

A Review Paper on Smart Helmet for Air Quality and Hazardous Event Detection for the Mining Industry

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Abstract: A smart helmet has been developed that can recognize hazardous conditions in the mining sector. When constructing the helmet, consideration was given to the three main types of hazards: air quality, helmet removal, and collision (miners are hit by an object).

The first is the degree of concentration of dangerous gases like particulate matter, CO, SO₂, and NO₂. The second risky incidence was a miner removing their mining helmet. The attempted development of an infrared sensor led to the successful usage of an off-the-shelf infrared sensor to detect when the miner's helmet is on his head. According to the Head Injury Criteria (HIC), the third risky occurrence occurs when miners are struck in the head by an object with a force greater than 1000. An accelerometer was used to measure the head's acceleration, and software was used to calculate the HIC. The layout of the visualization program was completed, but it was not executed properly. The calibration tests of the accelerometer were successfully finished. Among the PCBs made were a prototype board and a breakout board. The Contiki operating system served as the foundation for the entire software implementation that controlled sensor measurement and a computation using the measured values. The undertaken design, which includes remedies to the problems identified in earlier study, is presented in this publication.

Keywords: ZigBee, wireless sensor networks, safety, mining, and air quality.

I. Introduction

The safety helmets don't have any built-in technology that would notify miners when a co-worker has been in danger. In order to increase the safety of an existing mining safety helmet, the research described in this paper aimed to integrate a wireless sensor node network. The device's design was extended to make it long enough to run on battery power and compact enough to fit inside the safety helmet. Making changes to the helmet without altering its structural integrity presented another difficulty. There had to be as little extra weight as possible.

Intelligence must be included to mining helmets in order to increase worker safety. A miner must be alerted when he takes off his helmet. Even when wearing a helmet, a miner may become unconscious or paralyzed if an object falls on him. Whether or not a miner has suffered a potentially fatal injury must be determined by the system. These two incidents fall under the category of dangerous incidents. Thirdly, hazardous gasses must be identified and reported.

Real-time mine hazard monitoring and control is more complicated in the field of mining technology. Mine safety modules are set up to speak with a central station or ground control. Hazardous gasses are a major problem in mines. Strong vibrations and increased concentrations of harmful gasses, such as CO, SO₂, NO₂, and particulate matter, can be produced by mine systems. Miners don't always keep an eye on one another, and working conditions can be extremely noisy. Miners typically work in groups and keep a distance of no more than five meters (m) from one another. A warning system must be installed to notify miners within a 5-meter radius when a miner is going through a hazardous event. The event must be processed and transmitted by this system in one second (s). These devices use gas sensors to measure the miner's surroundings before implementing evacuations. These either don't notify the miner at all or just notify them audibly. These methods alert miners, however ground control must provide an external input if a miner is hurt or impeded [3][5]. Harvesting technology has been a significant factor in mining applications in recent years. There is some literature about mining technology, although it is somewhat sparse. Nutter et al. proposed a system for identifying safety hazards inherent in subsurface monitoring and control. They also created devices that could pose a safety risk. They created techniques based on computer-based hardware/software systems and analytical electronics [6]–[8]. The technology was created by Kock et al. with the South African coal mining industry's productivity, safety, and health in mind. Additionally, they are looking into productivity, coal interface detection, and communication methods (radio, power lines, optical fibers, and infrared). A case study on mines is presented by Misra et al. Among the communication methods they examined were through the wire (TTW), through the air (TTA), and through the ground (TTE) [10].

With an emphasis on contemporary wireless channel modelling, technology, and applications, Forooshani et al. Provide a comprehensive overview of wireless propagation in tunnels and underground mines [11]. With smarter equipment, it can also increase mining safety because more industrial applications are using the Internet-of-things, which makes all devices smart and connected [12], [15]. The literature also shows that, despite several attractive solutions, relatively few have been implemented and tested in the actual world, indicating a scientifically acknowledged gap between theory and reality. This study presents a smart helmet that complies with IEEE 21451 requirements. It offers many cutting-edge features, like minimal response time, portability, affordability, and accurately acceptable accuracy.

