining Development in Rwanda

Rwanda's mining sector started in the early 1930s, since then the sector has undergone different changes these days It's the second-largest export revenue earning from the mining sector. In 2017, the mining sector generated about $373.4 Million only from exports [1]. The major mineral resources in Rwanda are Cassiterite, Coltan, wolfram, peat (which can be used in the generation of electricity and used as an alternative for firewood after procession), gold, and Nickel. In different regions of the country, there are also precious stones including amphibolite, granites, quartzite, volcanic rocks, clay, sand, and gravel. The country nowadays is producing in-between 8,000 and 9,000 tons of mineral compounds yearly, the money generated depends on the recent prices on the world market dynamics. One of the more powerful mining regions in Rwanda is Rutongo Mines. It is one of the biggest cassiterite deposits in Africa. Rutongo underground mining for tin miners recently is eight mine shafts where they are using different techniques i.e.; blasting, and drilling conventionally. The process of extracting ore is manually done, underground trains, bobcat loaders, and onsite excavators are mostly used recently [1].

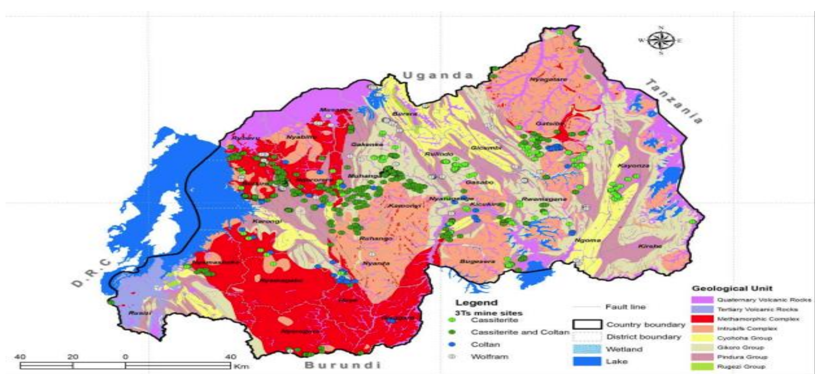

Figure 1-1. Map of Rwanda with Main Mining Regions areas

Today, Rwanda is considered the world's largest among the producers of different minerals i.e.; tungsten, tantalum, and tin, and gold and gemstones are considered as Rwandan exports. The mining sector of Rwanda has also many other minerals like coltan, cassiterites, limestone, talcum, wolfram, and granites. The figure below represents Rwanda most exported and produced minerals;

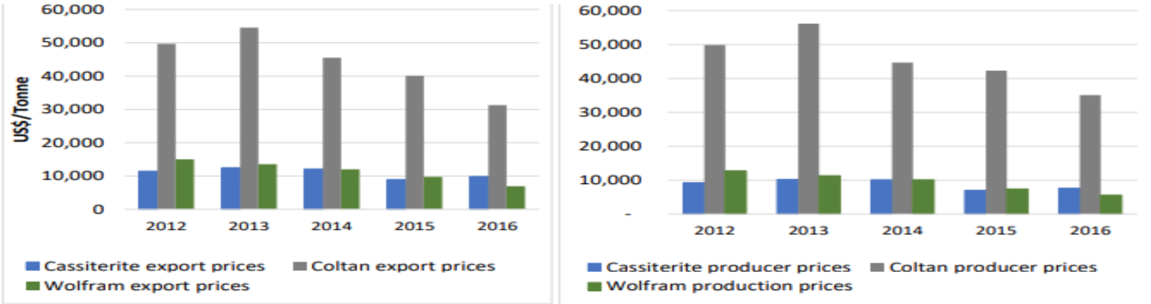

Figure 1-2:Graphs showing both most produced and exported mineral

1.1.1Internet of Things (IoT) in Mining

Internet of Things (IoT) extends Internet connectivity to physical various devices, and object on an everyday basis. It is always embedded with different electronic components, network connectivity, and many other devices which are in form of; where the devices interact and communicate with different other devices via the network connectivity, they are always controlled and monitored remotely. In the mining industry, IoT has become a means of safety improvements, for minimum cost optimization, productivity, and various artificial intelligence needs for mining development [3]. It has been considered a very useful tool and technique that brings a lot of different very large companies in various countries of mining that are used in evaluating, planning, and digitalizing very large industries in the mining sector for efficient managing day to day site operations. IoT in mining ensures mines, miners, and various equipment's safety. Different technologies in IoT are used for monitoring, and prevention of different hazardous events like gas leakages, falling of cave-ins, and rapid changes of humidity and temperature in underground mines. IoT real-time monitoring and reporting systems enable reliable, fast, and very convenient rescues, support, and evacuations in mines.[2]

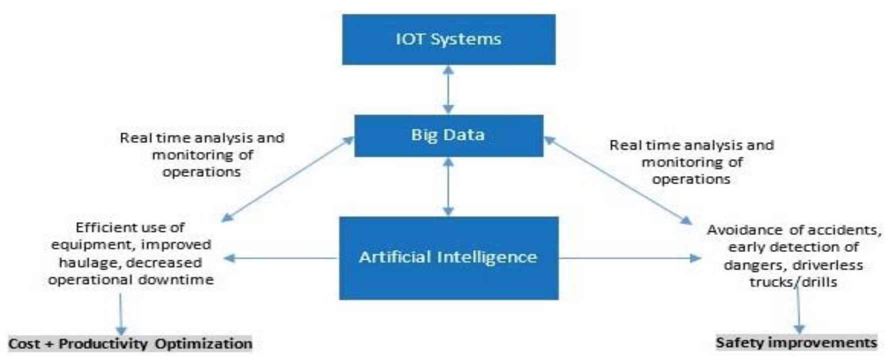

Figure 1-3: Showing the relationship between IoT and Mining

1.1.2. Moving from Preventive to Predictive

The mining sector for the fast and improved decision-making always undergoes numerous emergencies in an hour with a high-level degree of unpredictability. Internet of Things (IoT) is very helpful for balancing different mine situations, for decision making in situations where different and several aspects that are enabled active as the same as changing from everyday operations to different algorithms. IoT in the mining industry plays a big role as the underlying system that facilitates the use of machine learning. Machine learning enhances IoT solutions in the means for operation streamlining, processing, improving safety from preventive to predictive, and cost reduction in the sector of the mining industry.[3] Machine learning has enabled various predictive models, it enables various companies in the mining sector to the improvement of processing methods via more accurate techniques that are less environmental damage. Machine learning is efficiently used for truck and drill automation, which offers significant cost-effective and safety benefits to mines, and miners[4]

1.2 Background and Motivation

For years now, the prevention of accident schemes, growing safety regulations, and the development of mining vehicles and machinery have made the mining industry a much safer industry. Improved IoT engineering, as well as processes, have reduced the risk incidence of underground mining, namely; floods, mine walls exploding, dangerous gas leaks, and various unfinished accidents. That is why safety is a priority in mining areas because mining is a dangerous physical activity. Apart from flooding and cave falling, miners face other dangers, especially when underground. There is a risk of gas explosions, chemical leaks, and rapid changes in temperature and humidity. The miner's health may suffer as a result of exposure to dust, radon, fumes, mercury, noise, and expensive injuries resulting from falls or heavy labor. The Smart Miner Helmet is as powerful as a smartphone, but its unique design accepts a combination of additional sensors suitable for different mines. The helmet detects hazardous gas leaks and rapid temperature changes in mines[5].

According to Ali Gul (2011),[6] A graduate of the Balochistan University of Information Technology, Engineering and Management Sciences, Quetta, recently won the first prize at last year's project competition held under the auspices of the National Grassroots ICT Research Initiative, created by the National ICT R&D department of IT. “They proposed a smart helmet for detection, monitoring, and provision earlier warning for various range of gas leakages, location, monitoring miner’s health, rapid change of humidity, and temperature. Based on ZigBee [7] A low-cost wireless network protocol used to control and monitor applications, a helmet, which acts as a mobile node, transmits data to a central station that helps to evacuate in case of dangerous situations within the mine. The personal incident fueled the idea of helping coal miners. Ali Gul's older brother, who was a coal miner at the time, had an accident in 2011 inside the mine but fortunately received support. In 2012, Ali Gul enrolled in the department of computer engineering at Balochistan University and in his final year came up with the idea of designing a smart hat based on the technology.

According to Yeanjae Kim, Jieun Baek, and Yosoon Choi, students of the Department of Energy Engineering, Pukyong National University, Busan 48513, Korea; A wearable safety helmet based on the proximity warning system was proposed and upgraded to prevent miners' collisions with mining equipment underground mines.[8]. The helmet designed for mines had to be used to detect Bluetooth signals attached to mines, cars, and hazardous areas of the mines, providing visible LED signals to miners and local workers simultaneously. Performance tests were performed at the underground limestone mines. It was confirmed that as the transmission capacity of the Bluetooth backup increases, the Bluetooth signal low power (BLE) signal distance also increases. The average BLE signal acquisition was 15m, regardless of the angle the hat was facing. For future work, they have proposed a distance-based smart helmet and personal PWS that can be added to additional sensors using small control boards. [9]. The suggested gas leakage sensors i.e.; carbon monoxide, heart pulse sensors, temperature, humidity, and air quality sensors, and sensors for checking the worker conditions i.e.; alcohol sensors an alcohol sensor a warning system of miners in case of hazardous situations, rapid changes of temperature, and humidity including the monitoring system. Then the procedures for miner rescue and safety should be followed urgently.

According to Cai Jianjun, the Chief Engineer of Shanxi Administrating of Coal Mine Safety, "Their primary goal was to achieve none deaths in the coal mines They had hoped to achieve that in every coal mine across their country." China's 5,800 Coal miners supply power stations with more than half of the annual 3.68 billion tons of row Coal produced nationally, generating 7.1 trillion kWh of electricity.[10] Given the quality of the coal mining industry, creating a smart, efficient, safe, and clean working model is essential. Improvements have already been made to Shanxi miners when it comes to the environment. Today, coal is transported from forested areas through enclosed tunnels to coal-fired power plants, so as not to spill coal on the ground. Although coal mining sites are located in shady forests and the environment is cleaner than before, the problem of safety remains. Empowered by big data and AI, Huawei's Mine Brain solution can improve the safety of coal miners by improving the working environment and efficient steering. This can be changed in the event of an accident. Where it has the capabilities to report any unsafe behavior undermines the site monitoring and reporting system, where it can provide warnings to miners underground. The solution of Mine Brain could be of use for protection miners, it identifies the workplace changes and the environment, in general, [11]. It can identify un safety scenarios like warnings through broadcast systems. This system that was generated was mainly used for record generation in mines, future accidents review for assessing the mining environment safety. This computer vision meant that mining safety didn't rely on human beings. Through the identification of coal belts, deviation of belts, alerts that are remotely carried out which can be an issue in the control system of the coal mine belt control for the shutdowns," says Zhao. "My Brain is of great help in identification the management absence for the site inspection, provision site daily reports and records for future assessments." [12]They had a belief that the appropriate coal data created and promoted the coal mining site in terms of safety and these included worker violations sensing, generation of reports on certainties in violations, and in case it happened the alarm for protection was prompted. Mining included nationwide, including Shanxi, Inner Mongolia, and Anhui, the Mine Brain system had been assigned various functions including gas extraction and their operating system had changed from degradation to the surrounding area. Using Artificial Intelligence and data from the mining area, they suggest that it should move away from sound and vision to different hearing capabilities based on various IoT technologies to create routes to intelligent robots. Cai Jianjun, Chief Engineer of the Shanxi Administration of Coal Mine Safety, hopes that Huawei will continue to invest in Artificial Intelligence coal mining applications to eliminate mine deaths.[12]

According to Ghulam Mehdi Bhutto; Jawaid Daudpotoa and Izhar Mithal Jiskanib from Mechatronics Laboratory, Mehran University of Engineering and Technology, Jamshoro, Pakistan and Balochistan University of Information Technology, Engineering and Management Sciences, Quetta, in Pakistan, IoT introduces a reliable, efficient, and cost-effective system. which was used to monitor air quality and many additional features for pollution testing and forecast testing in mining industry.;[13] The underground coal mines for mineworkers had many challenging tasks for years. There were many both non-fatal and fatal accidents that happened in underground mines worldwide that resulted in many causalities of different body parts and life losses. Due to lack of mining site surveillances of both miners and different several types of equipment which can collide and cause several accidents which lead to death. Their study led to the development of safe wearable devices which consisted of various gas sensors, humidity and temperature for rapid change detection, and ultrasonic sensors. The gas sensor detected Methane, Carbon monoxide monoxide, and used the ultrasonic sensor to measure the distance between the miner and the working machine. The device triggered and made the alarm when the measured values exceed set threshold limit values. From their results that achieved, they concluded that the device worked efficiently by triggering an alarm when it detected the concentration of CH_4 and CO that exceeded threshold limit values of temperature and humidity.[14] The device also was used to detect vehicles that were at a certain distance close to the coal miners in slightly very few distances of 5 meters. It had the capabilities of differentiating miners to mining vehicles to avoid uncertainties.

According to Tarek Eldemerdash, Raed Abdulla, Vikneswary Jayapal, Chandrasekharan Nataraj, and Mayhem K. Abbas of the School of Engineering, Asia Pacific University of Technology and Innovation (APU), Kuala Lumpur, I -Malaysia Faculty of Science & Information Technology, University Technology PETRONAS, Malaysia; the mining environment, is a very noisy industrial area. The main objective of their research project was to develop and design a smart hat application system for the mining industry. they developed and designed a system to monitor hazardous events such as temperature, humidity, gas, miner's protective helmet, and damage to the mining helmet. They completed their design and developed a realistic exploration of the GuaTempurung cave in Gopeng, Malaysia. . The power they use for the circuit system circuit design has been assessed based on previous work consultations. Problem-solving strategies and programs are used in two phases; i.e.; part of the helmet, and part of the control room. Their implementation design aimed to reduce dangerous gases and noisy environments which they achieved by implementing the solenoid valve that worked as flow control to the tank of oxygen. All oxygen tanks come with a prefixed valve that sated the threshold pressure and the set was always open at the minimum working pressure. By monitoring the hazardous gas in terms of LPG, CO and Smoke the microcontroller was used to detect the high threshold gas to operate the valve or not. The system design resulted in miner safety before the gas concentration increased even more which could lead to leakages.[16] The power consumption of the system was evaluated which can be a very good factor to save energy by using the sleep mode of XBee. As it was considered to save twice the time of the battery life. As the power consumption of SHS during Transmission mode. The proposed improvements on designing and monitoring systems with real-time data to be viewed and checked in the control room.

According to Puja G. Panchbuddhe1, and his assistant Prof. T. Pathan PG. Student, Department of Electronics Engineering and Communication, Priyadarshini Bhagwati College of Engineering, Nagpur, Maharashtra, India, and Assistant Professor, Department of Engineering and Communications, Priyadarshini Bhagwati College of Engineering, Nagpur, Maharashtra, -India; they developed a smart helmet model for helping both miner supervisors and workers in the industry of mining sector. In their research, they found and discovered that at the mining site many dangerous events are harmful to mineworkers because they lead to life losses and unexpected deaths. They also discovered that at the site they mostly use helmets but, in their discoveries, they found that it doesn't provide all the necessary safety to miners but a few of them. But also found that by the use of sensors the smart helmet can be used in mining sites. Where the gas sensors detect dangerous and harmful gases like carbon monoxide, methane, Liquified Petroleum Gas, and natural gases when added to the helmet[14][17]. Adding other sensors for detecting nearby obstacles was also done. Their system transmitted data wirelessly through radiofrequency. They designed the helmet in a way that all the sensors installed on it had a certain critical value, when the value reached automatically the buzzer would switch on alerting the miners and their supervisor for prevention of certain. For future improvement; they suggested that a real-time monitoring system and data awareness system be developed to detect dangerous incidents such as the presence of dangerous gases, removal of helmets by a miner, and heavy objects that fall on the miner's head and send reputable information to the reception section. Therefore, rescue work can be done, and addition of devices for checking miners' blood pressure and heartbeat rates[8].

