International Journal of Computer Trends and Technology
ISSN: 2231-2803 / https://doi.org/10.14445/22312803/IJCTT-V68I4P134

Volume 68 Issue 4, 226-232, April 2020
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Review Article

Survey On Coal Mine Safety Monitoring Systems

Mercy Rajaselvi[1], Siva Chandran V[2], Sowndarya T[3], Varssha S[4]

[1]*Associate Professor, Computer Science and Engineering, Easwari Engineering College, Anna University, Chennai, India*
[2,3,4] *UG Students, Computer Science and Engineering, Easwari Engineering College, Anna University, Chennai, India*

Received Date: 17 March 2020
Revised Date: 30 April 2020
Accepted Date: 01 May 2020

Abstract - *Coal plays a very critical role in developing countries in meeting their energy demands. Consequently, coal mining becomes essential to sustain the energy demands in these countries. At the same time, the mining industry is plagued with many problems which primarily impacts the mine worker's safety. The underground mine environment is hazardous due to the presence of toxic gases like NO2, CO, CO2 etc. The concentration of these gases above the threshold limits seriously impair the mine workers' health and life. The stringent environmental and safety standards of the 21st century make it mandatory to ensure safe working conditions. Hence continuous monitoring of the concentration of these poisonous gases becomes the need of the hour. In this paper, a survey on various mine monitoring systems is discussed.*

Keywords – *coal mining, mine environment, safety issues*.

I. INTRODUCTION

The safety issues of coal mines have turned into a major concern for society. Coal is an important source of energy for operating industries and thus plays a pivotal role in the national economy. Coal mining is considered much more hazardous than hard rock mining due to the presence of poisonous gases, coal dust and flammable surroundings. Mine accidents can happen from a variety of causes, including leakages of poisonous gases such as hydrogen sulfide or explosive natural gases, dust explosions, collapsing of mine slopes, mining-induced seismicity, flooding, or general mechanical errors from improperly used or malfunctioning mining equipment (such as safety lamps or electrical equipment).

Mechanisms for monitoring of mine environment used currently in mines under CIL(Coal India Limited):

- Detection of mine gases by using a Methanometer, CO-detector, Multi-gas detector etc. Continuous monitoring of mine environment by installing Environmental TeleMonitoring System (ETMS) & Local Methane Detectors (LMD) etc.
- Periodic Mine Air Sampling and Analysis by Gas Chromatograph.
- Personal Dust Sampler (PDS).
- Use of Continuous Ambient Air Quality Monitoring System (CAAQMS) in large OCPs to assess the dust concentration and take suitable mitigative measures.

II. LITERATURE SURVEY

Kansong Chen et al. [1] have designed an early warning system based on wireless sensor networks. The two-dimensional DV-Hop safe localization algorithm was analyzed, and two improved algorithms were proposed in a study. The first improvement measure was based on the mean squared error criterion to calculate the average distance per hop. The second was to use the difference in hop values between nodes to arrive at the weighted average distance of each hop so that the estimated distance between nodes meets the distribution criterion of nodes in the network. Then the paper also extends the traditional two-dimensional DVHop safety positioning algorithm to three-dimensional space. Two corresponding improved algorithms were proposed for mapping to three-dimensional spacing requirements. The first is based on role-reversing weighted distance correction to optimize the positioning result, and the second is to locate the unknown Node regarded as an anchor node to re-estimate the distance. The improved algorithm results in a lower positioning error. On simulation, results show that the positioning accuracy has improved by 30% –50% compared to the original algorithm.

Yingli Zhu et al. [2] proposed an approach that displays carbon monoxide value present in ppm(parts per million) units. It also displays the temperature and humidity parameters using the ZigBee network. The equipment includes a sensor that will be worn by each miner. The environmental data is sent to the CC2530 microcontroller via a signal for collection, processing and packaging. CC2530 then sends the processed data to the ground coordinator. The centre monitors the field information periodically. ZigBee can be used for every 100-200 metres consistent with the mine environment and location of the mine. A mine is divided into ground and underground sections. The ground section performs the tracking operation. This system has the advantage of convenient networking, precise tracking, flexibility in installation and extendability, low installation and maintenance cost.