System Overview

Given that any new safety equipment that is not lightweight and unobtrusive will simply be removed, along with all the other safety equipment, it was difficult to solve the issue of miners taking off their gear. Because miners typically just wear their helmets, this is where the new safety gear was introduced. An accelerometer, an air quality sensor, and an infrared (IR) sensor were the three sensors that were used. These were used to assess the local air quality and ascertain whether a miner had removed his helmet or been struck in the head.

The three sensors were connected to a ZigBee module.

Using the Contiki operating system (OS), this module manages wireless communication between individual helmets in addition to handling all processing. Because the system runs on battery power, the entire system was examined during the design phase to minimize power usage. To keep the power level as low as feasible, different sensors were taken into consideration for each individual component. The system will be described. Component by component in order to explain the whole system and the options for each part. Helmet removal sensor, collision sensor, air quality sensor, data processing unit, wireless transmission, and alerting unit are the six parts of the system. The smart helmet's block diagram for mining safety is shown in Figure 1. Figure 2 displays the created prototype mining safety model. The prototype was developed in accordance with IEEE 21451 [12].

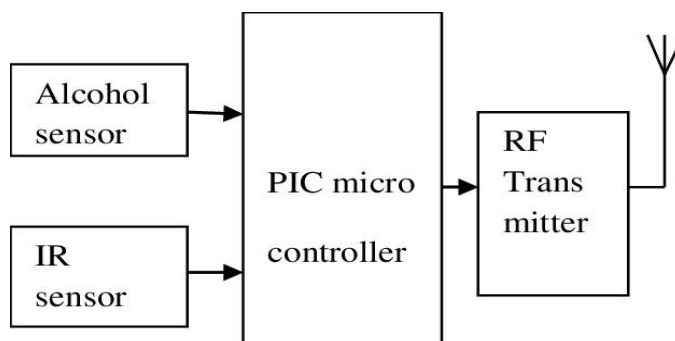


Fig.1The Smart Helmet's functional block diagram

Air Quality Sensor

Particulate matter and gases such as carbon monoxide (CO), sulfur dioxide (SO₂), methane (CH₄), and nitrogen oxides (NO₂) are the primary sources of air pollution from coal mines. It has been established via numerous research that human health may suffer when exposed to these substances or contaminants. Asthma, chronic bronchitis, and cardiovascular issues are all made worse by these imbalanced ratios of air pollution gases, such as suspended particulate matter [13]. We have measured the CO, SO₂, and NO₂ in this post. Per the literature we have chosen the electrochemical gas sensor because of its accuracy and low power consumption in the development of air quality detectors. Additionally, these sensors exhibit high selectivity for the target gas. Table 1 provides a summary of the features of the sensors that were utilized. The block diagram for air quality monitoring and hazardous gas critical level warning is shown in Fig. 3.



Fig.2 An intelligent helmet module for mining security.

We have utilized SGX Sensor Tech's electrochemical CO, SO₂, and NO₂ sensors. The electrochemical sensor's advantages, disadvantages, typical signal conditioning circuit, and mathematical formulation (output sensor signal conversion to gas concentration) were described in [13]. Regarding the CO content, it should always be kept below 4 ppm, however healthy individuals can take up to 6 ppm without experiencing significant health impacts [13]. The maximum CO, SO₂, and NO₂ gas concentrations for the developed system were set at 4 ppm, 0.2 ppm, and 0.10 ppm, respectively. A ZigBee transmitter module sends a signal to the helmet's alerting unit whenever an increase in the concentration level of air quality parameters is noticed. ppm, 0.2 ppm, and 0.10 ppm, respectively. If increases in the concentration level of air quality parameters are observed, then a signal is transmitted through a ZigBee transmitter module to the alerting unit of the helmet.

Helmet Removal Sensor

A number different method was taken into consideration in order to detect the helmet being removed. [1]–[11] reported on the comparative analysis, benefits, and drawbacks of the suggested methods in the literature. For this experiment, the IR beam based helmet remove sensor technology was judged superior to other alternative tactics including a switch, analogue distance sensor, and digital distance sensor. It is possible to construct the infrared beam to consume minimal power. Component by component in order to explain the whole system and the options for each part. Helmet removal sensor, collision sensor, air quality sensor, data processing unit, wireless transmission, and alerting unit are the six parts of the system. The smart helmet's block diagram for mining safety is shown in Figure 1. Figure 2 displays the created prototype mining safety model. The prototype was developed in accordance with IEEE 21451 [12]. For this application, a commercially available infrared distance detector was employed. Using the circuit depicted in Figure 3, the infrared sensor was designed to transfer a continuous signal from one side of the helmet to the other.