According to Sweater. B, Bhavya Shree. R, Disha. K. V3 from the Department of Information Science and Engineering Raja Rajeswari College of Engineering, Bengaluru, Karnataka, India; makes Smart Helmet able to detect dangerous events in both the mining industry and road accidents. Concerning their development of helmets, they have considered three main types of hazards Air Quality, Helmet Removal, and Obstacle barrier.[18] Here, the designer helmet may be used for a variety of road accident sets. Suppose, for example, that they suggest that when a passenger wearing a smart helmet becomes dangerous, warning messages can be sent to the recipients (using GSM). Then in the mining area, in the event of any dangerous situation, the buzzer triggers an alarm placed on the hat, which transmits information directly to the control room via a Zigbee trans-receiver so that miners/passengers have a chance to save. their lives from extraordinary events. In their research, they suggested that a few aspects of the system could be improved. Like; The addition of an external pole could extend the range or improve signal strength to allow for further human disturbance, although the distance is limited as it would be impossible to warn miners too far away to find a mining worker experiencing a dangerous event, they suggest. that the processing speed of the system can be improved to measure accuracy with an accelerometer, they said in their study to improve the IR sensor mounted on their protective helmet so as not to cause it.[18] Effective communication nodes in the control room where they propose stationary nodes are designed to jump only on any signal received. The system can be improved by adding measuring devices to check the miner's blood pressure and heart rate. The concentration of gas can also be measured. In the future, it may also be considered whether such modules could be used for secondary services, such as local staffing-related work.

According to S. Kesavan, Balaji, Shivashankar, Yogeshwar from the Department of Electronics & Instrumentation Engineering, Mahendra Engineering College, Namakkal in 2017; They proposed paintings on protection helmets which turned into used to keep away from the injuries at the mining website online administrative center. They determined to apply a helmet that helped maintenance of the safety of the miner workers and all of the operations performed at the websites. The mining website supervisors may want to monitor all diverse activities completed on the websites. The helmet had GPS for localization of the miner and picking out those who are not energetic. Their smart mining helmet became advanced to come across three styles of hazardous occasions i.e.; unsafe gases gangers, miner helmet putting off, and region of miners. Dangerous times are labeled as a mining operation that removes the mine hat off his head. Another dangerous incident has been described as an incident where miners were hit by heavy gadgets [19]. They proposed that machines can be progressed inside the future stepped forward with the aid of adding gadgets for measuring and checking miners' helmet removal and their place within the tunnel. Also measuring the concentration of gases in case of a volatile situation in the mine, the buzzer on the helmet signals the management room. For rescuing techniques from risky events. They proposed to introduce flexible electronics to improve the sustainability of the circuit part from physical harm in the future.[20]

According to C. J. Behr, A. Kumar, and G.P. Hancke from the Department of Electrical, Electrical, and University of Computer Engineering of South Africa from Pretoria, developed a smart helmet that became designed to come across unsafe occasions in the mines of South Africa industry. In their helmet development, they took into consideration different primary types of hazards managed including air great, helmet elimination, and collision (when miners are struck via very heavy objects). In their studies at the start, they worked on awareness of gasoline degrees of hazardous gases i.e.; carbon monoxide, sulfide, nitrous gases, and different mine situations[21]. A dangerous incident was the disassembly of the helmet when the infrared sensor developed unsuccessfully but the IR sensor outside the shelf was then used to cut properly while the helmet was turned on. An unsafe incident was described as an incident where miners were caught using heavy loads on their heads at a cost exceeding a thousand dollars in the Conditions for Head Injuries. They used an accelerometer to measure the top speed and Conditions for Head Injuries to calculate software usage. However, their use was unsuccessful, the most powerful test measuring accelerometer was a very simple success. They have observed that some mechanical features may be advanced and that the addition of an external antenna may increase the width or improve the signal strength to allow for further human interference.[22][23]

Mining in East Africa performs a big function in the latest economic system, in which many mining groups find it easy to apply the new technology as they're becoming extra famous and inexpensive. As a result, the mining enterprise gamers access possibilities to reduce the price of production and increase performance in their strategies. This enables them to resist the volatile commodity markets. The companies have implemented various new technology within the marketplace, together with the use of sensors, drones, automated trucks, and different machines, which have been confirmed commercially possible. Automation reduces manufacturing expenses and will increase efficiency and productiveness. In recent years mining become carried out historically, technological improvements have revolutionized the enterprise in numerous methods. In particular, there's accelerated automation, using machine studying and Artificial Intelligence, and widespread digitization of the tactics concerned. Although the development and usage of the new technology create a large fine effect inside the mining enterprise; challenges nonetheless exist in mitigating the negative outcomes of implementing today's technologies.[24]

Though many East African countries have not yet adopted IOT more especially in the mining sector as the use of smart miner helmets some of them are adapting;

In Kenya, the IoT was used to design a smart helmet monitoring system that continuously monitors dangerous events such as temperature, humidity, gas, miner's protective helmet, and damage to the helmet. The design of the IoT alert and the helmet that detects hazardous events was developed and enhanced by actual environmental testing with alerts and awareness messages to management and miners in the mining industry in the country[25]

According to **RWANDA MINES, PETROLEUM AND GAS BOARD(RMB)**, the government organization which is responsible for initiating and advising the government of Rwanda on various matters of national policies, strategies, and laws related to minerals, petroleum, and gases., that is mandated to coordinate and monitor all the start-up strategies related to the mining industry, petroleum, and gases,

The RMB states that in Rwanda recently mining process has been a dangerous job to carry out because of many concurrence deaths that have happened due to the cave explosions, floods, inefficiency communication between miners in the tunnel and their field supervisors, and many of miners don't always remember to wear the protective clothes and helmets, there's no appropriate way of monitoring mine activities and all these have caused loss of miner' lives moreover in Rwanda the miner's health is one of the important considerations in mining industry. [26]

However, In Rwanda, the core control algorithms that use IoT technologies have not been applied in mines yet that is why as an IOT student from the University of Rwanda decided to come up with a solution of **Smart Miner Helmet and Monitoring System** prototype that will assist both miners and field supervisors in the Mining Processing to identify Level gases, humidity, and temperature, an alert miner in case of danger like falling of caves, unnecessary removal of the helmet but facilitate efficient communication between the Miner inside the tunnel and the field supervisor. Based on this system **Smart Miner Helmet and Monitoring System** gas levels are the very important parameters when it comes to the miner life underground, and humidity and temperature parameters, this real-time system alerts both the field administrator and the miners underground in case of any emergency according to the measurements taken, it sends data to cloud network and any rescue or support will be given accordingly.

1.2.1 Definition of technical terms

The system is developed in three main sections. Where the first section is the helmet section used for Sensor networks connected with NRF 24l01module, Temperature, humidity, IR, Pressure, and gas sensors to sense the environmental events and button indicator to display the danger status of the minor.

The second part is the fixed part inside the mining tunnel which has sensors i.e., DHT11, MQ7, MQ135, BMP280, Buzzer, NRF Module, and Ethernet Shield and the third part is the Monitoring part. GPS technologies connect them to a remote server using a GSM/GPRS technology integrated with a microcontroller;

IR (infrared) sensor is an electronic tool used to detect certain local features. IR works with the help of emitting or receiving infrared radiation [27]

NRF24 Module an integrated, ultra-low-power of 2Mbps RF transceiver IC for 2.4GHz Industrial, Scientific, and Medical band. It is used on a variety of applications that require wireless control. They are transceivers which means that each module can transmit and receive data.[28]

GENERAL PACKET RADIO SERVICE is a communication device that assists information packets. It allows an uninterrupted flow of IP data packets over mobile applications such as Internet browsing and document transfer.[29]

Arduino Mega: This is an Arduino open-source software that makes it easy to write codes and get them on the board.[30]

Ethernet Shield: This lets in network connectivity to the Arduino board by using its Ethernet library**.**[31]

GSM: This is a communication system that is currently applied by various people worldwide. It compiles data and sends it down through a channel with other consumer information streams, each in its own time. Works at 900 megahertz (MHz) or 1,800 MHz frequency bands[32]

1.3 Problem Statement

Along with several researchers, it is discovered that mining currently is regarded as a very difficult, dangerous, and sensitive activity among all other income-earning activities worldwide, this is due to very harsh underground conditions miners or mine workers face during the mining process. Miners are encounter different worse conditions such as; hazardous gases like carbon monoxide, carbon dioxide, nitrous gases, sulfur dioxide, different tunnel pollutants, rapid changes in temperature, humidity, moisture, airflow, and many different hazards such as hoving particles mainly destroy the miners' heads. Whenever a miners' life is exposed to all the mentioned poisonous gases, rapid change of temperature and humidity, rapid obstacle hit on the head for an extended period, it usually results in bodily harm and unexpected deaths. The above dangers aren't detectable without facilities; unappropriated airflow in underground mines causes temperature and humidity to rise, resulting in decreased reliability throughout the production process; because of the weight, warmth, and inconveniency of protection gadgets many miners avoid taking them putting their lives in serious dangers; monitoring of the mining environment and people's health is considered the main problem in the mining industry to be addressed.

Today Rwanda mainly at Rutongo mines is facing all the above-mentioned problems and many numerous accidents occurring due to inefficient communication between miners inside and outside the mining tunnels, rise in humidity and temperature, and different hazardous toxic gases which have led to frequent death due to failure to report their occurrence on time.

1.3.1 Novelty

This research study focused mainly on the monitoring, and efficient communication processes of the mining environment between the miners in the tunnel and their field supervisors. In this way the gas status, rapid temperature/humidity changes, colliding with the heavy underground obstacles, all will be notified by both the miners and their field supervisor before damaging miners' lives. The miners, supervisors, and the government body in charge of mining will all benefit equally from the research project. The mining tunnel status before and when mining processes are ongoing, and miners' health monitoring are the critical aspects in this project research. Machine learning algorithms for classification, where logistic regression, K-Nearest Neighbors Algorithm for classification, and Decision Tree for classification are used. The results are compared to check their performance.

1.4 Objectives

1.4.1 Main Objective

The goal of the dissertation project is to develop a system that will prevent and reduce the death and other hazardous events faced by the miner's underground mining tunnels.

1.4.2 Specific Objectives

1. To Monitor and notify the miner and field supervisor in the situation of risk and any hazardous events
2. To generate a dataset of data associated with the miner inside the mining tunnel.
3. To implement a Smart helmet, test and analyze data generated based on the level of gases, temperature, humidity measured by deployed sensors underground.

1.5. Research Questions to Consider

1. What will be the data set status while the miner is inside the mining tunnel?
2. What are the risk factors associated with the status of the miner inside the mining tunnel?
3. When to notify the miner and the field supervisor?

1.6. The Scope of the Research

1.6.1 Research Project Scope

This task will give attention to five essential elements which might be: sensing, communication, garage, tracking, and evaluation of generated data. On the sensing part, sensors on microcontrollers (the sensor deployed inside the underground website online and those on the helmet) which include MQ7, MQ135, DHT11 which are programmed to probe records within the mining website, the 2 microcontrollers have to speak to ensure switch facts from the helmet to the static microcontroller in the underground is a hit the NRF24L01 comes in to allow the communique among the two microcontrollers, after receiving and amassing records collectively with the microcontroller shops it inside the database; data has to be considered both thru the consumer interface or the cloud platform, the analyzed information will determine if the mine is safe for the mining procedure.

1.6.2 Geographical scope

The research mission is carried out in Kigali Province, Gasabo district, Rutongo location, within the tin mines. The Rutongo tin mines are placed about 26km north of the capital town of Kigali in Rwanda. It is located on the Rutongo anticline, bordered through the Yanza syncline to the west and the Nzoko-Rwamahili syncline to the east. The result of this design is the prototype on the way to help miners and their discipline managers in tracking, surveillance, and processing process, and their safety from toxic dangerous gases.

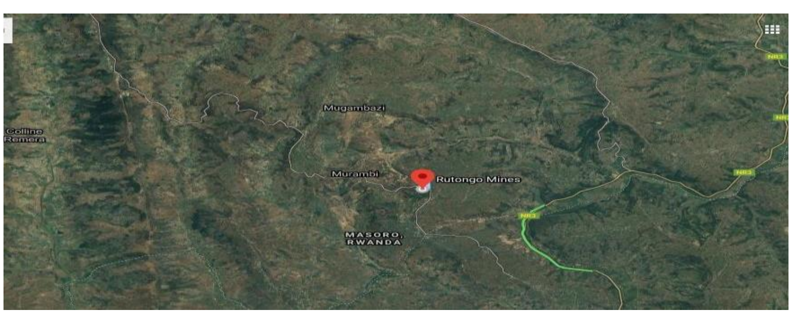

Figure 1-4: Geographical scope

1.7. Anticipated Outputs

The expected output of this study consists of but is not confined to the subsequent, IoT machine that is evolved and carried out to display the hazardous gases, changes in humidity/temperature tiers, set up efficient surveillance of mines, and green verbal exchange strategies among miners outside and inside the mining tunnel, tell a miner anyhow of helmet removal and colliding with protuberances within the tunnel. Developing and designing an IoT gadget may even assist in information evaluation of various parameters along with temperature, humidity, and risky gases like carbon dioxide, carbon monoxide, and nitrogen dioxide to assist to assess mine scenarios both when miners are interior or at the floor

1.8 Rationale and Significance of the Research

Rwanda Mines, Petroleum and Gas Board (RMB) has invested loads inside the mining industry however miners 'protection is still a completely big hassle in mines and this has caused unsightly production and, in that manner, Smart Miner Helmet and Monitoring System will enhance these subsequent:

Monitoring and Mine Surveillance: The mines are thoroughly monitored before anyone can enter due to the quantity of gas level, humidity, and temperature captured by sensors and analyzed, then the decision will be taken if safe to do the mining process

Communication: To efficiently smoothen the communication channel between miners and field supervisors effectively

Productivity and Quality: To increase the quantity and quality of output by a certain percentage due to safe mining conditions.

Hazard–risk recognition: Reduces various risks that can lead to life loss and uncertain deaths

Rescue: To give support to any miner who has experienced any problem immediately due to effective communication with the field administrator

Chapter 2 : LITERATURE REVIEW

2. Introduction

The chapter provides a high-level description of the present system, including how it operates, what parameters are used, and how the challenge was solved. Here we define and identify concepts and technologies that we will use in the system. As we are going to use different technologies as well as different technics, we have to describe them one by one according to their categories.

2.2 IoT overview

Karen and colleagues released "The Internet of Things: An Overview" in 2015. They defined the Internet of Things as an emerging topic of technical, social, and economic importance in their document. Consumer items, durable goods, automobiles and trucks, industrial and utility components, sensors, and other ordinary objects are being integrated with Internet connectivity and powerful data analysis capabilities to alter the way we work, live, and play. They went on to say that the impact of IoT on the Internet and economy will be enormous by 2025, with some forecasting as many as 100 billion connected IoT devices and a global economic impact of more than $11 trillion.

At the same time, they voiced serious concerns about the IoT technology, which might prevent it from attaining its full potential. From several viewpoints, emerging IoT involves a vast collection of complicated and interwoven concepts.[34].

IoT emerged as a vital topic inside the technology sector, policy circles, and engineering circles, and it has made headlines in both the trade and popular press. This technology is embodied in a diverse range of networked devices, systems, and sensors that take advantage of advances in processing power, electronics downsizing, and network linkages to provide previously unattainable capabilities[34].

