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Real-Time Monitoring and Alarm System for Toxic Gas in Underground Coal Mines Using Smart Helmets

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Abstract

Regarding the hazard-prone working conditions in underground mines, synchronous monitoring and alarm system is vital to increase the safety. By analyzing the accidents in underground mines in Iran, it can be deduced that most fatalities are related to gas leakage, objects drop off on the head, and not using helmets by the staff. Therefore, a smart helmet with the capability of measuring harmful gasses (regarding the type of the mine), detection of the existence of the helmet on the head, temperature and humidity measurement, and detection of blow on the head is designed and fabricated to eliminate the present dangers and problems. This system displays the evaluated data on a developed software through wireless data transmission hardware. The data transmission hardware is the primary a link between the intelligent safety helmet and the software. To follow the idea, practical experiments have been performed in Parvadeh four and East Parvadeh of Tabas coal mine to confirm the validity of data transmission that culminated in successful results. The results were altered by the complexity of the design of the underground spaces so that in a straight direction, data transmission was held until 430 meters. However, further progress was not possible due to tunnel limitations. Data transmission was reduced to 190 meters in access horizons with curvatures or tilts. According to present standards, some thresholds are defined for each of the mentioned cases such that alarm protocol is activated by exceeding these thresholds in critical circumstances. Then the helmet user and the software's operator will be informed of the occurred danger and will settle the problem.

The system outlined in this study ensures performance reliability through its alarm package. A key innovation is the in-depth examination of the impact of head injuries, transforming it into other factors by analyzing relevant content and setting boundaries for assessment rather than using specific numbers. Furthermore, the most evident aspect of this design is the enhancement of the managerial approach, which includes an attendance evaluation platform and performance reporting within the system.

1. Introduction

Considering the number of people engaged in mining directly, the high investment and operational costs of mining activities, the uncertainty of various mining units, and the dangerous nature of mining operations, increasing the safety of these people while working is an unavoidable issue. On the other hand, occupational hazards and the healthcare issues related to the activities of the mine workers are fundamental concerns of this industry. It is evident that the

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safety in open pit mines is more than in underground mines due to adequate light and fresh air access [1]. Regarding the complexity of geology, the structure of present non-continuities, and their direct influence on the type of stress distribution, the underground mines are more accident-prone. Unexpected accidents and existing dangers in underground mines such as carbon Nano particles could provide a stressful and dangerous workplace for workers and operational facilities that impose considerable life and financial threats. Hazards of working in underground mines require particular attention to all influential factors of safety due to the circumstances emerging from area constraints, environmental pollutants, geology complexities, inadequate light, etc. Figure 1 depicts the various types of carbon based Nano materials synthesized from coal as a raw carbon source.

Carbon Nano particles existed in mines have drastic effect on the workers' health based on the findings rendered by Geng et al. [3] (Figure 2).

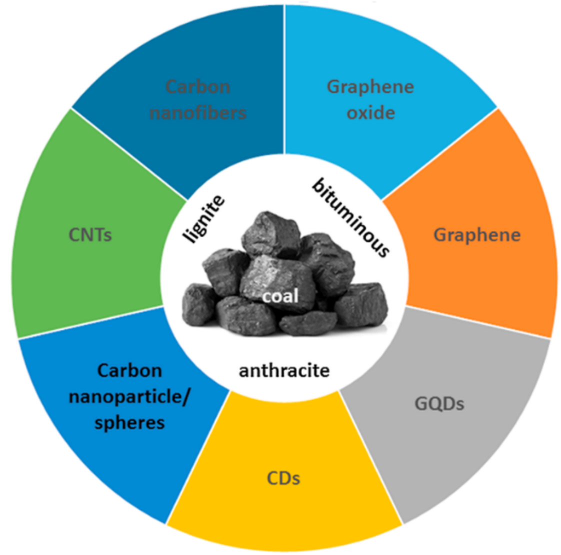


Figure 1 various types of coal as precursors for synthesizing carbon-based Nano materials [2].