Fig.3 Block diagram of the air quality monitoring and hazardous gas critical level alerting device

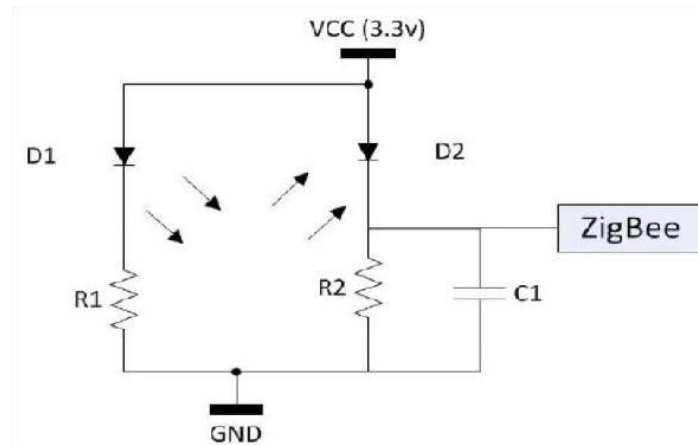


Fig. 4. The IR circuit schematic was created using IEEE21451 standards

Collision Sensor

A bump must surpass a specific threshold for a predetermined period of time in order to be considered truly harmful Federal Motor Vehicle Safety Standard 208 states that a Head Injury Criteria (HIC) cannot exceed 1000 (FMVSS 208).

The variables t_1 and t_2 represent the beginning and ending times, respectively, and $a(t)$ represents the acceleration over time. To measure the system's acceleration, an accelerometer was required. At least 70 g in three axes have to be measurable by the accelerometer. The ADXL377 accelerometer met all requirements. The application of the HIC equation has certain restrictions. There should be no more than 36 milliseconds (ms) in the time span $t_2 - t_1$. The time constraint restricts the equation to hits rather than continuous accelerations. Additionally, it is claimed that skull deformation can cause the accelerometers to provide erroneous readings. The accelerometer is mounted on the helmet rather than the plastic strap that holds the head in order to compensate and overdesign. By doing this, the accelerometer will be able to identify an acceleration in the helmet that is greater than the actual acceleration of the miner's head.

Wireless Transmission

It was necessary to transmit wirelessly between the various nodes. The three wireless system types that are feasible for the system requirements are Bluetooth, Wi-Fi, and ZigBee. ZigBee was designed to be a low-cost, low-power, low-data-rate gadget. The

advantages of ZigBee are identical to those of a Wi-Fi system. The IEEE 802.15.4 standard serves as the foundation for ZigBee [13], [16]. When routers and access points cannot be installed, a ZigBee module is a superior choice since it can be used to create bigger mesh networks more effectively than Bluetooth. In [3], every component is Velcroed to the safety helmet. To assist protect them from shocks and gasses, some of the components are contained inside the helmet.

However, if a miner experiences a particularly severe bump, this might lead to electronics becoming buried in their head. Because ZigBee modules' signals can pass through walls and function effectively in mines, they are the wireless chip of choice in [4]. Wi-Fi, or wireless, is occasionally used in mines, although it requires cable to the routers throughout the underground, which might get damaged [13]. A study was carried out to determine the best frequency to use in mines because the attenuation of signals over distance affects the signal's travel distance. The optimal frequency was determined to be 2.4 gigahertz (GHz). It was discovered that the signal was effective up to 15 meters away from the transmitter. [14]–[20]. The four most popular network architectures that ZigBee systems can be configured to operate in are star, light mesh, mesh, and cluster tree. When just a small number of nodes can access information that one node needs to send to all other nodes, mesh architectures are utilized. Mesh network architecture is also beneficial since it establishes several channels to every node. The advantages and disadvantages of ZigBee communication were examined in [13]–[22].

University of Data Processing

The original plan was to use a Raspberry Pi as the main processor and a ZigBee module as the wireless communication terminal, in accordance with an open hardware design [23]. The ZigBee module and the sensors would be connected to the Raspberry Pi.