IoT on the other side, as defined by Xiaoli Jia et al. a global network architecture connecting hardware and software entities through the use of capturing data and interconnection. That will provide particular item recognition, sensor, and connectivity abilities as that of the platform of creation of self-contained cooperation applications and systems. Independent big data, event transfer, networking capabilities, including compatibility would all be the main aspects. Through 2025.[33] Simultaneously, it presented significant challenges for IoT., which might prevent us from fully understanding its capabilities. That brings together a diverse group of different thoughts which are sophisticated as well as connected through multiple points of view. [34]**.**

2.3 IoT and Machine Learning

Artificial intelligence provides for the most appropriate decision in both basic and complicated circumstances. Deep learning has gained in popularity in the last few years, resulting in one of many new applications in a wide range of fields. During this time, there are progressively good alternatives capable of protecting laborers' health once they are subjected to elevated situations. As a result, within production, machine learning is used in conjunction with security precautions that establish the atmosphere that nurtures industrialization.[35]

IoT technology-aided advancements within Safety And health at work, enhancing safe operation. This implementation for IoT-based Standard Precautions minimizes the probability of occupational hazards by allowing such gadgets could decide based on environmental factors. Using Industrial IoT with Machine Learning enables the generation of Protective designs and the creation of equipment with much more additional features including management, surveillance, and vulnerability analysis, amongst many Such prototypes, regularly review the overall working environment and alert workers and its managers either irregularities or concerns. An intelligent headgear concept presented in their research checks all circumstances in the employees' vicinity & conducts an acceptable danger assessment. For analysis, the data acquired by sensors is transmitted to an AI-driven platform. [36]

2.4 Related work

According to Kim, Jien Baek, and Choi from the Energy department of Resource Engineering, from the National University of Pukyong in Busan, Korea.[8]. These researchers in their paper presented an Intelligent Head Protective using the Personnel Proximity Warning System for improving safety in the underground and for prevention of devices and mining vehicle collisions.

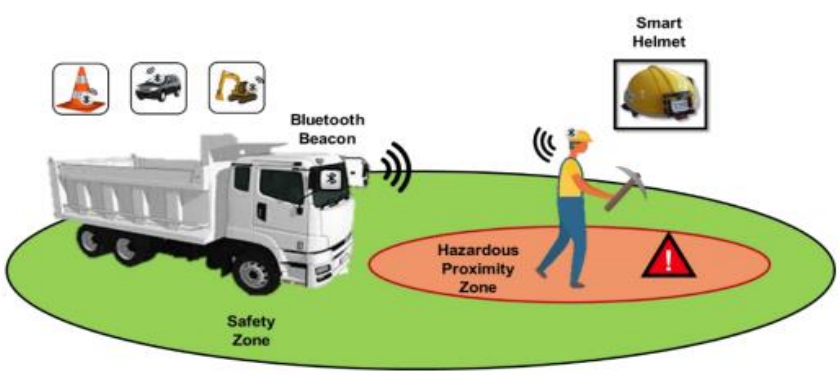

Figure 2-1Figure 2-2: An overview of the Intelligent Helmet using PWS

This Intelligent headgear was originally supposed to be taken by n miners to receive information from Bluetooth transmitters connected to machinery, vehicles, or risky areas, and also to deliver graphic Led notifications to miners and controllers at the same time. This same intelligent head hat- PSW is given adequate closeness alerting notifications to either the manufacturing engineer as well as miners and in their research, they suggested that more sensors should be added to the Arduino board for expansion in providing work status surveillances and risk analysis functionalities. This is what my research project will mainly focus on well as suitable communication between mine workers' tunnel and their managers at the ground.

According to You, Yang, and Ruisong from the School of Communication and Electrical from China Beijing Jiaotong University's in August 2015[36] During their study, researchers presented Video Collaborative Localization of a miner's lamp for coal mines using Wireless Multimedia Sensor Networks. They looked mainly at WIFI that can be of use in the coal mines in the tunnel and the location of visual light for workers operating underground the tunnel. They were devised to identify miners in situations with insufficient brightness and split subsurface tube network

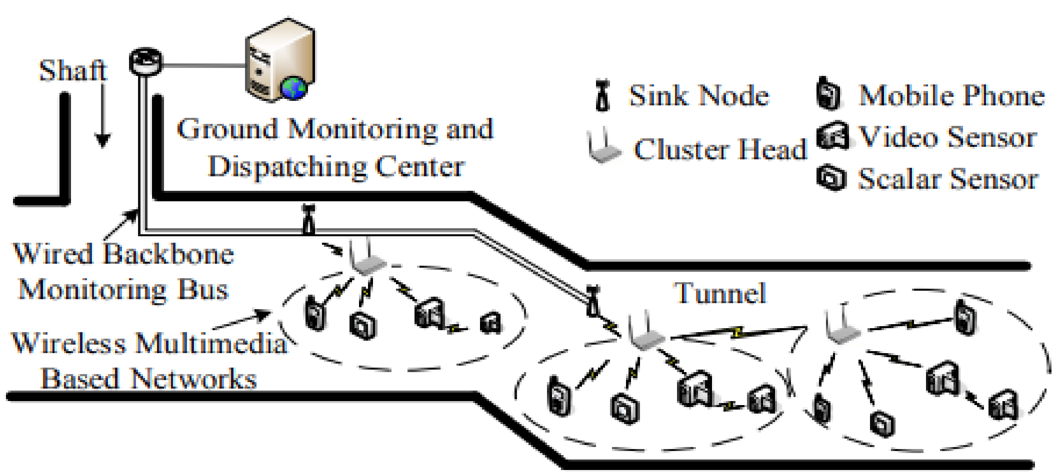

Figure 2-3: Wireless Multimedia Sensor Networks Architecture.

According to their paper, it is difficult to distinguish workers in subterranean tunnels caused by mining dust and insufficient illuminating, that's why miners bring lights to give auxiliary lighting fixtures in mines, which provide a sharp evaluation to the dull lineage. Researchers also stated that wirelessly multimodal sensor nodes will significantly improve the overall tracking performance of mining sites. A miner's lamp video collaborative localization algorithm was proposed based on WMSNs deployed within the underground mine to locate miners within the scene of bifurcated structures of the underground tunnel, but their paper failed to consider the safety of miners underground, whether they wore helmets or not, and the convenience of conversation among miners underground. [36]

According to Narasimha E, Kiran V1, and Shruthi Y of India from JNTUA University's in Brindavan Institute of Science and Technology, [37] In their paper, the researchers developed an Intelligent Hat for the coal mines using ZigBee Communication protocol according to the article they published. The Intelligent Hat has switched to ZigBee generation for tracking harmful gases, extreme temperature conditions, and humidity levels in the mining tunnels

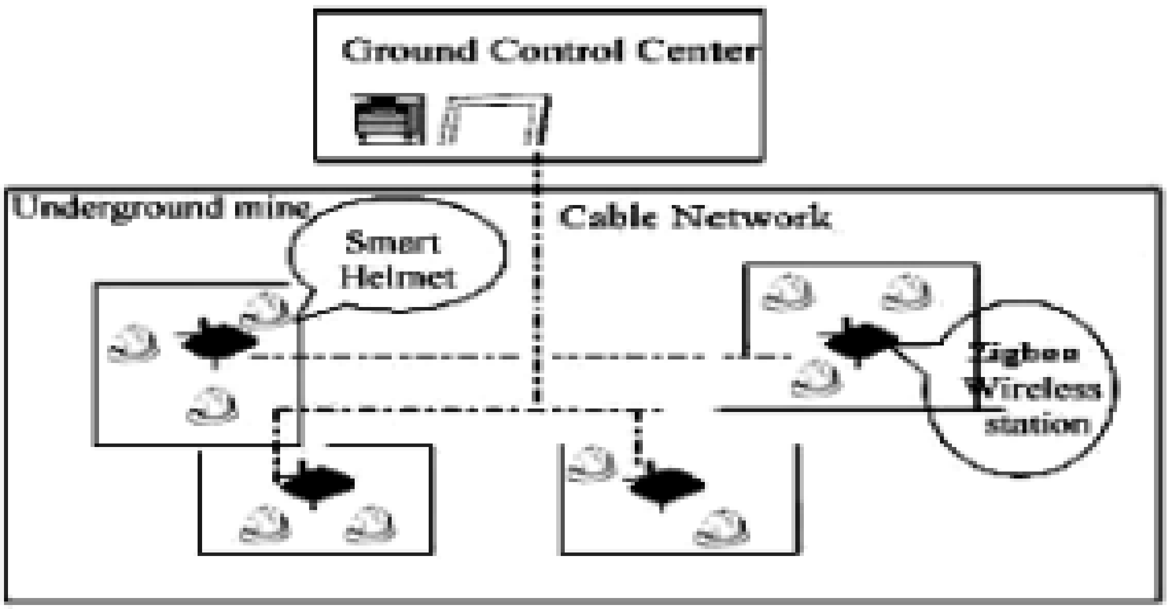

Figure 2-4: System Structure of ZigBee Communication

In their paper, the complete device consisted of the safety feature, WIFI terminals, as well as the usage of cables for the network which was part of their proposed system. The connector connecting Wireless connections and the ethernet cable is the base station of WIFI Miner's intelligent Hat, which is made up of a charging station, Lightbulb, plus the communication module of ZIGBEE, that is utilized as a cellular wi-fi sensor community node. The intelligent headgear gathered additional ingredients in real-time, then transmitted them to wireless base stations, and finally added the information to the ground management center via ethernet cable. They said that the advanced safety functions in their system dramatically improved the existence expectancy of the coal miners using alerting them to approximately risky gases. In their paintings they did not recall when the miner eliminates the helmet what could occur, the real-time conversation, the miner's lifestyles is in chance because of different hazards like falling of cava ins, hitting their head through robust obstacles and case of heart problems due to suffocation, and to know the repute of the mining tunnel before starting mining activities. All the above can be considered in my studies paper. [38]

According to Jagadeesh R and Dr. R. Nagaraja and M. Tech student, Computer Network Engineering, Dept. Of ISE, Bangalore Institute of Technology, Bangalore, Karnataka, in India and Professor and PG, In the year of 2017, the Director, in the department of ISE Bangalore in the Institute of Science and technology from India [39] In their paper, the researchers developed a prototype that can detect the high quality of air, temperature/humidity changes, unnecessary headgear removal, uncertainty hitter of obstacles. gasoline concentration in mines and carbon monoxide was their main target. The miner's helmet removal was likewise regarded as one of the vulnerable positions whereby the sensor used to detect it was Infrared. A pressure sensor was used to determine the impact of a heavy object on the miner's head

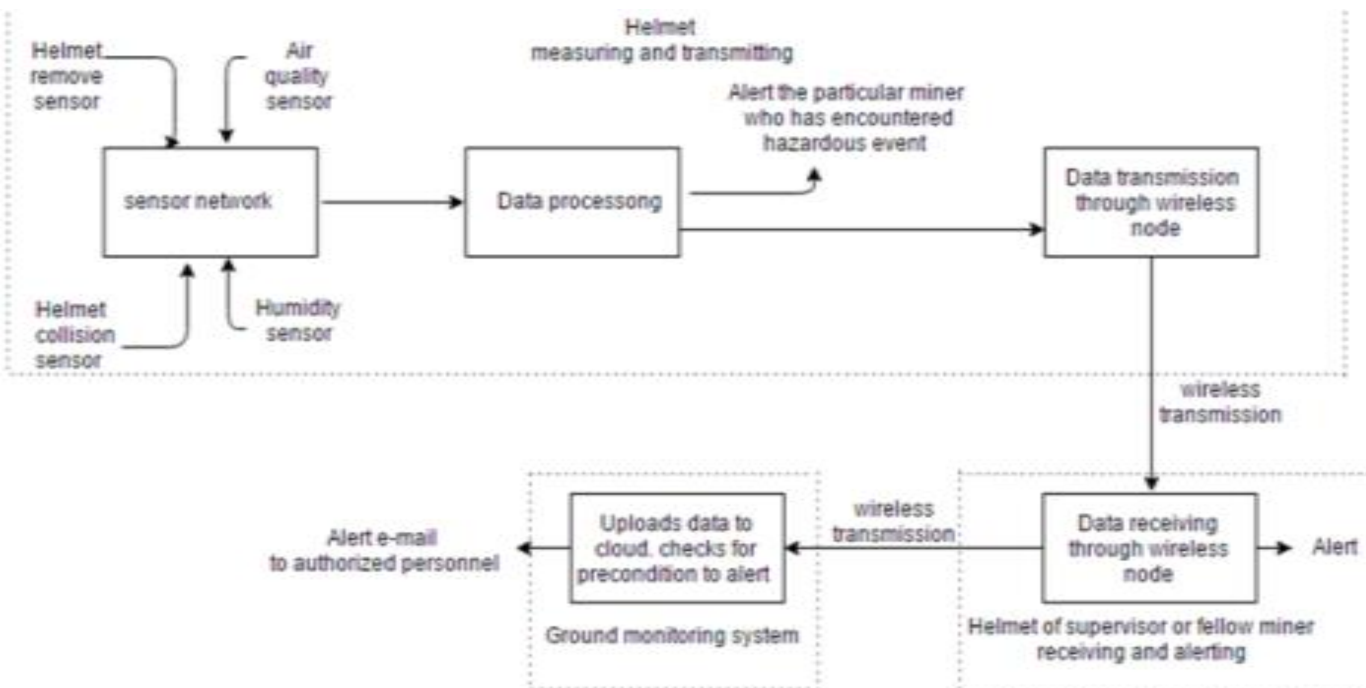

Figure 2-5: System Architecture Smart Helmet

In their paper, they proposed a machine structure that covered helmet sections and tracking sections. The helmet section consisted of sensor networks which covered fuel sensors for risky fuel detection where it detected carbon dioxide saturation, Infrared for noticing whether the miners are putting on their head protective gear or not, For the obstacle ls hitting miner head the pressure sensor was used. temperature/humidity sensors were used to know the mining tunnel status. They also covered the statistics processing module, which gathered the acquired records and notified the specific miner who had experienced the serious situation. They also used ZigBee to transmit records through the wireless node. They proposed that to improve their work their system may be more advantageous by using including greater measuring system to test the worker's heart charge and blood stress, they failed to give you the answer of understanding the mining scenario before the mining system begin, frequent tracking and surveillance of miners within the underground tunnel and, real-time conversation between miners underground and their supervisors at the floor. That's what we need to present as a solution within the studies work and consequently, all of the referred might be dealt with in this research project. [39]

2.5 Literature Gaps

The reasons for conducting more research on Smart helmet and monitoring systems in Rwanda are based on the existence of research gaps in the existing literature including;

Monitoring miners underground during the mining process and also knowing the mining tunnel status (gas levels, temperature, and Humidity) before anyone can enter was a very huge problem that led to several death, Communication barriers between miners in the Tunnel and those supervising them were also so difficult and this affected their work because those in danger couldn't ask for rescue in any case, the mining situation before the process begins also has to be known i.e.; hazardous gas leakage, humidity, and temperature changes. And finally, the dangers of a miner life in and out of the mines, which were caused by a variety of hazardous occurrences such as polluted air that can affect the miner's life, Protective hat removal, miner positioning, and humidity/temperature rapid changes in the mines,

Thus, coming up with a **low cost and effective Smart Miner Helmet and Monitoring System** to bridge all the above-mentioned gaps by providing effective communication to miners inside and outside mining tunnel, frequent monitoring of miners, change of humidity and temperature, gas leakages that can harm the miners' lives, unnecessarily removal of helmets, the collision of miners with hazards and using the panic switch which is on the helmet in case of any other emergency like panic attacks, underground animal problems, heart attacks and blood pressure in the underground tunnel, The System will also help the miner and their supervisor to know the tunnel situations before starting the mining processes.

The proposed system consists of three main parts; The Helmet to be worn by everyone inside the mine, the Fixed part underground and the monitoring section; The helmet probes all the data by all the sensors that are installed on it by NRFL01module they are transferred to the part in the tunnel, The GPRS serves as the link or gateway for data transferring to the cloud server then data can be viewed on the dashboard and GSM for transferring data to mobile devices. The data probed by sensors is finally analyzed using a classification machine-learning algorithm to predict the amount of temperature, humidity, and different changes of toxic and hazardous gases for safety in mines.