Liang Dan et al. [3] discussed an alternative solution that suggests a prototype using IPv6. The prototype is a 6LoWPAN wireless sensor network comprising sensor nodes and gateways. The existing system is based on ethernet technology for communication between two layers. This system suggests a wireless sensor-based approach using IPv6 for data transmission. The parameters measured by the system are temperature, humidity, oxygen level, carbon monoxide, methane concentration and dust. The prototype consists of 6LoWPAN sensors, sensor gateways, upper computers, internet, servers, router and clients. The 6LoWPAN sensor is placed in the working environment. Each 6LoWPAN sensor has a unique IP address, which measures the parameters and then sends information to the internet via the IPv6 gateway. The data which is being transmitted over the internet reaches the other end of the router. This router performs IP forwarding, where the data packets are sent to their respective cloud servers, from where the alerts are sent to clients. Only a basic prototype has been developed because the hardware which uses IPv6 is still primitive. So, IPv4 has been used to attain the results by using subnetting and NAT (private) network technology.

Ivan Alfonso [4] et al. proposed an idea that implements a WSN (wireless sensor network) to monitor gases in mines. It has two main objectives (1) a graph-based model to represent WSNs for gas monitoring in underground coal mines, and (2) a two-stage optimization strategy to locate the nodes, minimizing deployment cost while maximizing lifetime. The goal is to model all the segments and pitheads of the mine using a WSN node placed strategically. The principal downside arises when the Node runs out of battery. The lifetime of the network is assumed to be over when the first Node runs out of power. The nodes in this network are assigned three tasks - acquisition, communication and data processing. The network is static in nature and does not include disaster scenarios. Installing a proper sensor network is time-consuming and also not cost-efficient with respect to Indian mines. It also does not focus on the individual's health parameter and their monitoring.

Dingwei Li et al. [5] analysed the national coal mine accident records and extracted the gas risk impact factors and causal chain of accidents through Bayesian Network analysis to establish the multilevel forecasting indicator system for safety situations. It includes a multilevel prediction model for coal mine risk trends through the combination of the Bayesian network. The overall safety situation assessment of coal mine is quantified into the form of safety situation assessment value which is set as a threshold for safety standards. This system is more of a preventive measure and does not deal with the dynamic nature of a coal mine. It elaborates on the possible gas risks and acts as a precaution.70% of the data collected is used to train the model, and 30% of the data is used to compare the results of the prediction model with the existing values.

Hua Ding et al. [6] resolve the problems of low level of information control and susceptible tracking generation using visual interactive cloud platforms. This framework is constructed on the basis of the following parameters: communication interaction, video integration, business integration, unified conversation and a few primary capabilities. The gadget realizes real-time video tracking of the mines and workers' faces, which enhances the safety tracking of the coal mine. The device is divided into two components – 1. Terminal machines for the upfront communication 2. Outside help device for backend conversation. The terminal system includes useful modules like business system integration (which realizes integration between supervision room and law enforcement). The outside device consists of two systems: a unified verbal exchange machine and a video integration gadget. One of the disadvantages is that the software cannot seamlessly interact with the portable device.

Mandana Hajizadehmotlagh et al. [7] presented the design of a wearable, respirable (air containing fine dust particles of size 4-10 microns that are breathed in) miniature dust monitor to analyse the ISO respirable mass fraction of coal and silica dust in underground mines. It uses the system of air microfluidics to monitor the exposure to ISO respirable mass fraction of coal and silica dust. In 2014 MSHA (Mine Safety and Health Administration), an agency in the United States of America established a lower permissible exposure limit of 1 mg/m3 during an eight-hour shift. The system is about the size of a deck of cards and displays the cumulative current and dust concentration. Before entering the air-microfluidic circuit, which leads to the respirable fractionator, large particles must be excluded from entering the circuit to prevent clogging. The prerequisite is designing a specific cut-point wherein the net force on the cut-point particle is zero. Preconditioning of the gravimetric mass sensing setup was performed using a Nafion based dryer. Nafion is a polymer with a high affinity for water due to the sulfonic acid groups in its structure. This can absorb up to 22% of its weight in water. Deposition and mass sensing of fine particulate matter (PM), below 1.25μm, has been implemented in this system. This is concerned with only coal and silica particulate matter and not other poisonous gases.