The ZigBee module would be controlled and the sensors would be measured by the Raspberry Pi. After that, the user interface for viewing the logged data would be created using the Raspberry Pi. Power consumption was the first problem, and communicating with the Raspberry Pi was the second.

Because the system would be powered by a battery, the Raspberry Pi's power consumption was an issue because it is far higher than that of the ZigBee module. Since the Raspberry Pi would not have an integrated display, which would significantly limit the product's longevity, the interface issue was brought on by the difficulties of connecting to the device. Using a network cable to connect to the Raspberry Pi is the only alternative. Only then would the user interface be available. For the mining scenario, this network design would be a difficult and impractical procedure. After additional research, the ZigBee module ATZB-24-A2 wireless chip was chosen. It has an adequate amount of computing power and an integrated electronically erasable programmable read-only memory (EEPROM). The space and power consumption of any extra processing units would increase.

Alerting Unit

Considering the typical working circumstances found in a mine, alerting workers can be a challenging procedure. Because underground mines are extremely dark, miners wear safety helmets with integrated or detachable mining lights. The claustrophobic confines in the subterranean tunnels exacerbate the noise and vibrations produced by the equipment used in underground mines. The issue with the noise is that if a miner is facing a dangerous situation, using a speaker or an alarm system to alert them would probably be ineffective because they wouldn't hear the alarm. A second option that was considered was a vibrating unit inside the mining helmet. It would be effective to warn a miner using a vibrating helmet. However, it is likely that a miner operating near or with equipment that produces a lot of vibration will experience or mistakenly perceive the vibration as a component of the equipment's vibration. As a result, the system will only function under particular circumstances. The goal would be for the system to function in any situation. Light-emitting diodes (LEDs) mounted on the mining helmet's cap were also taken into consideration because they would serve as a visual alarm for the miner. Then, it was determined that integrating LEDs into a mining helmet that already had a large light attached to it would need no use of the resources that were available. Consequently, it was decided to install a system that will notify the miner by flashing the mining light repeatedly. Utilizing the miner's helmet light while they are experiencing the hazardous occurrence is an additional advantage of adopting this warning approach. The miner's position and the person experiencing the issue are both indicated by the light flashing continuously.

II. Experimental Work

Test of Air Quality

We have created the AQ sensor employing the static chamber approach and used the known gas concentration cylinder in the air quality testing procedure. The designed system is tested in an incubator. A rectangular plastic box with an opening on the side to accommodate a conduit for pumping in gas is all that the incubator is. After being turned on, the sensor node is inserted into the incubator and shut off. The gas was pumped into the incubator using gas cylinders. The gas concentration is then measured by the sensor node. Although the concentration levels were estimated and the system's accuracy was assessed, there was nothing to compare the measurements against because off-the-shelf air quality monitoring equipment is so costly.

Test for Helmet Removal

The purpose of this test is to show that the system can detect when the helmet is completely separated from the dummy head. To pass the test, the system must be able to identify when the helmet is being taken off with an accuracy of more than 90%. The helmet was connected to the PC via its USB port. The helmet was attached to the dummy head. Instead of sending the data over

the wireless network, the node was set up to send it via the USB port. The serial data was continuously shown on the computer. The helmet was then slowly removed until the serial port was notified by the infrared sensor that it had been removed. The distance between the interior of the helmet and the top of the dummy was measured. Ten iterations of the test were conducted.

Impact Evaluation

In this section, we examined the impact measurement from the accelerometer in two distinct scenarios. The first illustrates how a dangerous force, such as a hammer, could cause a dangerous incident. The second is a bump caused by a non-hazardous force, such as a human hand striking the helmet, demonstrating that it wouldn't cause a dangerous situation. As new information emerged from the results, the hammer test was modified a few times. The hammer was dropped ten times from a height of one meter above the helmet in the final hammer test.

The accelerometer was installed inside the safety helmet with a sampling rate of 250 Hz and a wooden bowl serving as the dummy head. The graphs in Fig. 5 were created by importing the data into Matlab once it was sent to the computer via USB. Two impacts were used for the hand test. The initial impacts involve mimicking a joke from a fellow miner and softly striking the miner's helmet. The second hit simulates a more powerful strike while maintaining a non-lethal force. Fig. 6 displays the findings.