Chapter 3 : RESEARCH METHODOLOGY

3.1. Introduction

This section provides the outline of the research method that will be employed throughout the research project. It displays the various processes and procedures and the processes and procedures employed all through the research, as well as how the assessed findings were given. The majority of research approaches are scientific, however, because data analysis is a part of this study, there are approaches like quantitive and qualitative that were not considered. The research method used was the scientific method where different methods were employed.

3.2 Development Research Approaches

This part describes the overview of the research approaches and the steps involved in system development from the step of gathering the idea to the final step of prototype and getting the result.

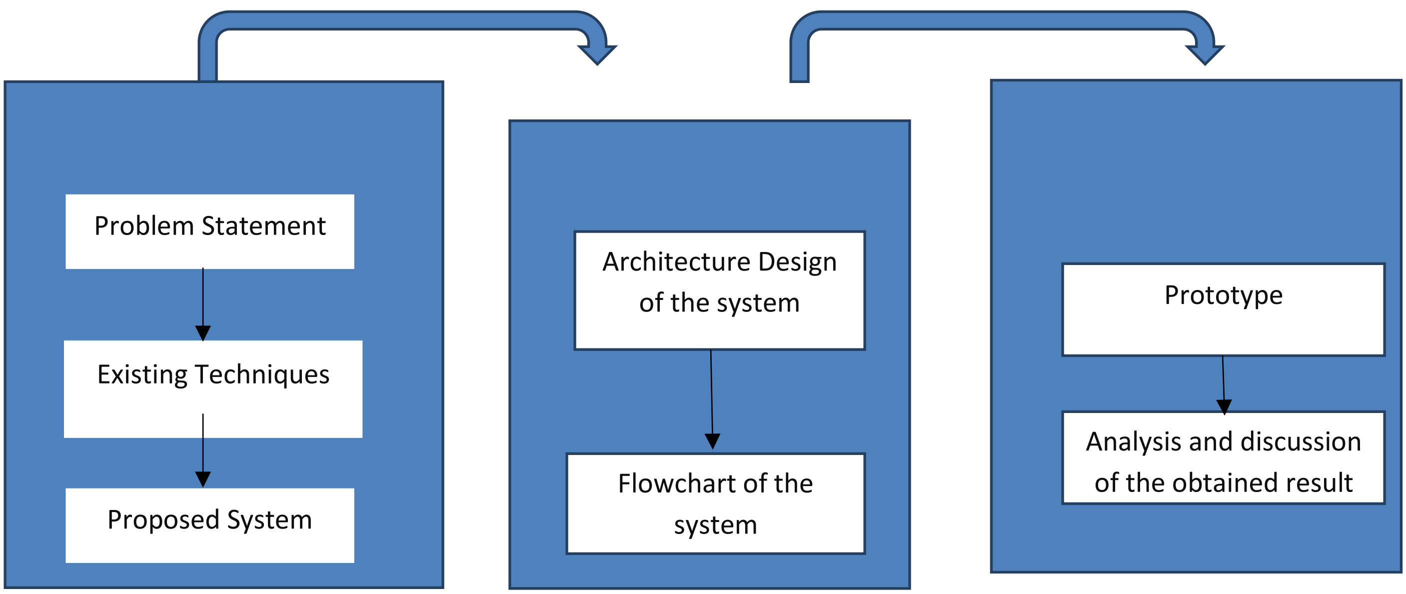

Figure 3-1: Development Research Approaches

3.3 System Development and Methodology

3.3.1Prototype Model

The prototype model is a system development that does not require freezing the requirement. A prototype acts as a sample to test the process. Prototyping allows the software designer and implementer to gain early input from users. The Prototyping model, a system development method (SDM) in which a project is developed, built, tested, and then repeated until it offers a valid final answer, was chosen as the study technique for this project.[40]

3.3.1.1Prototyping Model steps

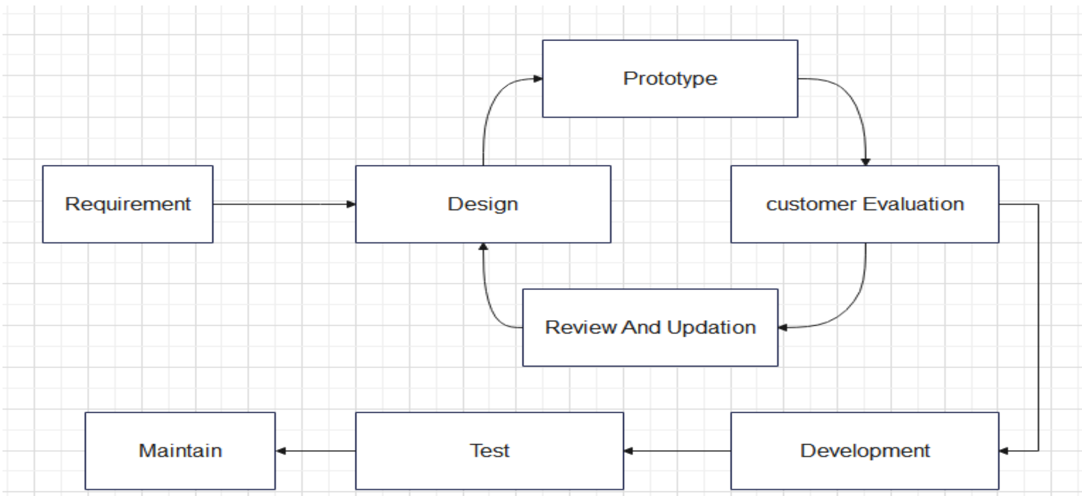

Figure 3-2: prototype model

1. **Initial Prerequisites:** Requirement analysis is the first step in a prototype model. The system's requirements are outlined in-depth at this phase. The miners and their supervisors are questioned to learn what they expect from the system as part of the process.
2. **Designing**: The second step is a tentative design after learning all of the criteria for the Smart Miner Helmet and Monitoring System. The system is designed in this stage using a simple design. It is not, however, a finished product. The users get a quick overview of the system. The prototype will benefit from the design.
3. **Prototyping:** This phase involves creating a real prototype based on the information acquired during the fast design phase. It's a scaled-down version of the system in question. This is also where the prototype's equipment will be kept. ESP8662, microcontroller, gas detector sensors, DHT11, actuators, LCD, gateway, cloud storage, and other accessories are included.

4. **Feedback from customers:** The proposed system is offered to the user for a preliminary assessment at this stage. It can assist in determining the working model's strengths and flaws. The developer receives the customer's feedback and suggestions.
5. **Evaluate and adjust:** If the user is unhappy with the existing design, all user input and state recommendations on the smart helmet are collected from the user and added to the project to improve it.
6. **Development**: In this phase, the designed prototype is coded, produced, and analyzed after the user has accepted the project successfully. Building code and connecting to devices are both included in this category. where the microcontroller will be connected to the underground section, and the command codes will allow us to see the result in real-time
7. **Test:** Testing a system following the development approach in which a prototype is produced, tested, and adjusted as needed until an acceptable result is obtained from which the whole system or product may be developed.
8. **Maintain**: The final system is thoroughly tested and deployed to production after being developed based on the final prototype. Routine maintenance is performed on the system to prevent large-scale failures and minimize downtime.

3.3.2 Methodology

The smart miner helmet consists of three main parts. The first is the IoT hardware component that builds the entire circuit. This part involves sensing components, data processing components, and actuators components. The second part consists of programming to make system hardware operational. The third part consists of data analysis. The analysis will be done using programming i.e., data cleaning, pre-processing, data visualization, and modeling the data using regression machine learning algorithms.

3.3.2.1 Hardware and Software Part:

This part of hardware and software has three main parts such as:

1. **Sensors and Actuators**: This part consists of all the tools used in this project. Including actuators used like the buzzer, the Arduino mega2560 helps us to program the embedded system. Including LCD, SPST switch**,** ESP 8266-01Emodule as a Wi-Fi module, and various sensors i.e.; MQ7, MQ135, DHT11, and Infrared sensor
2. **Data Processing:** All of the sensors on the helmet's microcontroller probe a specific gas level, temperature, and humidity changes, and any nearby impediment that could impact the miner, and

communicate data straight to the static microcontroller using NRF24L01. The ethernet cable is plugged into the ethernet shield, which is connected to the fixed component in the tunnel, and all probed data is delivered to the cloud for storage. The last phase is the control room monitoring, which occurs when a dangerous occurrence or a collapse occurs in the tunnel, and the miner wants to signal for assistance.

3. **Monitoring Section:** All probed data is sent to the cloud for storage through the GPRS as the gateway, data is monitored via the dashboard in the control room, and the GSM sends notifications to mobile phones of miners and field supervisors.

3.3.1.2 System block diagram

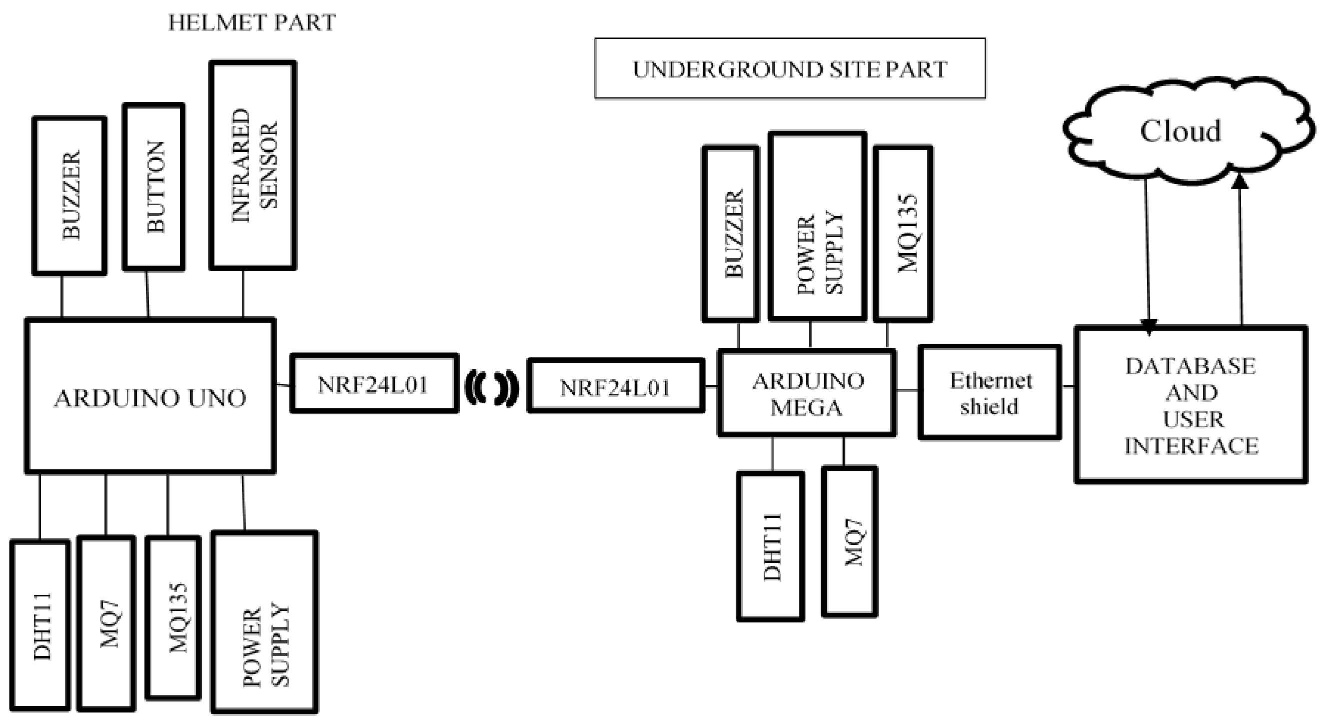

Figure 3-3: Block diagram

3.3.1.3 The explanation of the system block diagram

This initiative aims to give smart mine helmets and safety monitoring to the mining industry. We decided to design a monitoring system based on the challenges we faced and the research we conducted to assure real-time communication between those outside the mining tunnel and those inside the mining tunnel. The device can detect gas leakage both inside and outside the tunnel (before work), as well as changes in humidity and temperature, eliminating the need for miners to remove their helmets. For the safety of miners, this system will ensure that any dangerous occurrences caused by numerous parameters such as methane gas, carbon monoxide gas, temperature, and humidity are monitored. To probe the essential data, these sensors are installed in the miners' helmets and the permanent component underground. When any parameter exceeds a certain threshold value, a buzzer sounds to alert the miner. As a result, this system fulfills the role of miner safety monitoring and control. This aids in mapping the miner's present location across the mine. A panic/emergency button is also built into every miner helmet circuit. When tapped, an emergency sign regarding the miner emergency appears on the IoT web interface. This can be employed in a variety of situations, including hazardous gas inhalation, cave-ins, and physical injuries, among others. As a result, the system uses the IoT to safeguard the miners' lives who are inside the mining tunnels.

3.3.1.4 System algorithm description

The system consists of sensors installed on the microcontrollers of both the helmet and others fixed underground that probe certain level of gas and sense change in temperature and humidity in the mining environment, once there are perimeters probed by the fixed microcontroller which receive data from the microcontroller of the helmet then sends all data for both microcontrollers into the database using the ethernet cable that is plugged on ethernet shield, After getting the data into the database, an administrator can view and analyses data from the database and on the monitoring system. Once in the underground happens a hazardous event or a miner accidentally removes the helmet where miner wants to alert for support, he can alert by pressing the button on the helmet and at the same, the field supervisor from the control room gets notification via the system. When the level of gases reaches the danger level, the field administrator and miner in that particular tunnel are notified by the system and since some miners can't be aware since they are busy the field supervisor can start thinking of the supporting options to provide. On the monitoring part, there's a way of monitoring site data and when there is a high change in levels, he /she get notified easily.