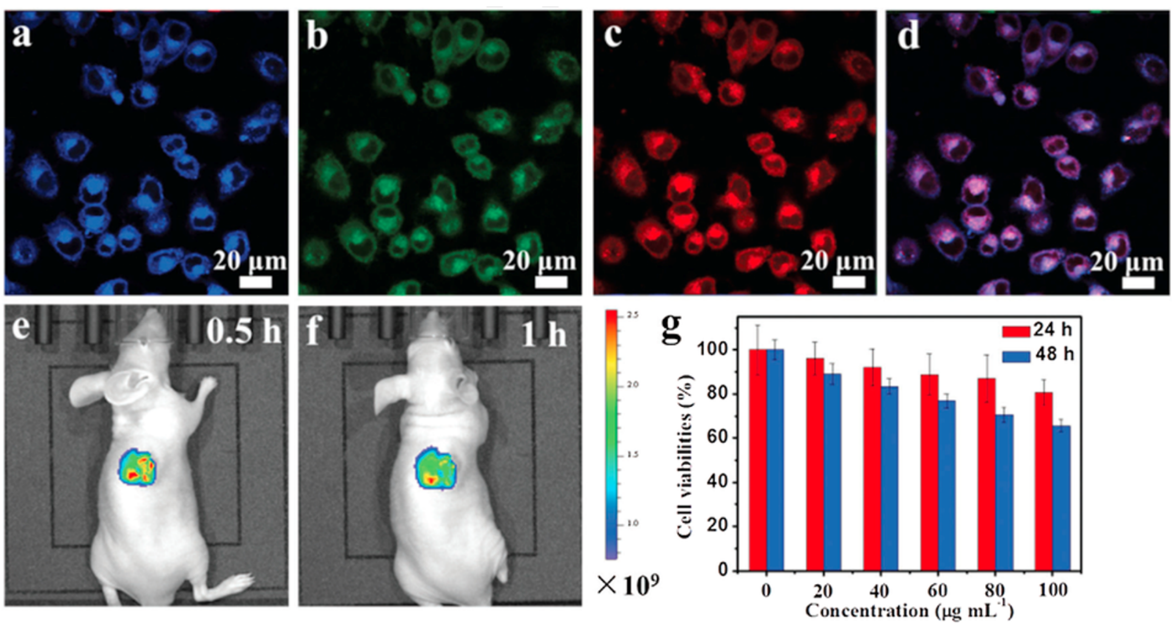


Figure 2 Confocal fluorescence image at 405, 488, and 546nm excitation (a–c) and merged image (d) of HeLa cells using liposome-CQDs internalized into the cytoplasm of the cells. (e and f) In vivo fluorescence images of HeLa tumor-bearing nude mice obtained in tumor sites at 0.5 and 1h after intra tumor injection of 200µL of an aqueous solution of liposome-CQDs. The color bars represent the fluorescence intensity. (g) Cytotoxicity assessment of liposome-CQDs at higher doses for incubation time varied from 24 to 48 h using HeLa cells [3].

The surveillance of the mining environment and the workers' health are considered essential parameters in mining. On the other hand, the workers tend to avoid bringing some safety equipment due to its weight, heat, and bothersome ergonomic. The current safety helmets are utilized to protect the workers' heads against the impacts caused by objects drop off or colliding with protuberances inside the tunnel.

In mining complexes, monitoring and appropriate communications are fundamental requirements for correctly managing human and machinery resources. HSE administrators should be aware of situations with hazard potentials. Therefore, it is crucial to have a monitoring and surveillance system to acquire the evaluated data, transmit it to the control center, and make the most appropriate decision at the earliest possible moment. There are two types of communication networks for underground places: wired and wireless networks. The wired networks have the following drawbacks:

- High installation and commissioning costs
- Being damaged during accidents
- High maintenance costs
- Time-consuming installation and repairing
- Difficult and time-consuming diagnoses

Regarding the mentioned disadvantages, implementing a wired network doesn't have technical and economic justifications. On the other hand, wireless networks do not have the weaknesses of the wired networks. Still, they are also technically and economically defensible, acquiring features such as high speed, high safety, self-diagnosis, remarkable reliability, etc.

This paper presents a continuous, real-time monitoring and surveillance system based on wireless communication to increase safety by monitoring various parameters such as temperature, humidity, dangerous gasses, and impact to the head, helmet wearing, and navigation. Moreover, in addition to mentioned parameters, this system can also detect helmet wearing and measure impact to the head. Alongside alarming the control room operator, the worker will also be informed of the sort of danger considering the predicted protocols. As a result, the proposed system will increase the workers' safety and efficiency of the mining operation.

2. Research Background

The workers' safety is generally threatened due to poisonous gasses that usually exist in underground mines. These gasses are not detectable without facilities. Therefore, Srivastava [4] studied toxic gasses in critical areas and their effects on miners. He implemented a real-time monitoring system using a network of wireless sensors. This system controls environmental parameters like temperature, humidity, and several poisonous gasses. Furthermore, it possesses an alarm section in the helmet that informs the workers and the people around of the dangerous circumstance according to the type of the threatening danger and can confront the issue at the earliest possible moment. The system uses ZigBee technology to generate a wireless sensor network. This network conforms to the IEEE 802.15.4 standard that is suitable to work under rough working conditions. Eick [5], designed a smart safety helmet using ZigBee technology to monitor hazardous gasses, helmet removal from the head, and alert protocol. The analyzed gasses are Carbon monoxide, Sulfur dioxide, and Nitrogen dioxide. Ravi Kumar [6], designed a smart safety helmet to monitor dangerous gasses based on ZigBee. In addition, a stick is implemented on the safety helmets to identify the workers using Infra-Red (IR) sensors and to ensure the helmet wearing. Then they evaluated the blow to the head using micro-electromechanical switch (MEMS) sensors. Behr [7], proposed a smart helmet to reduce mine dangers by analyzing three parameters of air quality, blow to head, and helmet wearing detection. The air quality factor includes the evaluation of the density of dangerous gasses. Borkar and Baru [8] suggested generating a safe network using smart helmets to analyze the environmental conditions around the workers and real-time data transmission. Chi et al. [9] described the relation for reconfigurable smart sensors for WSN industries on the Internet of Things (IoT) platform to gather all sensor data thoroughly. This system is designed based on the IEEE 1451 protocol. This system is totally convenient and fast to acquire real-time data quickly for the Internet of Things environment. Maity [10] exhibited mineral parameters like unusual gasses, temperature, and humidity on a system to prevent the presence of dangerous gasses and high environmental temperature to workers. Hermanus [11] investigated the performance of Occupational Health and Safety (OHS) against variations in the compositions of different sections in the mineral division of South Africa. They resulted that mining in South Africa suffers from a shortage of mutual interactions between workers and engineers, risk management education, and other things like these. Misra [12] described the common characteristics in a wide range of stressful environments, explained the factors that could affect communications while settling in these areas, and indicated the most challenging parameters in underground environments. Yarkan [13] studied underground communications, general issues that underground communication systems must consider, and various types of communications, methods, and their significance. Chehri [14] investigated and evaluated the UWB-based WSN navigation system with high accuracy in underground mines. The objective of these systems is to detect equipment and miners under regular operation or emergency conditions in the galleries of the underground mines. HongJiang [15] designed a real-time monitoring and alarm system based on CAN-BUS technology for underground areas and acquired data. S3C2410 microprocessor and ZigBee are implemented in this system as the central core of the system and wireless sensor network to transmit data, respectively. Chehri [14] introduced a navigation algorithm based on intelligent selection. This method only selects references that cause the navigation accuracy to be increased and minimizes the number of required iterations to correct the validity of the estimated location. Previous researches reported the same results [16-23].