Test of Wireless Transmission

The purpose of this test was to determine the degree of data transmission success and whether or not the wireless transmission between the nodes meets the minimal requirements of delivering data across a distance of more than five meters. Setting up a single node to transmit constantly per second at a distance of 0 m (the stationary point). The second node was positioned 8 meters beyond the designated distance, at intervals ranging from 1 to 13 meters. The second node was set up to use the USART to send and receive the data, establishing a computer connection and saving the first 100 seconds of the received system clock. The test was conducted in a setting where individuals were traveling within line of sight and there was a Wi-Fi network with the router located in the centre of the transmission, and the data for each distance was recorded and examined.

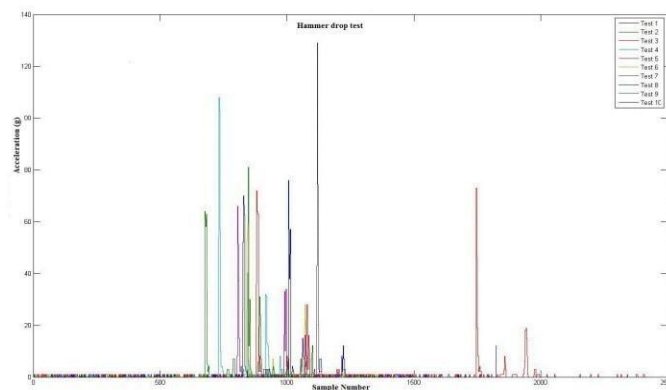


Figure 5: Accelerometer readings from a helmet impact test after a hammer is dropped.

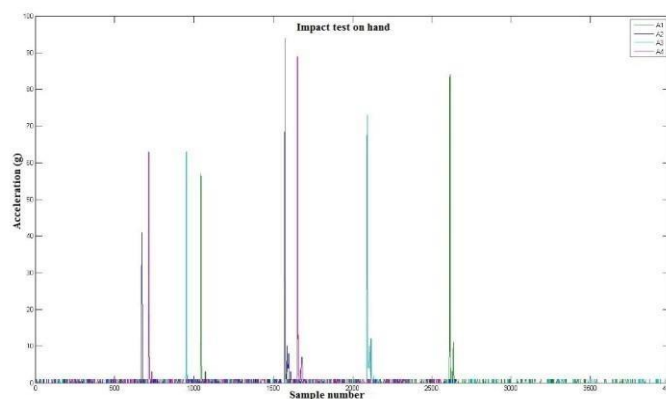


Figure 6: Accelerometer readings from a hand-held impact test on a helmet.

The data received and the associated system time were displayed in the findings. The 100 transmitted signals were then sorted into those that were successfully received, those that were skipped, and those that were received more than once. After that, Matlab was used to import the thirteen distances' data. The graph in Fig. 7 was then used to depict these findings. The top blue line shows the number of numbers that were received more than once, while the green peaks show the number of broadcasts that were not received.

III. Outcome and Conversation

Alerting units have identified the critical concentrations of dangerous gases, including CO, SO₂, and NO₂, in the mining sector. The helmet removal test was successfully finished using an infrared distance sensor that is sold commercially. Designed from the ground up, the infrared sensor was a working device. It was discovered that when the system was integrated, the sent infrared signals bounced off the dummy head and then off the surface of the helmet until they got to the receiver. The signal at the receiver side was almost the same amplitude as the signal received when the helmet was removed from the head. As a result, the system is unable to determine whether the helmet is removed or not. Because the alert signal was continuously generated by the system, the test results were not added.

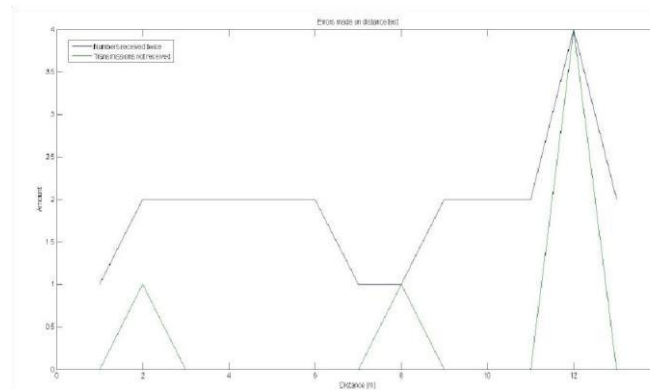


Fig.7. Distance test mistake, showing a transmission that was not received and transmission received more than ones.