3.3.1.5 System algorithm

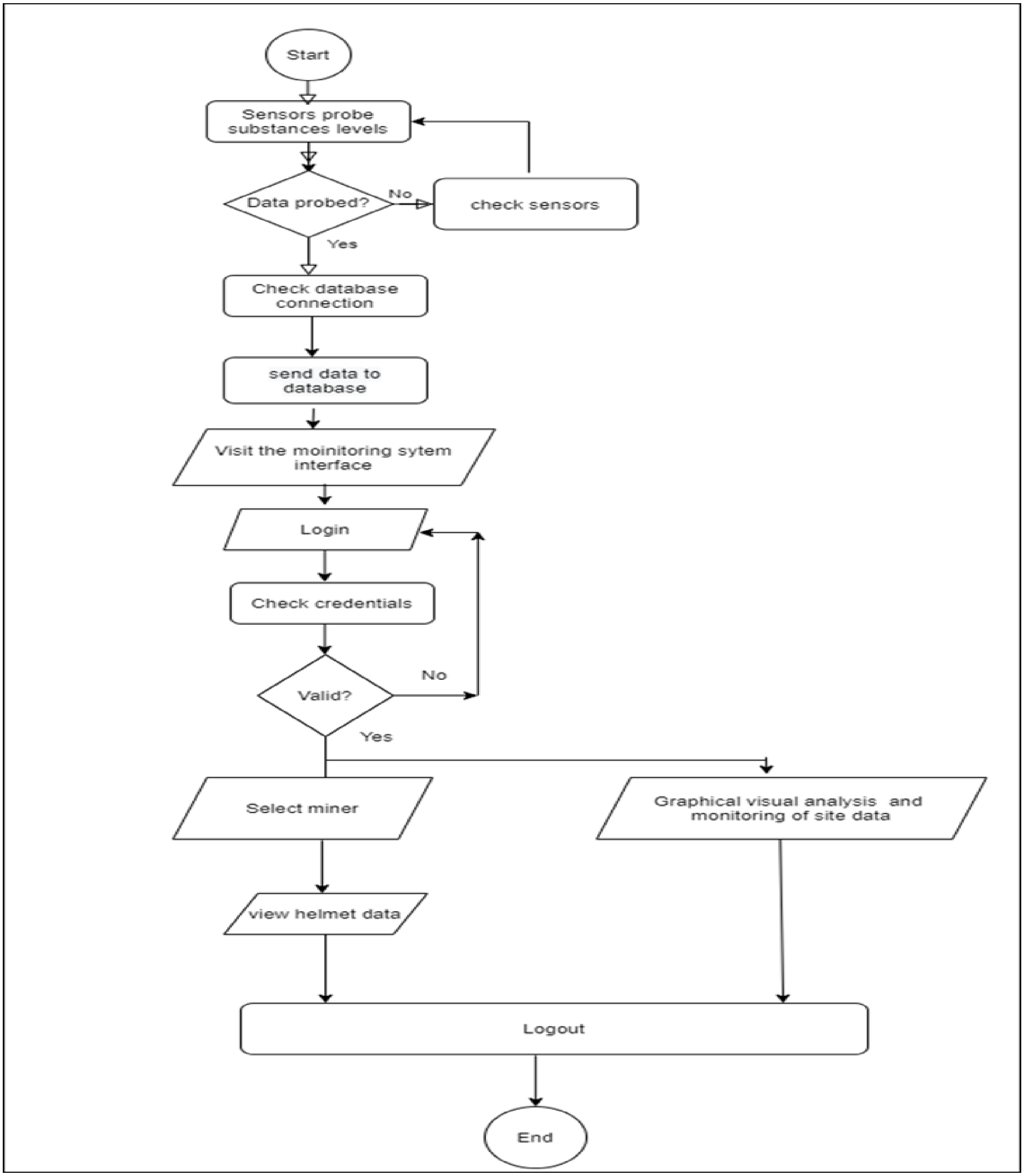

Figure 3-4: System Algorithm

3.3.2 Data Analysis and Machine Learning Algorithms

The system has the aim to develop a Smart Miner and Monitoring System that secures mines and miners in case of any hazardous events. i.e.; high gas levels, temperature and humidity changes, and falling off very heavy caves. The collected data have humidity, temperature, and gas levels as main characteristics to define the data.[41] The gas levels are the target variable for our data, it contains continuous numeric values which recalls the use of the regression machine learning method. The rest variables are the features. Although there are many machine learning algorithms for classification, we are proposing logistic regression, K-Nearest Neighbors Algorithm for classification, and Decision Tree for classification. Associated results will be compared to check their performance. On each of the above methods of machine learning, we will train, test, and evaluate the model.[42]

75 % of the dataset will be used in the training set, while the rest will be used in the testing set. The accuracy, Precision, and Recall will be used to assess the classification model that is used. The following paragraph contains the algorithm's description.

3.3.2.1 Logistic Regression: In the same way that linear regression finds an equation that predicts an outcome for a binary variable, Y, from one or more response variables, X, logistic regression finds an equation that predicts an outcome for a binary variable, Y, from one or more response variables, X. The response variables, unlike linear regression, can be categorical or continuous, as the model does not only require continuous data. [43]

3.3.2.2 K-Nearest Neighbors Algorithm for Classification: K-Nearest Neighbours is a handy but efficient system gaining knowledge of a set of rules used for powerful classifications in addition to regression. It is broadly for type prediction. KNN organizations data into coherent clusters or formerly skilled statistics. The input is assigned with which it shares the closest neighbors.[44]

3.3.2.3 Decision Tree for Classification: A decision tree is a classification algorithm that is expressed as a recursive division of the instance space. It is a tree that is created of nodes that make up a based tree, which is a driven tree with no incoming edges and a node labeled "roots." Each of the remaining nodes has one incoming edge. It is one of the most well-known approaches for representing classifiers in data classification.[45]

3.4 Research Tools & Techniques_ In-depth interviews

In-depth interviews were conducted as part of this study. Depth interviews are unstructured, intimate discussions to elicit feelings and thoughts, emotions, and opinions about a particular research topic. Personal interviews offer the primary advantage of providing personal and direct contact between interviewers and respondents, as well as the elimination of non-response costs; however, interviewers must have gained the necessary skills to conduct an interview efficiently. Furthermore, unstructured interviews allow for greater flexibility in terms of the interview's flow, allowing for the formation of conclusions that were not originally meant to be drawn about the study's topic. However, there's a chance the interview will stray from the study's stated objectives and goals. The research was conducted using a moderate questionnaire as far as records series tools were concerned, this was later used by the researcher as an interview guide. Some specific questions had been prepared to help the researcher steer the interview toward the satisfaction of the study's objectives, but other questions arose throughout the interviews.

3.5 Proposed system requirements

3.5.1 Functional requirements

Functions that the user requires from the system are known as Function requirements. Smart Miner Helmet and Monitoring System possesses the following functional requirements such as:

- Sensing the humidity, temperature, and gas concentration parameters through specific sensors.
- Will notify the miners and field supervisors when a certain thresh hold is met.
- Display the correct status of the parameters.
- Sending data to the cloud storage and monitoring platform

3.5.2 Non-Functional Requirements

The non-functional needs of the designed Algorithm of the Smart Miner Helmet and Monitoring System are as follows.;

- **Performance**: The system application can display timely and accurate data

- **Scalability:** Smart Miner Helmet and Monitoring System are scalable because they can include other parameters depending on the purpose. Here we can add other sensors that will make the performance better.
- **Manageability:** Smart Miner Helmet and Monitoring System is cheap and easily managed by specified users.
- **Usability:** No more important knowledge is needed after the installation of this system. Except to know how to view data on the cloud.
- **Security:** The system is secure does not allow any unauthorized access.

3.5.3 Hardware and Software requirements

Hardware requirement: The following are minimum hardware requirements for running Smart Miner Helmet and Monitoring System:

1. Computer with 8 GB RAM
2. 500GB free space of HDD
3. CPU: Core i5

3.5.3.1Hardware User in this system

1. **Arduino Mega 2560:** This is a microcontroller with different features of 54 digital input and output pins where fourteen are used as Pulse Width Modulation outputs, the Sixteen are analog inputs, four are hardware serial ports, sixteen oscillators, the universal serial bus for connecting, a power jack, a power jack, and a button for resetting when necessary. It utilizes an AC-DC power adapter or batteries.[46]

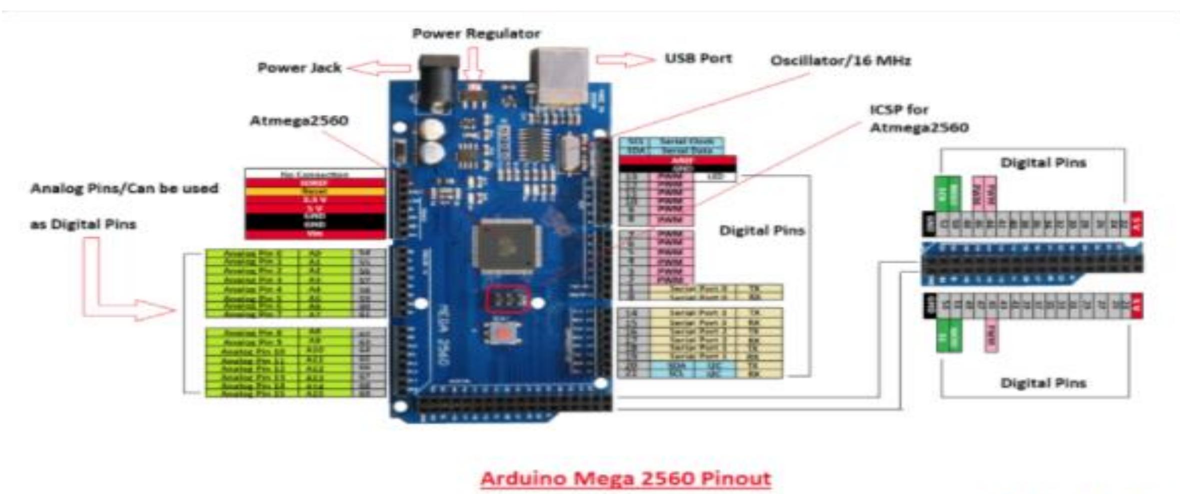

Figure 3-5: Arduino mega2560

Arduino Mega 2560 specifications

Microcontroller	Arduino Mega 2560
Operating volts	5v
Input-volts recommended	7-12v
Input-volts limit	6-20v
Analog input pins	16 pins
Clock speed	16mhz
Flash memory	256kb of 8kb
SRAM	8KB
EEPROM	4kb
Digital input pins	54pins
DC for input/output pins	40mA

Table 3-1: Arduino mega specifications

2. **NRF24L01Module:** It is a transceiver module that operates wirelessly. This means it can receive and send, it utilizes and operates at 2.4 GHz and is among the Industrial, Scientifical, and medical frequency bands, The nRF24l01 operates on 3.3voltages. It can also operate with devices with 3.2v and 5v [47]

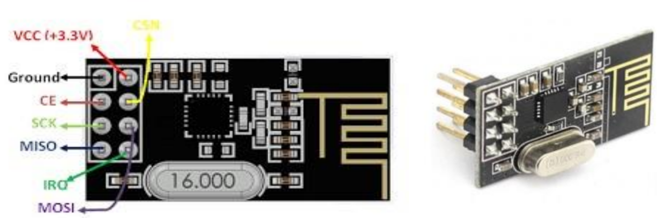

Figure 3-6: nRF24L01 module

nRF24l01 Specifications

Module	Nrf24l01
Operating voltage	3.3v
Nominal current	50mA
Operating Range	50-200 feet
Operating current maximum	250mA
Communication Protocol	Serial Peripheral Interface
Node’s maximum	6 maxima
The ranging channel	125
Rate Baud	250kbps-2mbps
Transceiver module	Operates with 2.4Ghz RF
Operating cost	cheap

Table 3-2:nrf24l01 specification table

3. **Ethernet Shield:** It allows the connection of Arduino to connect to the Internet. Devices connect to the internet through the use of the ethernet cables and the local area network; they are used to send and receive information over the internet [48]

Figure 3-7: Ethernet Shield

Ethernet Shield Specifications;

- Arduino board is required for operation
- Its operating volts is 5v which is usually provided by Arduino
- It uses 10 to 100mbs controllers with a simultaneous speed connection
- It uses socket connections up to four
- Through the SPI port it connects to Arduino
- It uses 9v output
- Input voltage range from 36v to 57v

4. **MQ 135 Gas Sensor:** It is ideal for the detection or analyzing Hydrogen, Nitrous gases, Ethanol, Benzoic acid, and Carbon dioxide and are utilized in air quality monitoring systems. The MQ-135 gas sensor has a Digital Pin that enables it to work without a microcontroller, which is useful when you simply want to detect a single gas.[49]

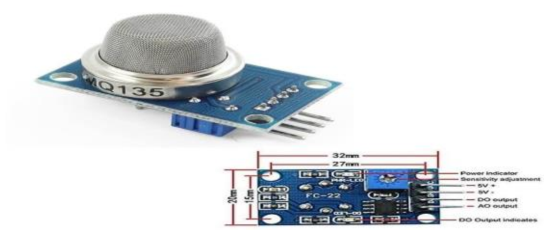

Figure 3-8:MQ135

MQ135 Gas Sensor Specifications

- Detection range is broad
- High sensitivity and quick response
- Longevity and stability
- +5V is the operating voltage.
- 0V to 5V analog output voltage
- 0V /5V digital output voltage
- 20 seconds of preheating

5. **MQ7 GAS SENSOR:** It is a low-cost, easy-to-use Carbon Monoxide sensor that can detect carbon levels in the air. It can monitor carbon monoxide levels ranging from 20 to 2000 parts per million. It has a strong carbon monoxide sensitivity as well as a lengthy and steady life cycle.[50]

Figure 3-9:MQ7

MQ7 GAS SENSOR SPECIFICATIONS

- 40x20mm dimensions
- 5V is required as a power supply.
- Analog Interface type
- Its Carbon monoxide sensitivity is high.
- It has a very quick reaction
- Long-lasting and stable

6. **Infrared Sensor:** This is a digital device this is used to feel sure traits of its environment does through either emitting or detecting infrared radiation.

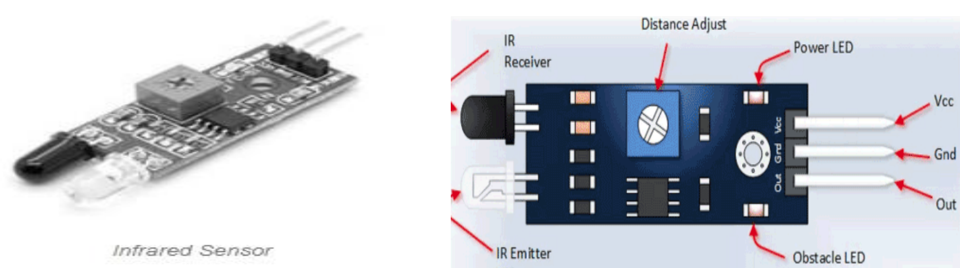

Figure 3-10: Infrared sensor

7. **DHT11**: It is a basic digital temperature and humidity sensor that is extremely low in price. To measure the ambient air, it employs a capacitive sensor and a thermistor and outputs a digital signal on the data.[52]

Figure 3-11: DHT11 sensor

DHT11 sensor Specifications

- Voltage Range of operation: 3.5V to 5.5V
- 0.3mA when measuring 60uA when standby
- Serial data is output.
- 0°C to 50°C temperature range
- 20% to 90% humidity range
- Temperature and Humidity are both 16-bit resolution.
- 1°C and 1% accuracy

8. **Graphic LCD Oled screen:** Organic light-emitting diode is a type of light-emitting diode that may be driven by an electric field and can also generate light via carrier injection and compound. The anode and cathode of the device are made of Indium tin oxide transparent electrodes and metal electrodes, respectively. Electrons and holes are injected into the electron and hole transport layers from the cathode and anode, respectively, and migrate to the luminescent layer through the electron and hole transport layers, where they meet to form excitons and excite the luminescent molecules, and the latter emits visible light through relaxation radiation.[53]

Figure 3-12: Lcd Oled screen

LCD Oled screen Specifications

- There is no angle difficulty
- |Its luminescence is actively functioning.
- It has a high brightness
- Efficiency high luminous
- The display of color is achieved easily
- Thin diameter
- High dynamic picture quality and a quick response time
- It's a simple process with a minimal price tag
- Because of its high earthquake resilience and several benefits, it is referred to as the future experts' perfect display

9. **Node-MCU-esp8266**: This is an open-supply platform based on ESP8266 that may connect gadgets and allow data transfer through the use of the Wi-Fi protocol.[54]

Figure 3-13: Node MCU esp8266

Node MCU Specifications and Features;

- It has 2.412 - 2.484 GHz Frequency Range
- It has 802.11b: +16 2 dBm at 11 Mbps Power Transmission
- Its Range of temperature: -40°C to +125°C
- It is an IEEE 802.11 b/g/n Wireless Standard
- Its transmission System is 802.11b: +16 2 dBm
- 15 mA output current per Pins at 3.3 V 12 - 200 mA operating current Stationary current of less than 200 uA
- Transmission in Sequence
- Lightweight and compact.

- The interface module CP2102 USB Serial Communication is used. Hardware/hardware IO is similar to Arduino (software-defined).
- The price is low
- It is Simple to use
- On-board PCB Antenna IO Capability for Wireless Form with 1 ADC, UART, I2C, PWM, GPIO

3.6. Process Design

Following the requirements collection and feasibility assessment, the design of the suggested smart Miner Helmet and Monitoring System was a crucial step. The design was done after assessing current schemes and then proposing a new system that was meant to archive both general and specific goals. As stated in Chapter 5, our plan outperforms the old scheme, allowing us to attain our goal.