The represented system in this research guarantees the performance of the system, relying on its alarm package. The novel insight is the detailed analysis of blow to head factor and converting it to the other factors by studying the contents related to the topic and bounding this factor instead of a number to judge. Also, the most transparent part of this design is increasing the managerial approach that added attendance evaluation platform and performance reporting to the system.

3. System Architecture

This project is a persistent monitoring system with the capability of monitoring parameters like:

- The presence of toxic gasses (methane, liquid gas, and Carbon monoxide)
- Temperature and humidity
- Helmet wearing detection
- Damage to the head scale.

The assessed values are transferred into the processor, and the processing operation is performed on the data. The processor compares the input data with the threshold limits (according to the present standards) and, by occurring unexpected unnatural conditions, activates the alarm protocol, including informing the control room operator and activating the alarm section installed on the helmet. This system includes safety helmets, data transmission, and monitoring sections. In the present set, the helmet plays the role of evaluating and transferring data to the data transmission section. The data transmission section provides the communication link between the safety helmet and the control room. In what follows, each section is discussed in more detail.

3.1. Safety Helmet Section

The structure of the safety helmet is demonstrated in Figure 3. This section is generally responsible for increasing safety (that is obvious), evaluation, processing, and transferring of data. The smart safety helmet has three subsections of evaluations, data transmission, and alarm. The responsibility and performance of these subsections are discussed in the following.

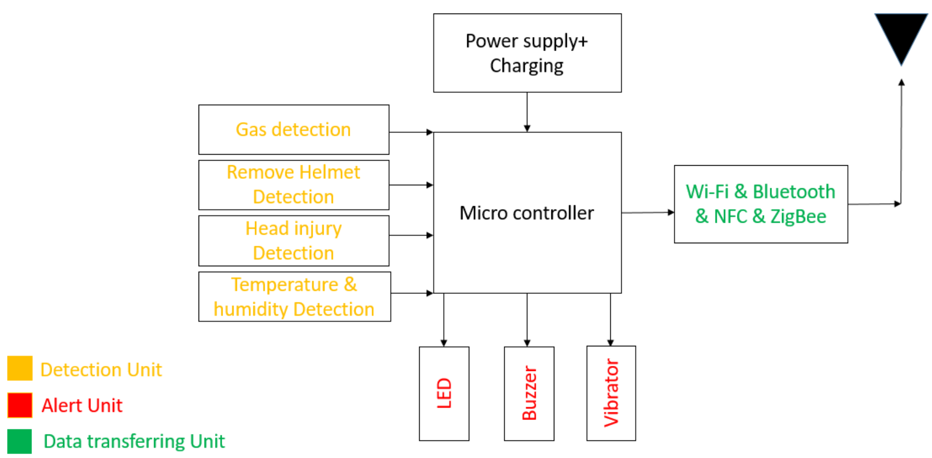


Figure 3. Architecture of the safety helmet.

3.1.1. Evaluation Subsection

This subsection has the responsibility of monitoring and includes DHT11, CNY70, MQ9, LM35, and ADXL345 sensors that are temperature and humidity, infra-red, gas detection, temperature, and accelerometer sensors, respectively. The type and method of operation by these sensors are described in what follows:

A) Gas measuring:

In underground mines, air pollution is caused by methane gas, sulfur dioxide, nitrogen oxides, carbon monoxide, and also hovering particles. When a person is exposed to toxic gases for a long time, it could cause physical damages. MQ9 sensors are utilized to measure liquid gases in this project. MQ9 gas sensor has a high sensitivity to carbon monoxide, methane, and LPG. This sensor is fabricated from a ceramic AL2O3 micro-pipe and a sensitive layer of tin dioxide (SnO2) using a plastic grid and anti-corrosion steel [24]. The detection performance of this sensor is through temperature and humidity variations, and the rising density of the gas increases the conductivity of the sensor. These sensors detect carbon monoxide gas while the temperature is falling. As the temperature is rising, this sensor detects gasses of methane, propane, and other flammable gasses [24]. As mentioned before, the sensor above has different responses to the density of gasses in various temperatures and humidities. Therefore, some temperature and humidity sensors must be applied at the proximity of these sensors.

Figure 4 represents the index of sensitivity of the MQ9 sensor in 20 degrees Celsius, 65% humidity, and oxygen density of 21%. As it is evident from the figure, the sensor's resistance has different responses for three kinds of gasses, including carbon monoxide, methane, and liquid gas. It is worth mentioning that these details are programmed by coding in the processor of the helmet and the developed software.