An off-the-shelf infrared sensor was then used for the test. It produced the anticipated and necessary outcomes for the exam to pass. The system correctly detected when the helmet was removed 10 cm from the dummy head, with an average variation of 0.3% too far. As a result of these findings, any miner who removes the helmet entirely from their head as instructed will cause the alert signal to sound. Figure 5 showed the consistent values, which ranged from 81 g to 64 g, with an average of 71 g. According to the results in Fig. 6, the average weight of the first impact was 56 g, but the average weight of the second, more severe impact was 85 g. The outcome demonstrated that the accelerometer required more precise calibration because its output was scaled incorrectly. The test could not be repeated since the accelerometer was calibrated correctly, which is 80% g of the values displayed above. Additionally, the test revealed that the accelerometer's sampling interval was insufficient. Since the ZigBee module only has one ADC and various ports are connected to it via port switching, the system sampled the accelerometer's various axes sequentially. The way the Contiki OS operates is by repeating processes at eTimer intervals. However, eTimers can only be set up to repeat every 4 ms on an 8 MHz device. This implies that the accelerometer's single axis can only be tracked once every 12 milliseconds. Equation 1 can be used to determine that the maximum acceleration that can be measured safely for nonhazardous events is 92.967 g. The value of 90 g was chosen in order to account for safety considerations. At more than double the distance required, the transmission was successful.

IV. Final Results and Future Directions

A smart mining helmet was created that can identify three different kinds of dangerous situations: the presence of dangerous gasses, the removal of a miner's helmet, and collision or impact (when a miners are hit by an object). The dangerous incident was defined as a miner taking off their mining helmet. The helmet's position on the miner's head was then successfully detected using an off-the-shelf infrared sensor. Miners being hit in the head by an object with a force greater than 1000 on the Head Injury Criteria (HIC) is another risky situation. The head's acceleration was tracked using an accelerometer, and software was utilized to determine the HIC. The layout of the visualization program was completed. The calibration tests of the accelerometer were successfully finished. Among the PCBs made were a prototype board and a breakout board. A comprehensive software solution based on Contiki OS was finished in order to regulate sensor measurement and calculations using the measured data. To find out if the system meets the requirements, it was put through a rigorous testing process.

It was noted that in order to account for the weight differential, the accelerometer ought to be mounted within the helmet rather than on the plastic strap. In order to properly calibrate the accelerometer, the calibration was then adjusted. There are several places where the system could be improved. The signal strength or range would be increased by adding an external antenna to account for additional human interference. The distance could still be limited to a minimum because it would be impractical to notify miners who are too far away to find the miner experiencing a hazardous event.

To enable more precise accelerometer measurement, the system's processing speed can be increased. By avoiding activation due to reflections, the infrared sensor can be made to function within the helmet. Node hopping can be used to enable transmissions to the supervisor or even a central control station. This can be achieved by adding stationary nodes that are set up to only bounce received signals. Additional measuring tools to monitor the miner's heart rate and blood pressure could enhance the system. It is also possible to measure gas concentrations. The possibility of using such modules for secondary services, including worker location in relation to one another, may be taken into consideration in the future [24].