Akunya Mishra et al. [8] proposed a system that uses two sensor modules to monitor the hazardous gases in real-time and feed the data to the microcontroller. The microcontroller then analyses these parameters and compares them with a set range, and sets off the buzzer in case any of the parameters are exceeding it. The use of a compact humidity & temperature sensor ensures a lightweight and power-efficient circuit, while the use of an RF module helps in wireless transmission. RF modules lack the required range underground, which limits the scale of the project.

Wang Longkanga et al. [9] proposed a design of ZigBee-based three-layered network structure and ZigBee wireless network communication system for coal mine, which can effectively overcome the interference of coal mine terrain with communications. It covers the blind zone and transmits the data gathered in coal mines in real-time to the ground command centre and group management centre. The paper includes a design of network nodes that can, in real-time, monitor the environment parameters and various kinds of data in a coal mine. The software system can improve the working efficiency and service life of ZigBee nodes. The positioning algorithm designed in the paper is a multilateration positioning algorithm that can realize the exact positioning of operators. It exactly estimates the location of the mobile Node by adding the number of secured nodes, using the principle of the least square method to compute the gap between the actual coordinate and the estimated one. This works out the coordinate of the mobile Node, which is the dynamic position of the miner. The method of improving positioning precision is done using root mean square. This system facilitates the attendance of coal miners by the ground management centre by knowing the dynamic positioning of coal miners at work. In case of an emergency, rescue efforts can be effectively carried out. An alarm is given to the coal mine operators in the forbidden zone.

Bo Cheng et al. [10] have designed and implemented a web-based lightweight remote monitoring and control system, which is developed using a wireless sensor network with the REST (REpresentational State Transfer) style. REST is an architectural style for developing web services using standard HTTP status codes. The WSN can be used to monitor underground methane gas levels, temperature, humidity and other signals. The field data is packaged by the central Node and sent to a monitoring centre to complete the remote control automation. REST principles define an extensible and lightweight interface for underground physical instruments and sensor devices. This architectural style is used to build a RESTful smart control gateway that is lightweight, scalable and has extensive software components to allow web-based interactions with all types of underground physical sensor devices. Communication with underground physical devices, obtaining data streams, sending control commands or accessing sensor characteristics is achieved via the RESTful API. The javaScript-based dashboard is used to display a variety of sensor data visualizations and remote control automation for underground physical devices.

Yaqin Wu et al. [11] have proposed to establish a dynamic information platform for underground coal mines using IoT platforms. It is divided into six layers, including the supporting layer, perception layer, transmission layer, service layer, data extraction layer and application layer. The supporting layer, service layer and data extraction layer are considered in the developed underground coal mine platform. The supporting layer is used to integrate the wired and wireless network function, including the hardware and software. The service layer receives the data delivered by the transmission layer. Then received data is cleaned, integrated, and transformed. In the data extraction layer, analysis and valuable information output are completed. The functions of all the platform layers are analyzed in the application layer. The main functions of this layer are divided into four subsystems. These four subsystems are the 3D virtual mine system, safety diagnosis system, safety inspection system and emergency rescue system.

III. COMPARATIVE ANALYSIS

S.no	TECHNIQUE	RESULTS	PROS	CONS
1	[1] - 2D DV hop algorithm 3D DV hop algorithm	The positioning accuracy is improved by 30% - 50% by analysing the factors such as communication Network, Localization Error.	Using MatLab, the factors such as node communication radius, the total number of nodes, and the proportion of anchor nodes are calculated. Calculating the distance will reduce positioning errors of the WSN and improves data Transmission.	Unknown Node is not a linear path. The WSN network, in order to find the shortest path, sometimes works under this assumption, Thus bringing about an overall distance error.
2	[2] - ZigBee Network	The level of detection of the temperature of the gases differed by the range of 5 degrees compared to the measurements by the thermometer. The measurements carried out by the sensor nodes were accurate.	Detection of coal levels and the gases and data are stored. It divides the system into ground and underground mines	The system merely monitors the level of gases and coal. It does not provide proper alert messages to the miners.
3	[3] - 6LoWPAN sensors network using IPv4/IPv6 gateway	The average network packet loss rate is 0.66%. The test results show that the network stability is good, and the normal transmission of system data can be guaranteed. The system also predicts monitoring of the quality of coal mine working environment and flexible wiring	Real-time analysis of poisonous gases emitted in a coal mine is done efficiently in the prototype	This system takes into account the environmental conditions but does not consider the health conditions of individual miners. The IPv6 equipment is still primitive in nature.
4	[4] - Wireless Sensor Network (WSN)	A WSN network is implemented. It includes (1) a graph-based model to represent WSNs for gas monitoring in underground coal mines and (2) a two-stage optimization strategy	Since it is a graph-based model representing WSNs it is precise. The two-stage optimization strategy used for locating the nodes minimizes deployment	The lifetime of the network is assumed to be when the first Node runs out of battery charge. The low lifetime brings its own set of risks when implemented in the coal mine(e.g. delay in disaster