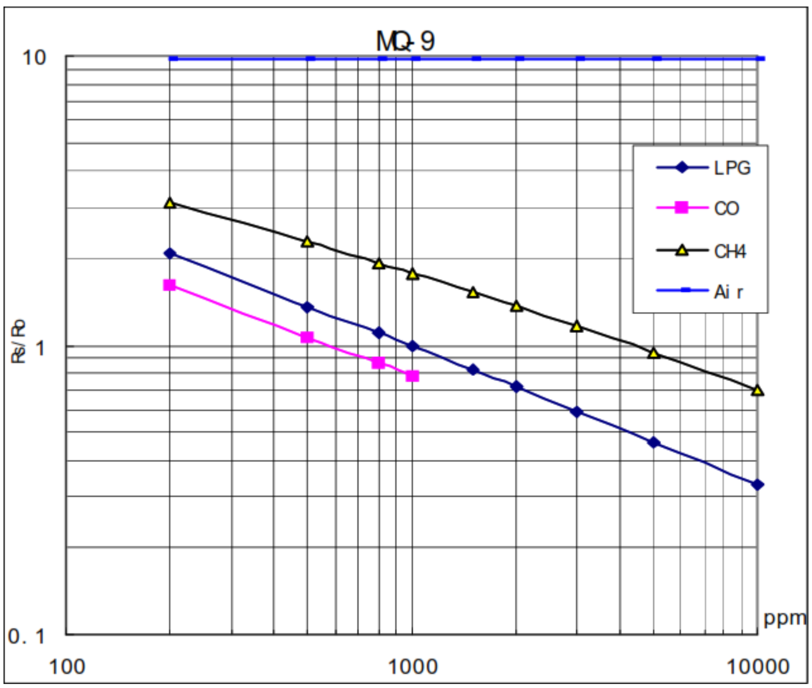


Figure 4. Sensitivity index of MQ9 sensor [24].

B) Helmet wearing detection

IR sensors are utilized to recognize whether a worker is wearing a helmet or not. The mentioned sensor is composed of a transmitter and a receiver. The IR transmitter is a light-emitting diode radiating IR rays. Although IR lamps look like a regular Light Emitting Diode (LED), the radiated wave is invisible to human eyes. IR receivers are renowned as IR sensors as well because they detect radiation from an IR transmitter such that an IR wave is illuminated on the head while wearing a helmet, and the receiver of this ray does not acquire any data. Otherwise, it is realized that the helmet is not worn after propagation of the wave and receiver's acquisition [25]. In addition, to increase the assurance of helmet wearing, IR sensors and accelerometers are implemented simultaneously. It could be deduced that the human head has a particular acceleration range by doing numerous experiments in various modes such as stationary, moving, etc. As a result, in case of not wearing the helmet, if the measured acceleration by accelerometer remains unchanged, wearing or not wearing the helmet would be detected. One of the other anticipated applications of these sensors is reporting the personnel's working hours and attendance performance.

C) Blow to head detection

According to the Federal Motor Vehicle Safety Standard 208 (FMVSS 208), a scale is defined with the symbol of HIC to detect the blow to the head, which should have values not exceeding 1000. This value is calculated using equation (1) [26-30].

$$HIC(\Delta t_{max}) = \max\left[\left(\frac{1}{t_2 - t_1}\int_{t_1}^{t_2} \hat{a}dt\right)^{2.5}(t_2 - t_1)\right] \quad (1)$$

The damage scale is known as a measuring scale. The severity of the damage could be evaluated using the Abbreviated Injury Scale (AIS) that is varied from AIS(0), meaning no damage up to AIS(6), meaning unavoidable damage [28]. In order to validate and calibrate the relation between the injury scale and the damage to head scale, some experiments should be performed under certain circumstances. HIC is a damage scale related to a skull fracture (AIS ≥ 2) and brain injury (AIS ≥ 4). The conversion from HIC into damage scale could be achieved by referring to the data plotted on figures 5 and 6 that are represented according to the experiments by Mertz [31] to detect the presence or absence of skull fracture and intracranial hemorrhage. Furthermore, it is noted that the accelerometer produces wrong measurements. To overcome this design issue and compensate for it, the accelerometer is placed in the helmet rather than its plastic tape, which holds the head [32].

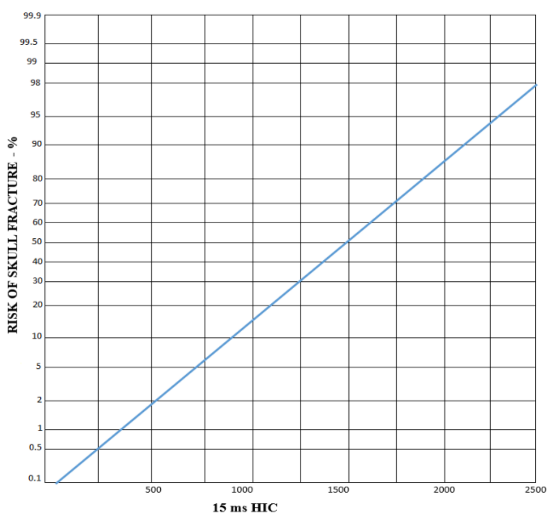


Figure 5. Skull damage scale as a function of HIC15 function [31].

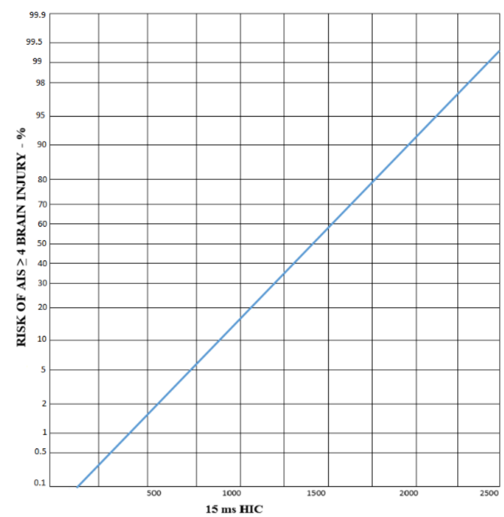


Figure 6. Brain injury scale as a function of HIC15 function [31].