3.7 Research Limitations

As it is for every study, this dissertation had the following limitations:

- The sample size was limited because of the Covid-19 pandemic, only Rutongo mines were visited

- A larger sample size would likely improve the research's dependability, similar to three separate mining locations

- Most of the information required from the mining site wasn't given accurately as required like at Rutongo mostly used email for communication which isn't efficient because we needed field data mainly

- Most miners couldn't give the exact reality needed from the mining site and this greatly affected my research project.

Chapter 4 : SYSTEM DESIGN AND ANALYSIS

4.1Introduction

The section elaborates how the smart miner helmet and monitoring system can be used to prevent several deaths in mines. The overview of the system analysis, design of the existing or present system, and improvements of the proposed changes system will be discussed. This will aid in the understanding of the current condition, the identification of improvements, and the final definition of the proposed solution's needs. This chapter will describe how the system will control the mines and provide measures related to various parameters such as gas leakage levels, changes in humidity and temperature, and falling or being disturbed and hit by nearby obstacles, all of which can result in the death of miners or put their lives in great danger.

4.2 System Analysis of Existing System

Following the research study that was carried out, which included using all research instruments as well as analyzing all data and information found on the site using a method known as descriptive statistics, which is based on percentage by comparing a value or group of respondents within the data to a larger group of respondents and frequency, which is the number of times a response is found. We discovered that the Rutongo mining site had poor communication, which makes it difficult for miners working underground to communicate with each other and their field supervisors. Normally, hazardous events such as gas leakage or temperature change occur while digging minerals underground, and when they needed to know the level of gases, they have to send a person with a portable meter, to measure and returns with the results, exposing that person to risk in the event of gas leakage or temperature change. Another thing we realized is that whenever a hazardous event occurs in the underground there is no way to alert or ask for help.

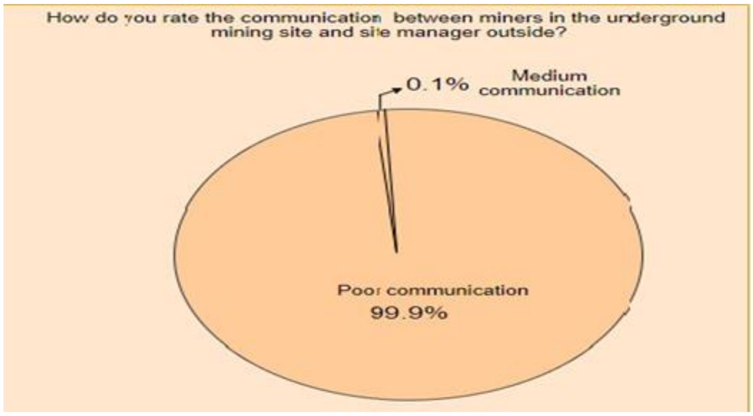

Figure 4-1: Data analysis

4.2.1Barriers of the existing system

The existing system faced the following challenges:

- Measuring gas levels involved sending a person in the underground, which was very risky.
- Notifying for help in case of danger was passive, not real-time
- There was no monitoring and analysis of data found inside the mining tunnel to know their status before the mining process and when the mining process was ongoing
- There was no real-time communication between miners underground and field supervisors from outside the tunnel.
- Miner surveillance underground during the mining process wasn't possible with the system they were using.

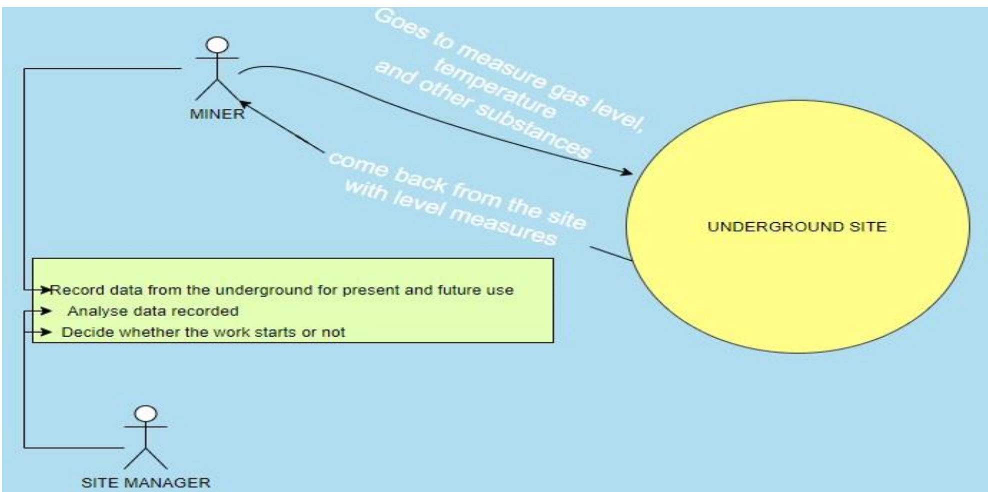

Figure 4-2: Context diagram of the system

4.3 Proposed solution

From mining barriers, we observed and research we made, we decided to develop an IoT system and a web application that helps to ensure real-time communication between miners underground and supervisors on the ground. The system can detect gas leakage during both the mining process and before the process, eradicating the traditional way of sending a person to measure the level of gases, and gas levels will be monitored by the field supervisor from the control room. We propose this new system because all hazardous events that may occur from the underground site can be managed easily since miners from the underground site and field supervisors from outside have real-time communication.

4.3.1 System model of the proposed system

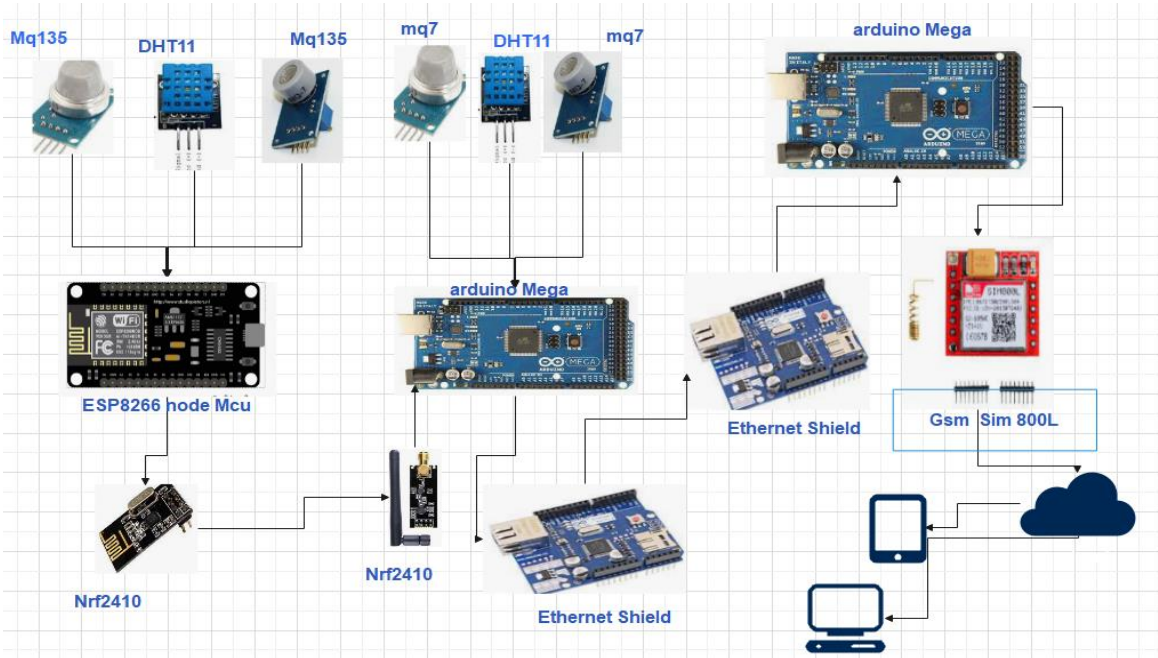

Figure 4-3: System model

Description of the above figure contains all components used in the project and how it is connected, the sensors deployed in the underground site, and helmet such as MQ7, MQ135, DHT11 are programmed to probe data in the mining site, the two microcontrollers will communicate to transfer data from the helmet to the static microcontroller underground be met and successful then NRF24L01module facilitates the communication between the two microcontrollers, after receiving and gathering all data is transferred to a database for storage, and finally, data has to be viewed optionally in two ways either through the user interface or to the cloud platform.

4.3.2 Gas Permissible Limits in Mines

Highly combustible gasses (CH_4), noxious gases (NO_2, NO_3, N_2O_5), carbon monoxide (CO), carbon dioxide (CO_2), hydrogen sulfide (H_2S), sulfur dioxide (SO_2) at levels that expose that individual to risk in event of an underground mine explosion[55])[56]. The following are the allowed limits of common gases in underground work for the safety regulations:

GAS	ABBREVIATION	PERMISSIBLE LIMIT
Carbon dioxide	CO2	5000 ppm
Carbon monoxide	Co	25ppm
Hydrogen Sulphide	H_2S	1ppm
Sulfur dioxide	$S0_2$	0.25ppm
Nitrogen dioxide	NO_2	0.2ppm
Nitric acid	NO	25ppm

Table 4-1: Permissible gas limits

4.4 IoT Layered Models

The architecture layered approaches that come to be essential in IoT structures is the Three-layered technique and this is the architecture that became more desired in Smart Miner Helmet and Monitoring System;

Perception Layer: Capturing information and data from the miner environment. Predominantly sensors i.e., DHT11, MQ7, MQ135, Infrared which are programmed to probe data and information in the mining tunnel environment

Network Layer: Responsible for connectivity and processing the raw data captured from sensors in such a way it is meant for use in the case of Smart Miner Helmet we used the NRF24L01 module for communication between the helmet and the fixed sensors inside we also used Ethernet cables which were more preferable than wireless because of its inconvenient undermines

Application Layer: Responsible for delivering application-specific service to the cloud server through GPRS as the gateway GSM for notifications to field supervisors and data will always be monitored on the dashboard.

The perspective of IoT architecture, the Smart Miner and Monitoring System three-layered architecture adopted three-layered architectures as its IoT architecture with its three layers distributed as follows: The SMHMS system high-level architecture consists of sensors at the perception layer, wireless communication at the network layer, and cloud services at the application layer

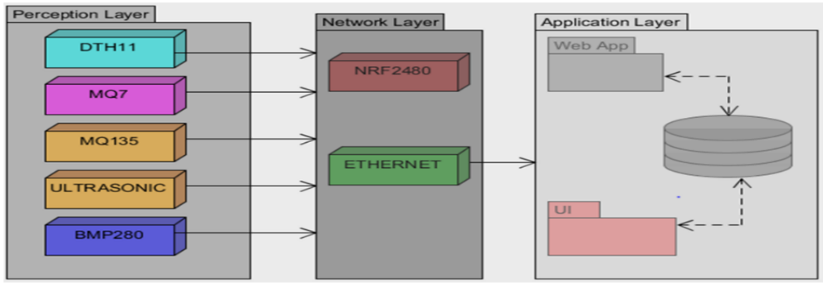

Figure 4-4: SMHMS Three-layered architecture

4.5. Smart Miner Helmet and Monitoring System (SMHMS)Components Model

The **Smart Miner Helmet and Monitoring System (HMS)** is a hybrid system that integrates several components with various technologies, resulting in a system with a heterogeneous design. The system would be simple to use and would not necessitate any prior knowledge or expertise.

The fundamental SMHMS feature enables an automatic manner of item connection while also providing and ensuring always responsive services, either explicitly or implicitly. It was divided into three sections:

1. Helmet Section: This is the segment that consists of various sensors i.e.: DHT11, MQ7, MQ135, Infrared, SPST switch, and buzzer; the extraordinary sensors probe extraordinary information temperature, and humidity, carbon dioxide, air pleasant, removal of helmet respectively, then the transfer is for use in case of any hassle that a miner has uncounted underground and the buzzer for the alert in case there are any emergency underground mines.
2. Fixed Section: This is the section that has sensors fixed underground, it communicates with the helmet section via the nRF24L01 module communicates via ethernet connection, and transfers information to the cloud server via the GPRS gateway.
3. Monitoring Section: The dashboard, which is a desktop computer, displays data transferred from the cloud platform via the GPRS gateway, and notifications are sent to mobile phones via the GSM gateway.

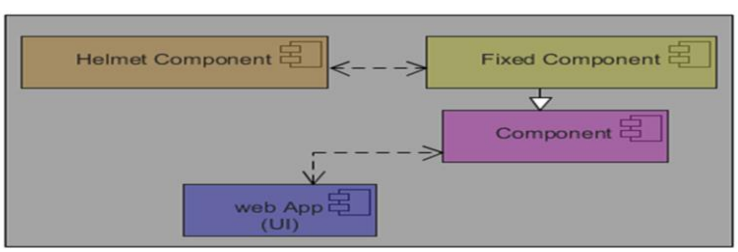

Figure 4-5: SMHMS Component Diagram

4.6. Activity Diagram

Another significant behavioral diagram for describing dynamic aspects of the system is the activity diagram. An activity diagram is a more complex version of a flow chart that depicts the flow of information from one activity to the next. The flow of activities from the miner helmet, to the static part (fixed part) in the tunnel, through data processing in the cloud, is depicted in the activity diagram below.

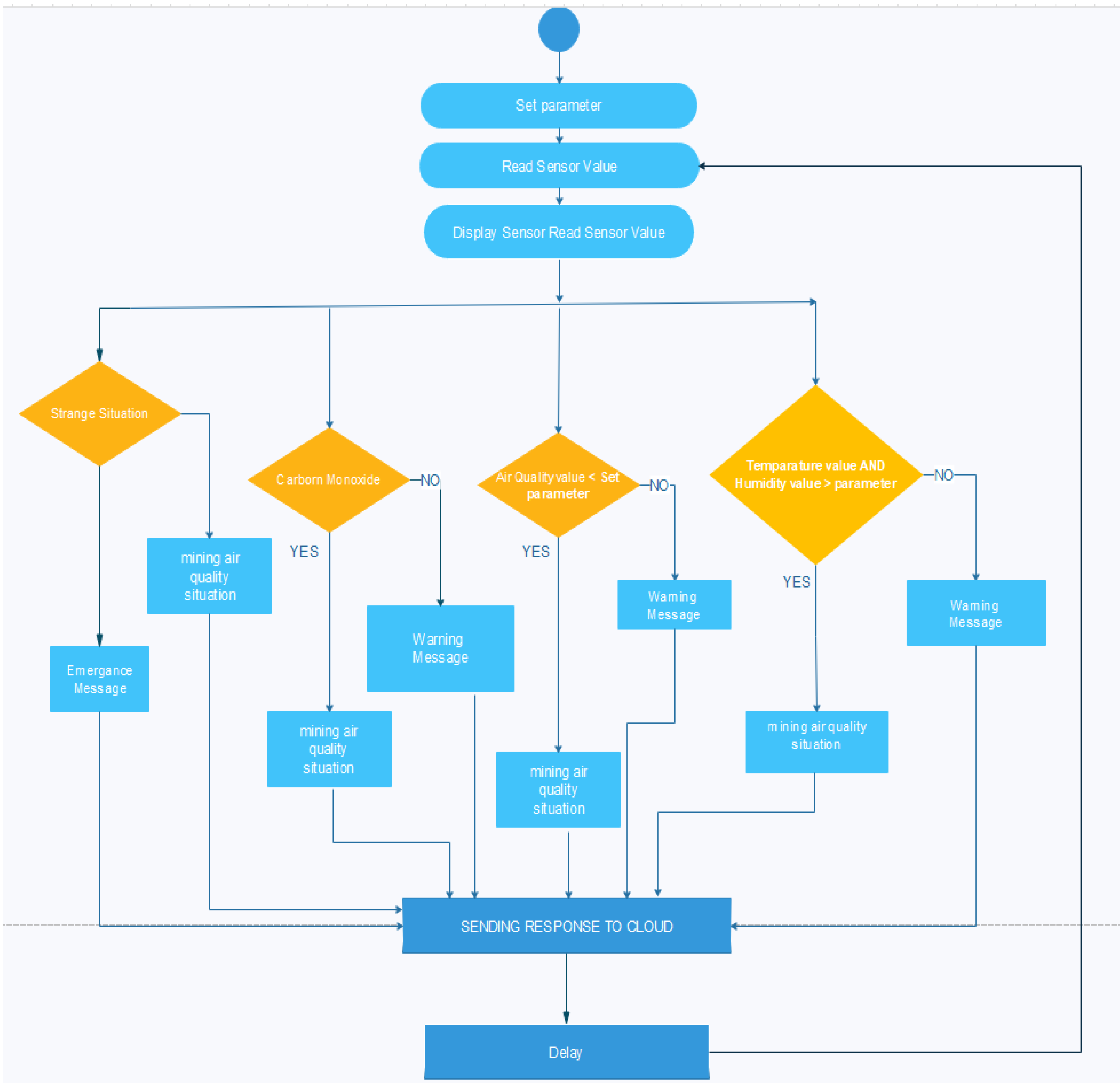

Figure 4-6: Activity diagram

4.7. System Architecture

A system's structure model defines the system's structure, behavior, and other aspects. This thesis projects include all smart miner helmets and monitoring systems devices overview that was used