References

1. "The Southern African Institute of Mining and Metallurgy Journal, August 2007, vol. 107, pp. 531–538," by M. A. Hermanus, "Occupational health and safety in mining—status, new developments, and concerns."
2. pp. 209–216 in the July 2001 issue of the South African Institute of Mining and Metallurgy Journal; A.P. Squelch, "Virtual reality for mine safety training in South Africa."
3. C. Qiang, S. Ji-ping, Z. Zhe, and Z. Fan, "ZigBee Based Intelligent Helmet for Coal Miners," IEEE World Congress on Computer Science and Information Engineering (WRI 2009), vol. 3, pp. 433–435, 2009.
4. "The use of ARM and ZigBee technology wireless networks in mine safety system monitoring," by H. Hongjiang and W. Shuangyou, IEEE International Colloquium on Computing, Communication, Control, and Management (ISECS 2008), Guangzhou, Aug. 3–4, 2008, pp. 430–433, 2008.
5. X. Liu, J. S. Huang, and Z. Chen, "The study of ranging with timing over packet networks for the mine safety application," Journal of Networks, vol. 7, no. 7, pp. 1054–1062, July 2012.
6. [6] In IEEE Transactions on Industry Applications, vol. IA-19, no. 3, pp. 445–449, R. S. Nutter published "Hazard evaluation methodology for computer-controlled mine monitoring/control systems" in May/June 1983.
7. During the 4th WVU Conference on Coal Mine Electrotechnology, which took place from August 2–4, 1978, R. S. Nutter gave a presentation titled "A distributed microprocessor monitoring and control system for coal mines."
8. R. S. Nutter and M. D. Aldridge, "Mine monitoring and communications status," IEEE Trans. on Industry Applications, vol. 24, no. 5, pp. 820–826, Sep./Oct. 1998
9. IEEE Transactions on sector Applications, vol. 33, no. 1, pp. 100–105, January/February 1997; A. D. Kock and J. W. Oberholzer, "The development and application of electronic technology to increase health, safety, and productivity in the South African coal mining industry."
10. IEEE Communications Magazine, April 2010, vol. 48, no. 4, pp. 66–73; P. Misra, S. Kanhere, D. Ostry, and S. Jha, "Safety assurance and rescue communication systems in high-stress environments: a mining case study."
11. IEEE Communications Magazine, April 2010, vol. 48, no. 4, pp. 66–73; P. Misra, S. Kanhere, D. Ostry, and S. Jha, "Safety assurance and rescue communication systems in high-stress environments: a mining case study."
12. C. P. Kruger and G. P. Hancke, "Improving Internet of Things vision in industrial wireless sensor networks," IEEE Int. Conf. on Industrial Informatics, July 2014, pp. 627–632.
13. Volume 14, Issue 8, pages 2557–2566, August 2014; A. Kumar and G. P. Hancke, "Energy efficient environment monitoring system based on the IEEE 802.15.4 standard for low cost requirements." IEEE Sensors Journal.
14. "Using IEEE 802.15.4 and ZigBee to enable smart home energy management," by D. M. Han and J. H. Lim, IEEE Transactions on Consumer Electronics, vol. 56, no. 3, pp. 1403–1410, August 2010.
15. "Internet of Things device benchmarking," by C. P. Kruger and G. P. Hancke, IEEE International Conference on Industrial Informatics, July 2014, pp. 611–616.
16. K. Gill, S. H. Yang, F. Yao, and X. Lu, "A ZigBee-based home automation system," IEEE Trans. on Consumer Electronics, vol. 55, no. 2, pp. 422–430, May 2009.
17. Journal of Consumer Electronics, vol. 57, no. 1, pp. 90–98, 2011; Byun and S. Park, "Development of a self-adapting intelligent system for building energy-saving and context-aware smart services."
18. In "Wireless sensor networks: a survey," published in 2002, I. F. Akyildiz, W. Su, Y. Sankarasubramaniam, and E. Cayirci cite Computer Networks, vol. 38, pp. 393–422.
19. V. C. Gungor and G. P. Hancke, Industrial Wireless Sensor Networks: Applications, Protocols, and Standards, CRC Press, 2013.
20. "Zigbee wireless standards," ZigBee Alliance. Technology/RF-articles/wireless-zigbee www.didgi.com
21. Available at <http://www.contiki-os.org/> [1] Contiki OS.
22. In October 2015, IEEE Trans. on Industrial Informatics published "Experimental Link Quality Characterization of Wireless Sensor Networks for Underground Monitoring," vol. 11, no. 5, pp. 1099–1110. G. P. Hancke, A. Kumar, and B. Silva.
23. Sensors, vol.15, no. 3, pp. 6818–6844, 2015; "Open Hardware: A Role to Play in Wireless Sensor Networks?" by R. Fisher, L. Ledwaba, G. P. Hancke, and C. Kruger.
24. AM Abu-Mahfouz and GP Hancke, The International Journal of Sensor Networks, vol. 13, no. 2, pp. 94–111, May 2013. "An efficient distributed localization algorithm for wireless sensor networks: based on smart reference-selection method."