D) Temperature and humidity detection

The lack of appropriate ventilation in underground mines leads to temperature and humidity rise in these spaces that could cause reduced efficiency of the production process. Therefore, real-time and continuous monitoring of the temperature and humidity of the workplace is an unavoidable issue. On the other hand, to measure the density of the gasses precisely, the need for temperature and humidity sensors is obvious. The implemented temperature sensor in this project is DHT11, one of the accurate temperature and humidity sensors with an analog output with a linear dependence on the environment's temperature in degrees Celsius. One of the advantages of this sensor is measuring the temperature on a Celsius scale, while most sensors work on the Kelvin scale. In addition, the humidity measured and represented by this sensor is in the form of relative humidity. This sensor does not need further calibrations [33].

3.1.2 Data Transmission Subsection

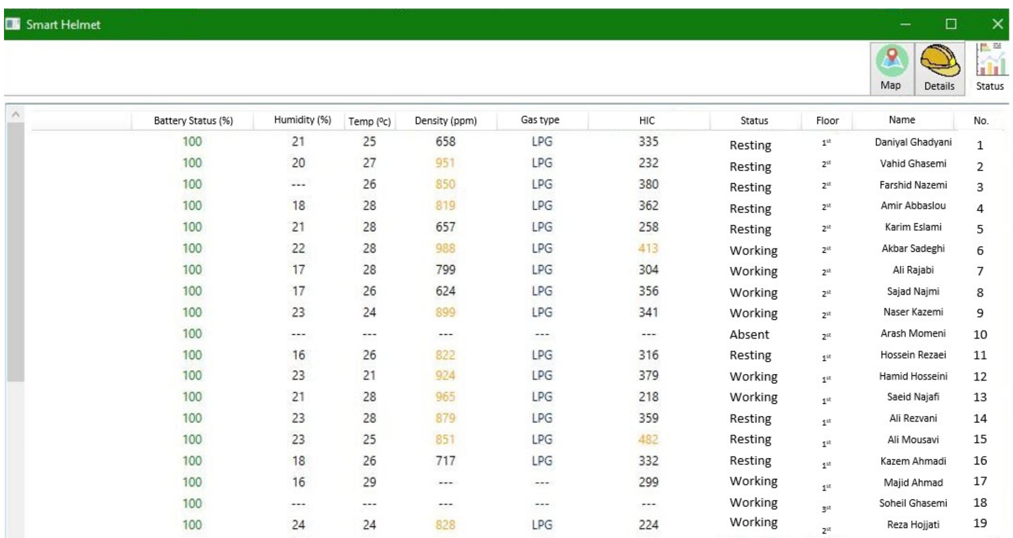
After processing data acquired from the evaluation subsection, the processor must send these data to the control room for monitoring and decision making. So, in order to transmit mentioned data, we decided to use a radio module. The processor is the core of the project because it processes the evaluated data from sensors and communicates with the data transmission subsection according to its predefined responsibilities [34]. The ZigBee module is a wireless chip signals of which are capable of penetrating the walls and conforming to underground mine circumstances. The standard ZigBee module has a digital interface that allows every processor or microprocessor to rapidly use this protocol's services. ZigBee's performance is conformed to the IEEE 802.15.4 standard [15]. ZigBee systems could be programmed to work in various network topologies like the star, light mesh, mesh, and clustered tree, four of the most applicable structures. Temporal networking structures are used where a node should send the information to all other nodes.

3.1.3. Alarm subsection

Alerting the mineworkers is a tricky process due to working conditions. There is not enough light in the space of underground mines, so the workers use safety helmets with replaceable mineral lamps. The utilized equipment generates too much noise and vibrations due to space limitations. The alarm subsection is composed of vibration, alarm buzzer, and LED units to overcome the mentioned problems. The considered protocol for alarm subsection is capable of responding in various conditions.

3.2. Monitoring Subsection

After acquiring the processed data, all of this information will be transferred into a software through a wireless network platform. The provided software has the duties of on-time detection of the occurred dangers and activation of the relief and rescue protocols. Figure 7 shows the developed software.



Battery Status (%)	Humidity (%)	Temp (ºc)	Density (ppm)	Gas type	HIC	Status	Floor	Name	No.
100	21	25	658	LPG	335	Resting	1st	Daniyal Ghadyani	1
100	20	27	951	LPG	232	Resting	2st	Vahid Ghasemi	2
100	---	26	850	LPG	380	Resting	2st	Farshid Nazemi	3
100	18	28	819	LPG	362	Resting	2st	Amir Abbaslou	4
100	21	28	657	LPG	258	Resting	2st	Karim Eslami	5
100	22	28	988	LPG	413	Working	2st	Akbar Sadeghi	6
100	17	28	799	LPG	304	Working	2st	Ali Rajabi	7
100	17	26	624	LPG	356	Working	2st	Sajad Najmi	8
100	23	24	899	LPG	341	Working	2st	Naser Kazemi	9
100	---	---	---	---	---	Absent	2st	Arash Momeni	10
100	16	26	822	LPG	316	Resting	1st	Hossein Rezaei	11
100	23	21	924	LPG	379	Working	1st	Hamid Hosseini	12
100	21	28	965	LPG	218	Working	1st	Saeid Najafi	13
100	23	28	879	LPG	359	Resting	1st	Ali Rezvani	14
100	23	25	851	LPG	482	Resting	1st	Ali Mousavi	15
100	18	26	717	LPG	332	Resting	1st	Kazem Ahmadi	16
100	16	29	---	---	299	Working	1st	Majid Ahmad	17
100	---	---	---	---	---	Working	3st	Soheil Ghasemi	18
100	24	24	828	LPG	224	Working	2st	Reza Hojjati	19

Figure 7. Status tab in the developed version of the software

4. Performance Style

At first, an identification number is assigned to the helmet of every person that facilitates attendance evaluation, identification of working people in workstations, and conforming to personal hygiene. It is worth mentioning that to do data transmission experiments in mines, the Tabas coal mines are selected, and initial data transmission experiments have been performed there successfully.