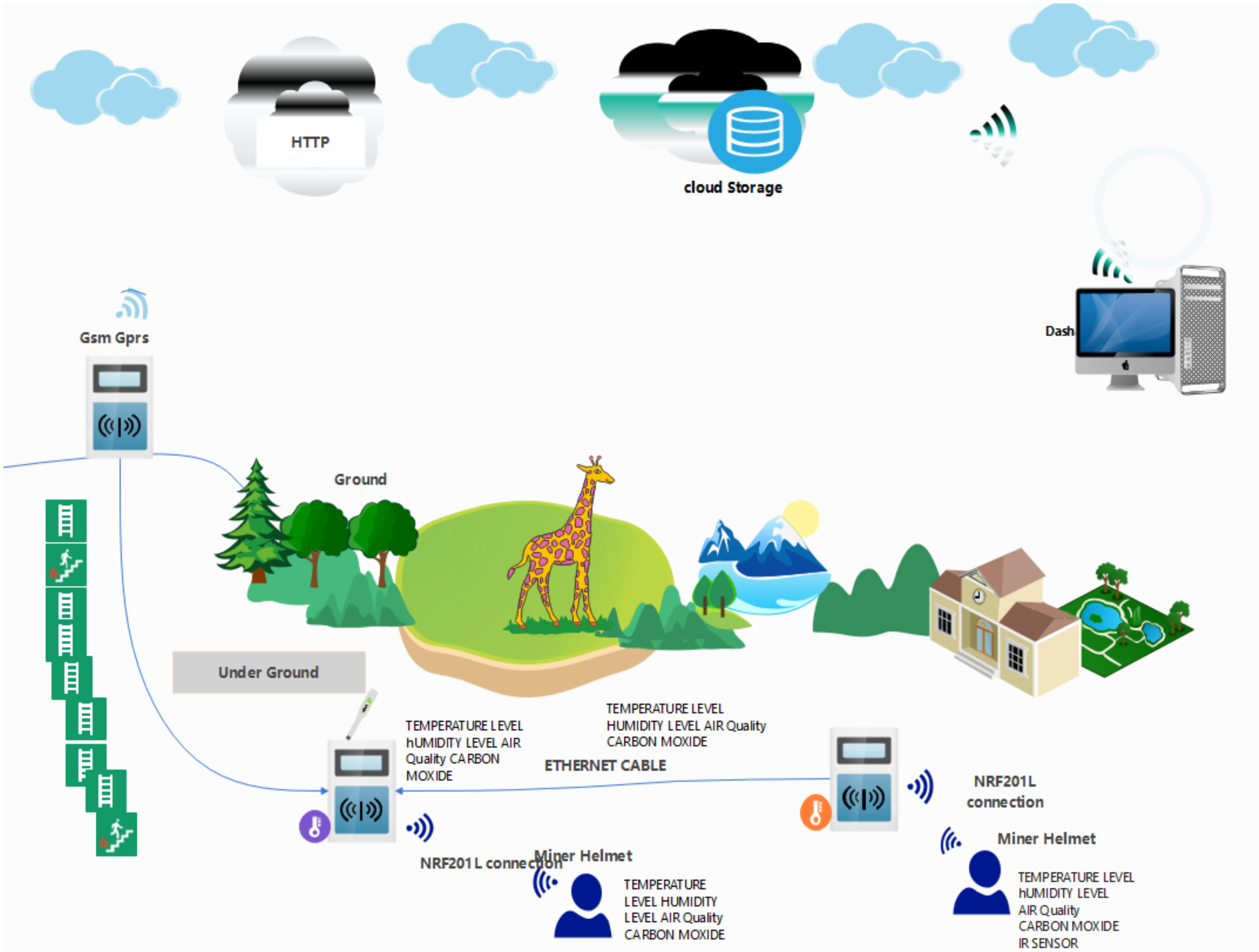

Figure 4-7: Architecture diagram

The Smart Miner Helmet and Monitoring System project is a continuous surveillance and monitoring system that can monitor miners during the mining process. The following are the properties that are being monitored;

- Toxic and poisonous gases concentrations, leakages, and air quality i.e.; methane, carbon monoxide, corbondioxide
- Rapid changes in temperature and humidity.
- Detection of miner helmet removal and collisions with heavy objects and walls within the tunnel

The assessed values are transferred, and processing of data is performed, with such a comparison of the input data specified by current standards and, when unexpected unnatural conditions occur, the alarm button is activated, alerting the central management operator. Safety helmets, tunnel-fixed parts, data transmission, and monitoring portions are all part of the system. The helmet is responsible for data evaluation and data transfer to the fixed part underground. The data transmission component is responsible for connecting the fixed underground part to the central station or cloud platform through GPRS as the gateway, and GSM for notifications on mobile devices. The following sections are explored in detail.:

4.7.1 Safety Helmet Section:

The helmet part is responsible for data probing using various sensors attached to it namely; dht11 temperature and humidity sensors, mq7 gas sensor, mq135 air quality sensor, Infrared sensor for detecting whether the miner helmet is on or off, the probed data is transferred to the fixed part in the mine through the nrf24l01module. The section is also responsible for sending alerts in case something went wrong in the mine or to the wearer,

4.7.2 Fixed Data Transmission Section:

This part has two main functions; It probes data with the installed sensors, whether the mining process is ongoing or when the process isn't ongoing like night hours to determine the mining status in the morning hours before the process begins, It also receives the data from the helmet through the nrf24l01 module; it acts as the mediator between the helmet and the cloud platform through the GPRS getaway, it is connected using the Ethernet cables for efficient transferring of data to the cloud platform where viewed through the dashboard in the control room

4.7.3 Monitoring Section:

After processing data to the cloud platform through the GPRS getaway, data is either viewed via the dashboard or desktop in the control room by the field supervisors but also the supervisor can view the message or alerts on his/her mobile devices through the GSM as the gateway. This means that the system consists of a cloud platform for data storage and processing strategies.

4.8. Use Case Modelling

It is a description of different sets of roles by actors which yield observable useful results to the actor. A use case diagram gives a graphic representation of how different elements of a system interact. The Use case below illustrates action every action in the system and shows each user of the system and his role.

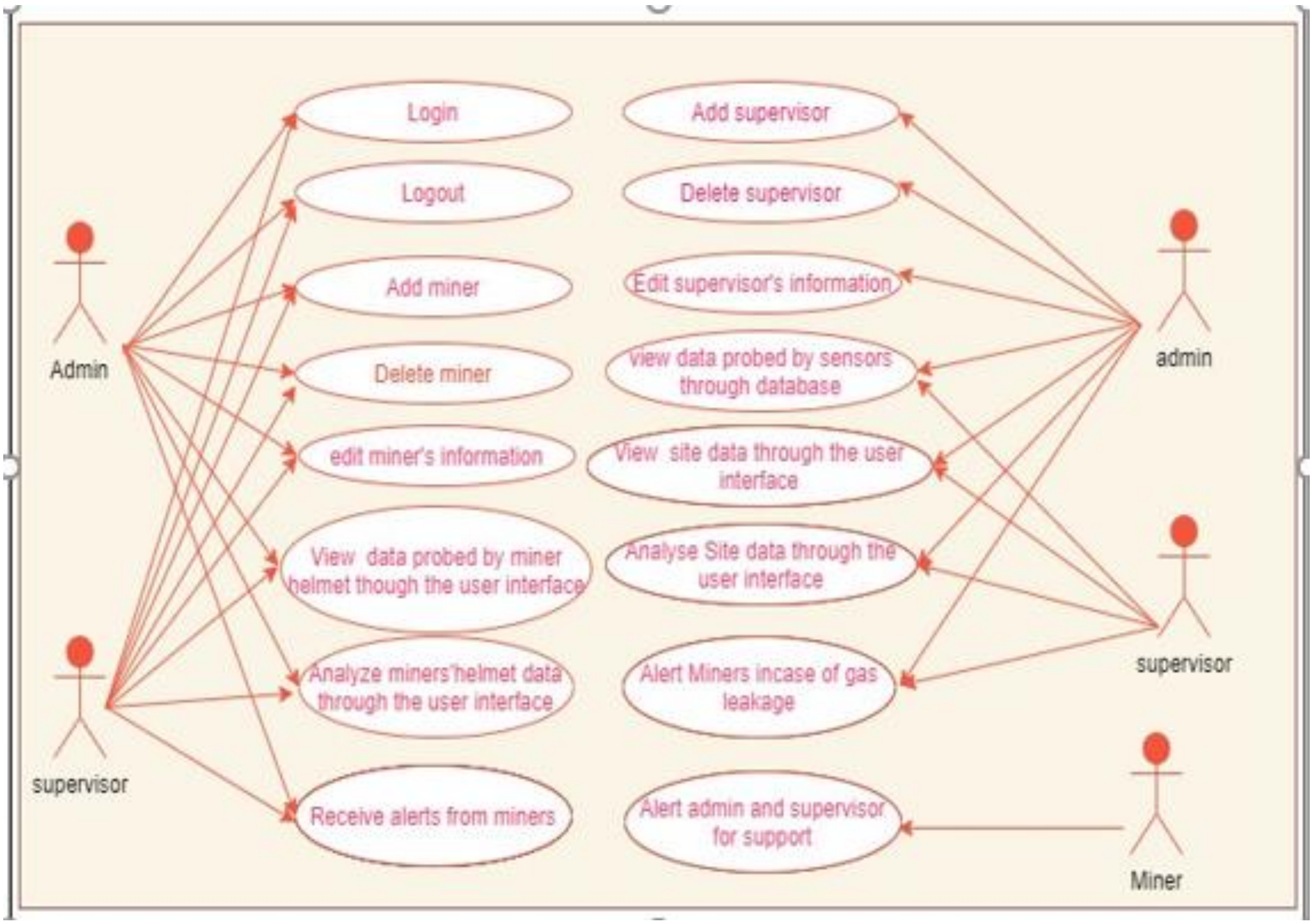

Figure 4-8: Use case Diagram

4.9. Circuit diagram

This circuit has two parts, as shown above, one part is the underground part on which the ethernet shield, Arduino, and other sensors are connected, and the helmet part on which we have only Arduino and sensors connected. Finally, we have the system part on which data can be viewed and monitored from the underground part;

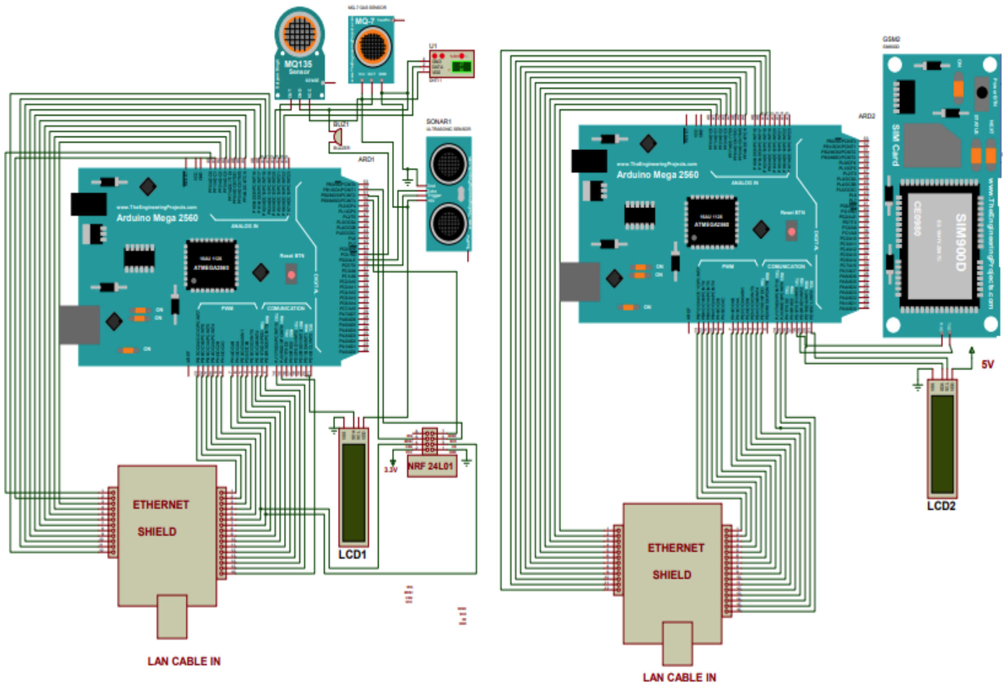

Figure 4-9: Circuit diagram for the underground section

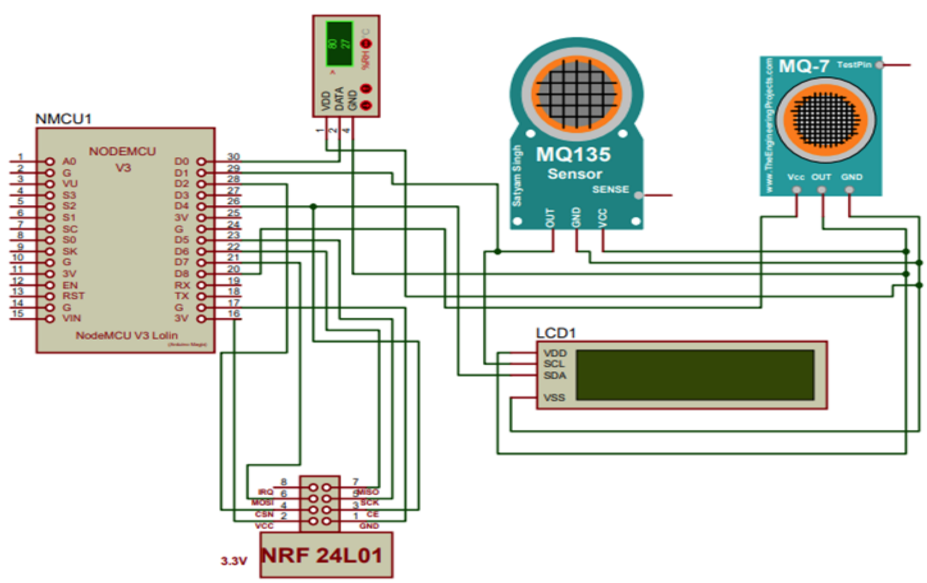

Figure 4-10: Circuit diagram for ground section

4.10 System Prototype

The hardware forms the core of the application. The various sensors were integrated into a printed circuit board. The sensors were connected to the processor via Arduino mega2560 microcontroller using jumpers. Each sensor was connected and tested separately before they were integrated into one unit, the prototype has three sections i.e., the helmet section, fixed part underground, and the ground section, The helmet part is responsible for data probing using various sensors attached to it namely; dht11 temperature and humidity sensors, mq7 gas sensor, mq135 air quality sensor, Infrared sensor for detecting whether the miner helmet is on or off, the probed data is transferred to the fixed part in the mine through the nrf24l01module. The responsible for sending alerts in case something went wrong in the mine or to the wearer, The fixed section has two main functions; It probes data with the installed sensors, whether the mining process is ongoing or when the process isn’t ongoing like night hours to determine the mining status in the morning hours before the process begins, It also receives the data from the helmet through the nrf24l01 module; it acts as the mediator between the helmet and ground part through the GPRS getaway. After processing data to the cloud platform through the GPRS getaway, data is either viewed via the dashboard or desktop in the control room by the field supervisors but also the supervisor can view the message or alerts on his/her mobile devices through the GSM as the gateway. This means that the system consists of a cloud platform for data storage and processing strategies.