		to locate the nodes, minimizing deployment cost while maximizing lifetime. Designs the segments and pitheads of the mine using a WSN node placed strategically.	cost and maximizes lifetime.	response). A proper sensor network is installed, which is time-consuming and not cost-efficient in the Indian context.
5	[5] - Bayesian Network	The minimum mean square error estimation of the test results is 0.2577, and the fitting correlation coefficient is 90.7%. These results indicate that there is a strong mapping relationship between the first-level indicator, gas concentration and its corresponding multilevel indicators set. Gas poisoning occurs when the gas risk probability reaches 40.1%.	The Bayesian model monitors and extracts gas risk impact factors, which helps in predicting possible high gas risk impact areas in the coal mine. It establishes the multilevel forecasting indicator system.	The system is a prediction model and does not deal with the dynamic nature of coal. The model has been trained on historical data, whose relevance in today's context might vary
6	[6] - Visual Interactive Cloud Platform	The internal information of the coal mine and the analysis and processing of the data have achieved remarkable results; visualization of information providing real-time video of the underground mines to the managers are a few of the advantages. The system removed the shortcomings of accessing resources between different systems.	The system realizes real-time video monitoring of the mines, which enhances security and monitoring.	Difficult to implement a cloud platform. Pre existing high data transmission networks should be available. The system only monitors the workers. It does not monitor gas content, drainage system, ventilation system, mining equipment. The software is not compatible with portable devices.

7	[7] - RF Module	The design for a novel wearable real-time gravimetric monitor (WEARDM) is suggested, which should operate at a flow velocity of 250 mL/min.	It analyses the ISO respirable mass fraction of coal and silica dust in underground mines. .	The system takes only coal and silica particulate matter into consideration
8	[8] - Microcontroller, RF Module and ZigBee Network	The system senses the increase in the level of temperature and hazardous gases within 2 seconds.	The usage of a compact humidity & temperature sensor guarantees a lightweight and strength efficient circuit at the same time as using RF modules enabled in wi-fi transmission.	RF module lacks variety and infrastructure
9	[9] - Multilateration Positioning Algorithm	The coordinate of the mobile Node computed by the multilateration positioning algorithm is improved. It also identifies the exact position of the operators.	It covers the blind zone and transmits the data gathered in coal mines in real-time to the ground command centre and group management centre.	RSSI (Received Signal Strength, which is a measure of power present in received signal) easily fluctuates. Deviation appears in the distance estimation.
10	[10] - RESTful API	The pre-existing WSN network underground is integrated with an RESTful API.	The REST-based structure has faster response time and improved complexion time. The memory consumption is also less when compared with the SOAP method**.** It enhances the flexibility of the data collection and reduces the costs of the system.	It fails to track the miners through the wireless sensor network, and localization precision should be improved
11	[11] - IoT	Supports traditional IoT by improving the support to the network layer and perception layer in the process of data transfer.	It integrates the wired and wireless network functions, including the hardware and software.	It is not suitable for long-distance communication.

IV. CONCLUSION

Coal is one of the leading and long-term sources of global energy supply and will continue to be so until a viable alternative is implemented on a large scale. So, the direct, secondary and cumulative impacts on miners should be assessed throughout the process of mining. This survey has brought attention to the potential and realized threats that coal mining poses. It focuses on the qualitative aspects of coal monitoring systems and includes an integrated approach to monitoring systems.

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