4.1. Introduction to Tabas coal mines

The Parvadeh region is one of the coal regions of Tabas, with an area of 1200 square kilometers and coal layers extending over 40 kilometers. This extension, along with the continuity of coal layers in the whole region, is unique and enables the design of numerous mines in their proximities.

The Parvadeh region includes Parvadeh No. 1, Parvadeh No. 2, Parvadeh No. 3, Parvadeh No. 4, Parvadeh No. 5, and East Parvadeh. The coal regions are demonstrated in figure 8. In this article, the data transmission experiment is implemented in two areas of Parvadeh 4 and East Parvadehh.

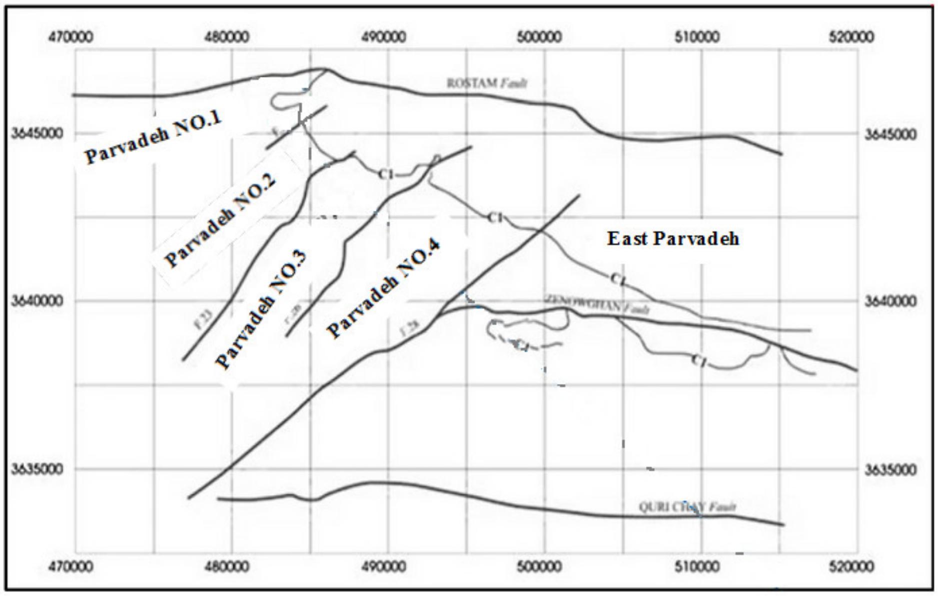


Figure 8 Plan of coal regions of Parvadeh area (with no scales) [35].

Parvadeh No. 4 deposit is located 85 kilometers south of Tabas city. The coal in Kansar Parvadeh No. 4 is generated in a large synclinal along with shale rocks, sandstones, siltstones, and upper Triassic Basin carbonate stones. Regarding geological and sedimentology observations, it seems these stone units have sedimented in a free marine environment. The coals from Parvadeh No.4 deposit are bituminous coking coals with high sulfur ratios (Yazdi 2004). East Parvadeh No.4 deposit is located 120 kilometers southeast of Tabas city. East Parvadeh is in the eastern part of the coal region of Parvadeh after Parvadeh No. 4 region. The area has a smooth topography, and high mountains do not exist [35]. The tunnels openings are through two central ramp accesses. Both tunnels start with a 12-degree slope inside the layer and continue with a slope of 16 degrees. One of the tunnels is equipped with a conveyor for hauling purposes, and the other is designed for various services of the mine using a winch [36].

4.2. Designed Radio Module

A wireless communication system simply consists of a transmitter and a receiver. The responsibility of the transmitter is to convert the considered message to an electric signal and then convert the electric signal to radio waves. At the destination, the receiver is responsible for acquiring waves and converting them into electric signals, amplifying them, and finally extracting the considered data from them. Radio communication systems work in different frequencies that are categorized as represented in Table 1 [37].

Each of the frequency bands is utilized for particular applications based on its feature. For instance, marine communication is generally performed in lower frequencies such as VLF. At the same time, terrestrial communications are in higher frequencies like FM radio in VHF (88~108MHz), television signals (600~700MHz), Mobile (900MHz and 1800MHz), and Bluetooth-based and WiFi-based systems (2.4GHz). In general, the waves with frequencies equal to or higher than 1GHz are called Microwaves, and the waves with frequencies equal to or higher than 30GHz are called Millimeter waves [37]. Therefore, to resolve one of the primary requirements of this project in underground mines that is data transmission, an infrastructure is provided in this project using a communication platform in the UHF band. Figure 9 represents the radio module. Using this module in Tabas coal mines, a data transmission test has been designed and performed. Regarding the tilts in the main tunnels and access horizons, data transmission is successfully accomplished by a 190-meter transmission in one horizon with four inclinations and no direct vision and a 430-meter transmission in the main slope, including three ramps of 12%, 14%, and 16%.