Figure 4-11: System Prototype

Chapter 5 : RESULT AND ANALYSIS

5.1 Introduction

The implementation, analysis, and testing of the application are all covered in this chapter. The platforms for the hardware, software, and algorithms that were employed will also be revealed, and the outcomes will be discussed;

5.2 System Result

In our dataset we considered both data that were probed by sensors, i.e., from the miner helmet (Yes Case Miner and No Case Miner), where Yes case Miner is data collected by sensors on the helmet showing a problem, No Case Miner are data collected by sensors on helmet showing no problem, and data from sensors i.e., DHT11, MQ7, MQ135 that are fixed underground are referred as free. The total measurements that were taken in one month are 3000 with Yes Case miner, No Case Miner, and Free where statistical numbers are;328,2080, and 592 respectively.

Miner Dataset

	helmet_co	helmet_temp	helmet_humidity	helmet_Air_quality	Site_temp	site_humidity	Site_air_quality	MINER_CASE
0	0.004956	22.700000	51.000000	0.020411	22.700000	51.000000	0.020411	N
1	0.002840	19.700001	76.000000	0.013275	19.700001	76.000000	0.013275	N
2	0.004976	22.600000	50.900000	0.020475	22.600000	50.900000	0.020475	N
3	0.004403	27.000000	76.800003	0.018628	27.000000	76.800003	0.018628	Y
4	0.004967	22.600000	50.900000	0.020448	22.600000	50.900000	0.020448	Free
5	0.004391	27.000000	77.900002	0.018589	27.000000	77.900002	0.018589	N
6	0.004976	22.600000	50.900000	0.020475	22.600000	50.900000	0.020475	Y
7	0.002938	19.700001	76.000000	0.013628	19.700001	76.000000	0.013628	N
8	0.004345	27.000000	77.900002	0.018440	27.000000	77.900002	0.018440	N
9	0.004970	22.600000	50.900000	0.020457	22.600000	50.900000	0.020457	N
10	0.004960	22.600000	50.900000	0.020425	22.600000	50.900000	0.020425	N
11	0.004383	27.000000	78.000000	0.018563	27.000000	78.000000	0.018563	N
12	0.004972	22.600000	50.900000	0.020461	22.600000	50.900000	0.020461	Y
13	0.004451	27.000000	78.000000	0.018786	27.000000	78.000000	0.018786	N
14	0.004965	22.600000	50.900000	0.020439	22.600000	50.900000	0.020439	Free
15	0.002905	19.700001	75.800003	0.013509	19.700001	75.800003	0.013509	Free

Table 5-1:Miner dataset

This table shows, the dataset combined both Yes Miner Case, and No Miner Cases/also recorded the miner data situation in the underground tunnel when no miners are present namely free.

The histogram below presents the three groups of different categories of data that were collected in the mining tunnel i.e.; Yes, Miner Cases, No Miner cases, and free: 328,2080, and 592 respectively.

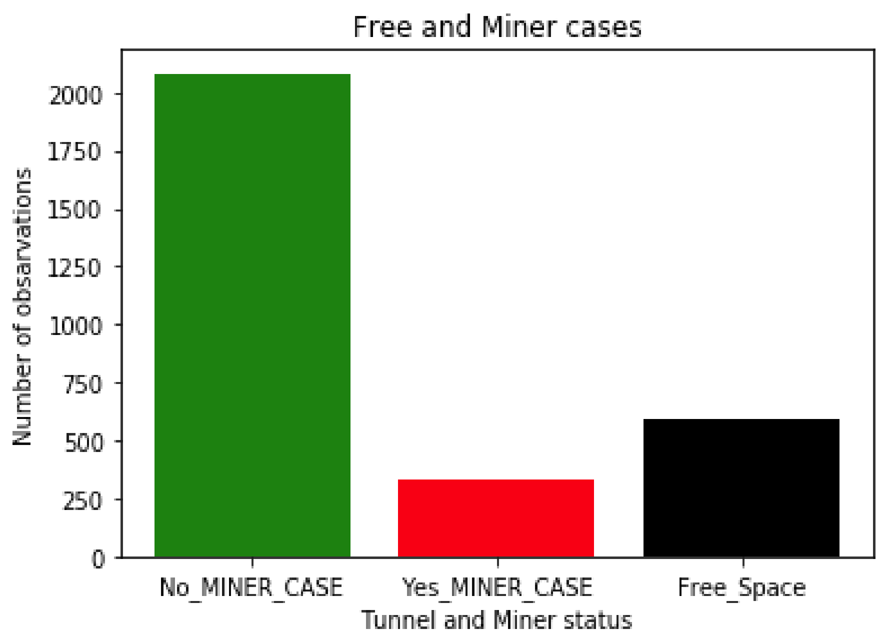

Figure 5-1: Histogram of Miner Cases Occurrences

The figure above shows that there’s a crucial case for the minority class of yes cases that need to be handled for the reason of production of a good classification model.

Therefore, we need to overcome the case above; we decided to use two ways namely:

1. Over Sampling: This is where we used to oversample Yes cases to the number of No cases, but the result was producing a poor performance of classification, and in that case, we didn’t produce the poor performance of classification
2. Downsampling: In this sampling, we used the Yes cases that we had to downsample the No cases to the number of yes cases, where Yes cases were 328 and No cases 328, and sampling was done randomly where 328 were picked from 2080 of No cases;

Below are tables of Downsampling showing similar results to produce a good classification;

New size of Yes case Miner: 328

New size of YES cases: 328

	helmet_co	helmet_temp	helmet_humidity	helmet_Air_quality	Site_temp	site_humidity	Site_air_quality	MINER_CASE
3	0.004403	27.000000	76.800003	0.018628	27.000000	76.800003	0.018628	Y
6	0.004976	22.600000	50.900000	0.020475	22.600000	50.900000	0.020475	Y
12	0.004972	22.600000	50.900000	0.020461	22.600000	50.900000	0.020461	Y
30	0.002905	19.700001	75.900002	0.013509	19.700001	75.900002	0.013509	Y
43	0.004942	22.600000	50.900000	0.020366	22.600000	50.900000	0.020366	Y

Table 5-2: New size of Yes cases

New size of No case Miner: 328

	helmet_co	helmet_temp	helmet_humidity	helmet_Air_quality	Site_temp	site_humidity	Site_air_quality	MINER_CASE
2312	0.004230	26.799999	77.599998	0.018060	26.799999	77.599998	0.018060	N
2278	0.002501	19.700001	75.800003	0.012031	19.700001	75.800003	0.012031	N
353	0.004303	27.000000	77.699997	0.018299	27.000000	77.699997	0.018299	N
278	0.002840	19.700001	75.099998	0.013275	19.700001	75.099998	0.013275	N
1456	0.004995	22.600000	51.100000	0.020535	22.600000	51.100000	0.020535	N

Table 5-3: New size of no cases

The histogram below presents the two kinds of data after downsampling.; Yes, Miner Cases, No Miner cases, 328, and 328 respectively;

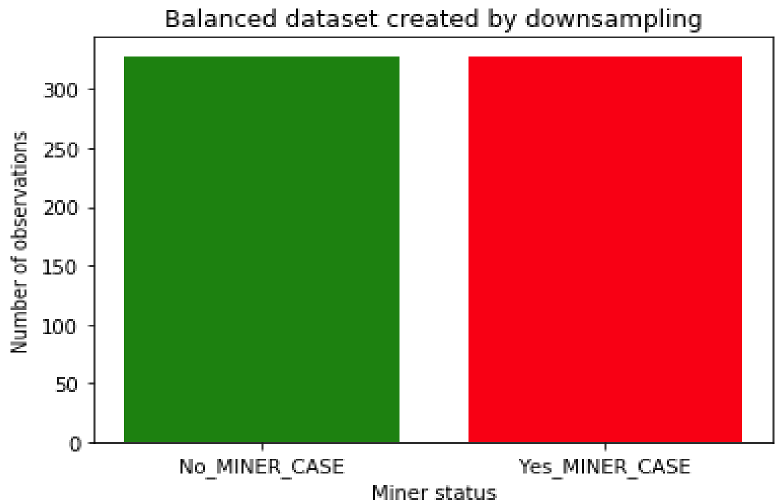

Figure 5-2: Histogram of Miner case of the balanced data set

In the previous figure 30, we have seen that there's a class imbalance that needed to be fixed, therefore the histogram of figure 31, shows the balanced dataset histogram after downsampling of No cases to the number of Yes cases.

Due to the randomness of the downsampling stage, we had to run the experiment multiple times (10 times), therefore a good classification model result was achieved after the multiple runs were calculated on different particular algorithms on the average run.

The three algorithms that were used are;

1. Logistic Regression
2. Decision Tree for Classifier
3. KNN Classifier

For each of those algorithms we reported Precision, Recall, and Accuracy performance metrics;

The result achieved is shown in the table below;

Classifier	Metrics	Run1	Run2	Run3	Run4	Run5	Run6	Run7	Run8	Run9	Run10	Average run
Logistic Regression	Precision	0.55	0.54	0.59	0.59	0.68	0.58	0.56	0.52	0.55	0.67	**0.583**
	Recall	0.49	0.67	0.51	0.51	0.49	0.49	0.49	0.64	0.49	0.05	**0.483**
	Accuracy	0.51	0.52	0.55	0.55	0.6	0.54	0.53	0.5	0.51	0.48	**0.529**
Decision Tree	Precision	0.52	0.48	0.56	0.56	**0.61**	0.52	0.69	0.5	0.5	0.25	**0.519**
	Recall	0.74	0.23	0.1	0.1	**0.62**	0.79	0.1	0.64	0.62	0.01	**0.395**
	Accuracy	0.71	0.45	0.64	0.64	**0.84**	0.65	0.62	0.92	0.82	0.95	**0.724**
KNN	Precision	0.46	0.46	0.51	0.51	0.59	0.54	0.51	0.5	0.55	0.53	**0.516**
	Recall	0.4	0.41	0.49	0.49	0.44	0.44	0.51	0.52	0.47	0.53	**0.47**
	Accuracy	0.62	0.58	0.5	0.5	0.7	0.64	0.6	0.69	0.46	0.47	**0.576**

Table 5-4: Accuracy table of matrix

5.3 Evaluation of different parameters of the system from the database

The system used different parameters to measure hazardous gases, temperature and humidity, and air quality, these were the main parameters that were considered after the analysis that was made, and below are the graphs that were generated by the system through the probed data of different parameters;

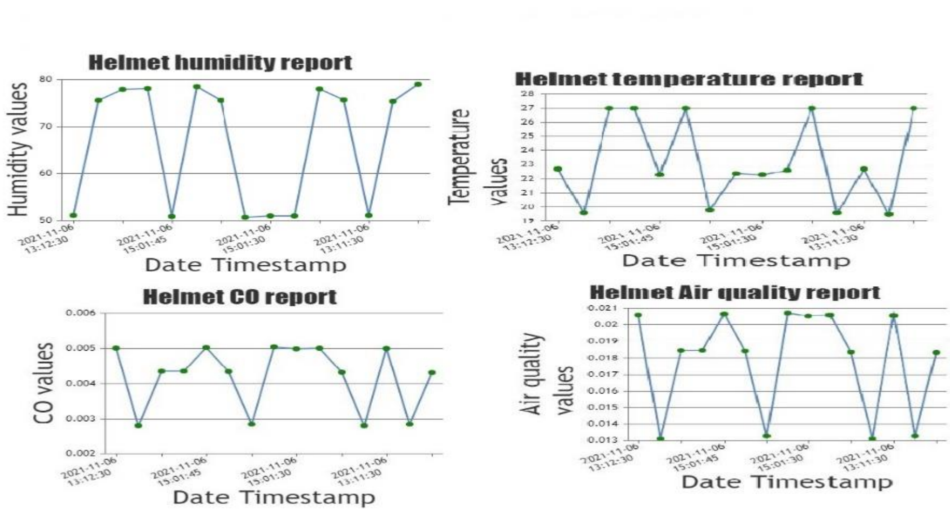

Figure 5-3: Parameter reports

Chapter 6 : CONCLUSION AND RECOMMENDATIONS

6.1 Brief overviews of Contributions

In the form of global, regional, and local settings, the offered dissertation identified some of the major problems for the mining industry that has not yet incorporated IoT technology in mining. The study offered an expanded and unique vision of technology in the IoT that saves the end-user time and effort. It also ensures that users are provided with and offered services that are always responsive. The Smart Miner Helmet and Monitoring System, which was just introduced, is a revolutionary solution that uses IoT to automate communication and interactions between field supervisors and miners. Its function is to allow efficient communication and monitoring of miners, then give an alert to them in case of gas leakages, cave-in serious injuries, inconvenient changes in temperature and humidity, unnecessary helmet removal, and other emergencies. The connected services can be accessed via a dashboard or a computer in the control room, also an alert message will be sent to the field supervisor's mobile devices and a user identification algorithm is used to ensure user identity.

6.2 Conclusion

Smart miner helmet and monitoring system has been successfully developed. all sensors deployed on microcontroller on the helmet and fixed part of the tunnel probe data, data get sent to the database and the site manager can view and monitor data both on local user interface and on the cloud platform, there is communication between miners in the underground and people from outside the underground site because the site manager can notify miners in case of the hazardous event via the user interface and the miner has the button on the helmet that he uses in case he needs rescue.

As an output of the dissertation, Smart miner and monitoring system is among the first IoT in the mining industry in Rwanda if not in the region to address miner problems during the mining process mostly in Rutongo mines which help to Rwanda mines, petroleum, and gas board (RMB) to increase productivity. Data generated from the system would contribute to further studies or/and future research.

6.3. Recommendations

6.3.1 General

The IoT center with the help of the college together with the university management should avail the required materials (IoT modules) in a timely to facilitate the prototype development to meet the project objectives. During theoretical learning, the time for practical assignments should be increased as well as the number of practical works. This can contribute a lot to the moment of project realization.

The university did a lot for supporting our projects but the support wasn’t on time as was expected to serve the purpose as they are proposed to solve different problems like all project requirements and components to be bought on time. After the completion of the project, we hope it will be helpful in the mining industry since there will be a way of managing risks before they get worse, we would like to suggest other researchers who will be interested in developing solutions, particularly for the mining industry to add more sensors for heartbeats, avoidance of being hurt by cave-ins, and work on the problem of the collapse of different mines.

6.3.2 Survey Challenge

Surveys are one of the most prevalent methods for getting customer input and concerns on a variety of commercial and technical issues.

From a technical standpoint, users' concerns about their privacy, when personal information is provided, is always a sensitive field, which could be a reason for their unwillingness to use the system., all the information needed from the mining site wasn't given accurately as required, such as at Rutongo mining site, were mostly used email for communication, which wasn't efficient because we needed field data, and their supervisor was somewhat reserved, which hampered my research.

6.3.3 Testing, and Analysing Challenge

One of the goals of the research project was to test and analyze the prototype, which was difficult for me because of the Covid-19 epidemic guidelines at Rutongo Mine. We had to go there for several days but they wouldn't let us enter the mines, finally, they agreed but time was against us, so instead of collecting three months' worth of data, only collected one month's worth of data in November. It had a detrimental impact on the dataset's outcome because the amount of data obtained in one month was insufficient, as well as the accuracy in general.

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