Table 1. Different frequencies of radio communications [37].

3KHz – 30KHz	VLF	Very Low Frequency
30KHz – 300KHz	LF	Low Frequency
300KHz – 3MHz	MF	Medium Frequency
3MHz – 30MHz	HF	High Frequency
30MHz – 300MHz	VHF	Very High Frequency
300MHz – 3GHz	UHF	Ultra High Frequency
3GHz – 30GHz	SHF	Super High Frequency
>30GHz	EHF	Extreme High Frequency

Figure 9. Designed radio module for testing data transmission in the tunnels of underground mines

The software has a page called "report" responsible for continuous data acquisition and uploading the data in a cloud storage space. Figures 10 and 11 exhibit the sent reports using a smart safety helmet and a plot of mine. According to the standards mentioned earlier, the safety zones for each factor are measured. In case of exceeding the predefined threshold by any factor, the factor is indicated in red in the software.

Finally, the most important managerial section is performance reporting. Figures 10 and 11 provide a unified representation of the performance report that indicates the working time in green and the stopping time (for any reason) in red.

4.3. Discussion

In order to test the concept, practical trials were conducted in Parvadeh Four and East Parvadeh of Tabas coal mine to verify the reliability of data transmission, resulting in successful outcomes. The underground space design complexity affected the results, allowing data transmission up to 430 meters in a straight path. However, further progress was impeded by tunnel limitations. In areas with curved or inclined access horizons, data transmission was limited to 190 meters. Specific thresholds are established for each scenario based on current standards. Exceeding these thresholds in critical situations triggers the activation of the alarm protocol. Consequently, the helmet user and software operator are notified about the potential danger and are tasked with resolving the issue. The system implemented in this study ensures operational reliability through its alarm system. A unique aspect of this research is the comprehensive analysis of head impact, converting it into other parameters by studying relevant material and replacing this factor with a criterion for evaluation. Another notable feature of this design is the enhanced managerial approach, which introduces attendance evaluation and performance reporting to the system.

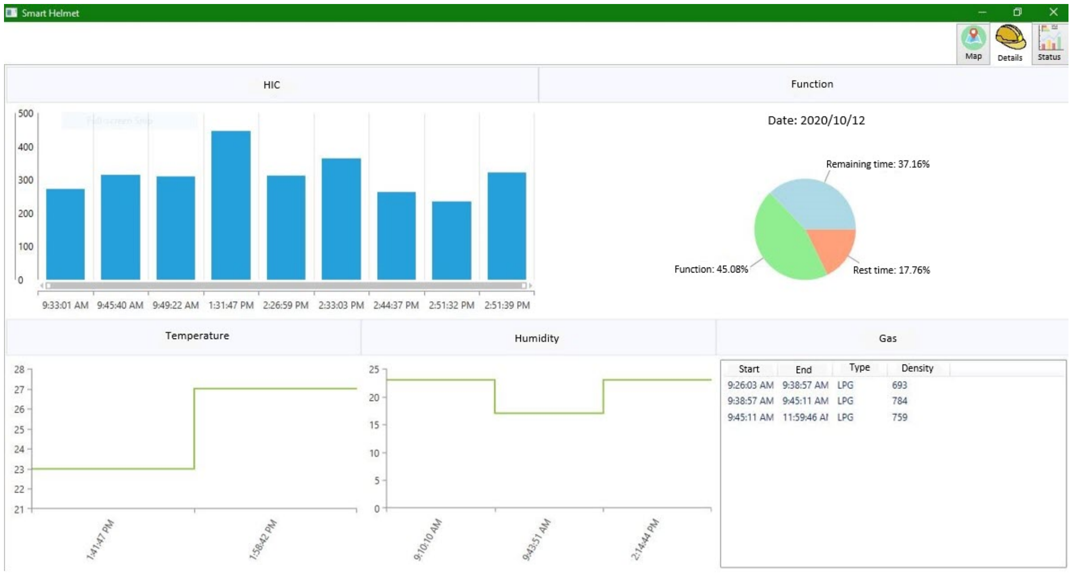


Figure 10. Graphical representation of typical data in the "Details" tab.

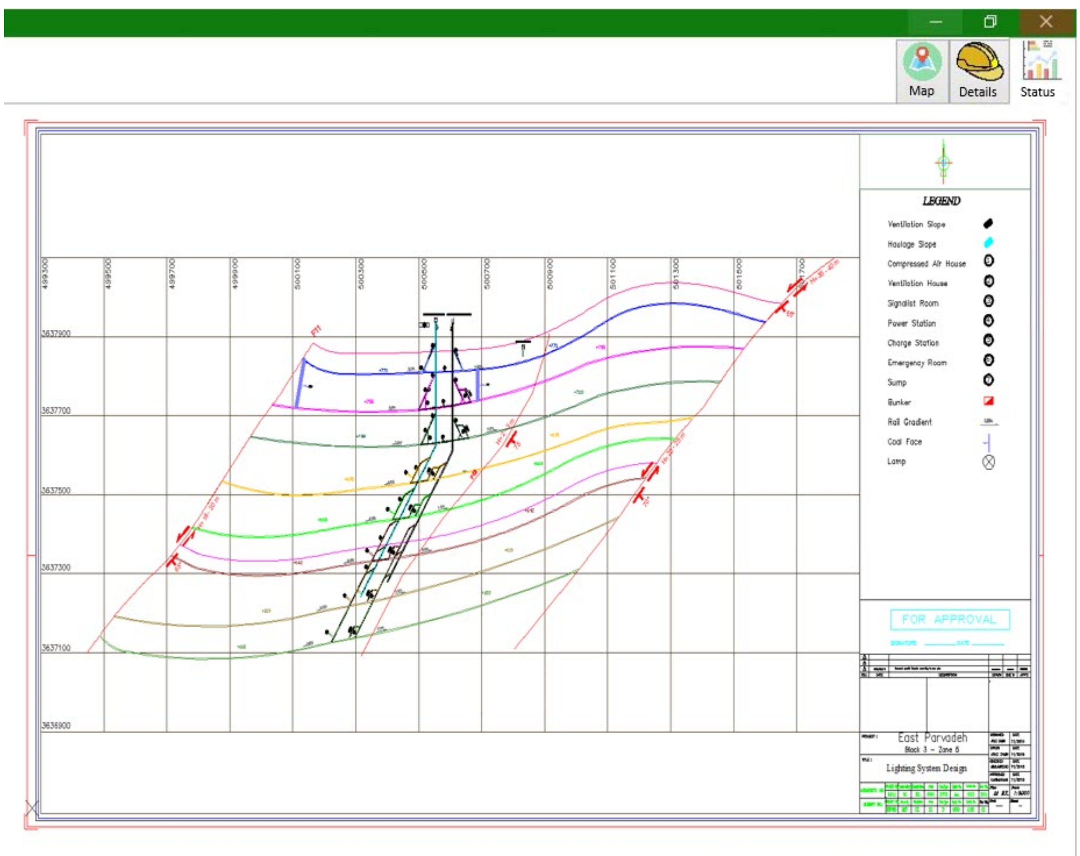


Figure 11. Graphical representation of a mine in the developed software.

5. Conclusions

A real-time monitoring and alarm system is essential for detecting dangerous accidents such as the presence of harmful gasses, helmet removal by workers, object drop off on the head of a worker, and transmitting data to the relevant administrators. Therefore, the smart safety helmet is successfully designed and tested for the mining industry to detect and register dangerous events. Appropriate hardware is implemented precisely for each of the considered performances of the safety helmet based on the current standards and by relying on the performed researches. The recent endeavors help to improve the performance of the system. The installation of this system is quick and simple and has high reliability. The result of all these actions is graphically implemented and displayed in the user interface. The user can make the required decisions using the developed software in different conditions. One of the other outputs of the system is the conversion of the blow to the head into the damage scale, which could facilitate and speed up the rescue effort to the damaged person in critical circumstances.

Conflict of interest

No conflict of interest exists in the submission of this manuscript, and the manuscript is approved by all authors for publication.

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سیستم مانیتورینگ و هشدار آنی برای گاز سمی در معادن زغالسنگ زیرزمینی با استفاده از کلاه ایمنی هوشمند

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چکیده:

با توجه به شرایط کاری پرخطر در معادن زیرزمینی، نظارت همزمان و سیستم هشدار برای افزایش ایمنی حیاتی است. با تحلیل حوادث معادن زیرزمینی در ایران می‌توان دریافت که بیشترین تلفات ناشی از نشت گاز، ریزش اجسام بر روی سر و عدم استفاده کارکنان از کلاه ایمنی است. از این رو کلاه ایمنی هوشمند با قابلیت اندازه‌گیری گازهای مضر (از نظر نوع معدن)، تشخیص وجود کلاه ایمنی روی سر، اندازه گیری دما و رطوبت و تشخیص ضربه به سر برای حذف طراحی و ساخته شده است. خطرات و مشکلات موجود این سیستم داده‌های ارزیابی شده را بر روی یک نرم افزار توسعه یافته از طریق سخت افزار انتقال داده بی‌سیم نمایش می‌دهد. سخت افزار انتقال داده، رابط اصلی بین کلاه ایمنی هوشمند و نرم افزار است. برای پیروی از این ایده، آزمایش‌های عملی در پروده چهار و پروده شرقی معدن زغال‌سنگ طبس برای تأیید صحت انتقال داده‌ها انجام شده است که نتایج موفقیت‌آمیزی را به همراه داشت. نتایج به دلیل پیچیدگی طراحی فضاهای زیرزمینی تغییر یافت، به طوری که در جهت مستقیم، انتقال داده‌ها تا ارتفاع ۴۳۰ متری انجام شد. با این حال، به دلیل محدودیت‌های تونل، پیشرفت بیشتر امکان‌پذیر نبود. انتقال داده‌ها در افق‌های دسترسی با انحنا یا کج به ۱۹۰ متر کاهش یافت. طبق استانداردهای موجود، برای هر یک از موارد ذکر شده آستانه‌هایی تعریف شده است که در شرایط بحرانی، پروتکل هشدار فعال می‌شود. سپس کاربر کلاه ایمنی و اپراتور نرم افزار از خطر رخ داده مطلع شده و مشکل را برطرف خواهند کرد .سیستم مشخص شده در این مطالعه قابلیت اطمینان عملکرد را از طریق بسته هشدار خود تضمین می‌کند. یک نوآوری کلیدی، بررسی عمیق تأثیر صدمات سر، تبدیل آن به عوامل دیگر با تجزیه و تحلیل محتوای مرتبط و تعیین مرزهایی برای ارزیابی به جای استفاده از اعداد خاص است. علاوه بر این، بارزترین جنبه این طراحی، ارتقای رویکرد مدیریتی است که شامل یک پلت فرم ارزیابی حضور و غیاب و گزارش عملکرد در داخل سیستم است.

کلمات کلیدی: معادن زیرزمینی، کلاه ایمنی هوشمند، نظارت هوشمند، انتقال داده‌های بی‌سیم.