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An Assesment of Underground Mine Enviromental Monitoring Methods at Zambia's Copper Mines

Nchimunya Chaamwe, Wenyu Liu and Hongbo Jiang
Department of Electronics and Information Engineering,
Huazhong University of Science and Technology, Wuhan, Hubei, China

Abstract: Zambian underground mines are becoming more mechanized and extensive with the coming in of foreign investors resulting in the deterioration of the research place environment for the miners. In order to improve the underground mine working environment, more stringent monitoring and assessment standards need to be formulated and applied to the mining industry. It has been the main goal of the professionals in academia, government and the private sector to bring improvement in the mine atmosphere and mitigate its hazards. Due to their efforts there has been impressive professional progress in the area of mine ventilation and safety. However, mine disasters continue to occur throughout the world and Zambia in particular. Therefore, a need has been felt for further advances in planning, designing and managing of mines in Zambia particularly with reference to health and safety of miners. Keeping this in view, the research involved assessing the current methods used for monitoring underground mine environments in Zambia. A research involving 6 mining companies are carried out on the Copperbelt province in Zambia. The main objective of the survey research was to find out the current monitoring methods that are being used in Zambian underground mines and how effective they are.

Key words: Zambia, underground mines, underground environment, monitoring, Wireless Sensor Networks (WSNs), Copperbelt Province

INTRODUCTION

Zambia is a land locked African country having common borders with Angola, Democratic Republic of Congo (D.R. Congo), Tanzania, Malawi, Mozambique, Zimbabwe, Botswana and Namibia covering an area of about 752000 m^2. It has a population of well over 12 million people. Zambia like many African countries is endowed with a lot of mineral resources which include copper-cobalt ore, gold, uranium, nickel, lead-zinc, iron and manganese. In addition Zambia is also endowed with very high quality gemstones such as Emerald, Amethyst, Aquamarine, Rubies, Gamest and Diamonds which are still unexploited. Zambia's economy has been highly reliant on copper industry with >70% of its GDP coming from the copper sector. The latest figures shows that 67.1% of the country's export product in July 2009 was copper but concerns remain that the economy is not diversified enough to cope with a collapse in international copper prices.

Safety in underground mines: Production of copper comes with its own risks where hundreds of miners lose their lives in the line of duty. But while the production of copper is improving every other year following heavy injections of dollars, pounds, Euros and other such foreign currencies from foreign investors, little seems to have been done on the safety of the facilities to ensure workers research in secure environments. A mining accident is a dangerous and often deadly accident that occurs in the process of mining minerals from underneath the surface of the earth. Thousands of miners die from mining accidents each year especially in the process of coal mining and hard rock mining from underground mines. Most of the deaths occur in developing countries (Kanduza, 2005). While mining in Zambia today is substantially safer than it was in the previous decades, mining accidents are often very high profile such as the Chambeshi copper mine tragedy where at least 46 people were killed when a blast tore through an explosives factory destroying the plant and ripping workers apart in 2006 (ABC News, 2005). Another recent high profile incidence was when at least 19 miners were killed at the same mine, Chambeshi copper mine. These and many more accidents are reported in the mines in Zambia and world over.

Corresponding Author: Nchimunya Chaamwe, Department of Electronics and Information Engineering, Huazhong University of Science and Technology, Wuhan, Hubei, China

Over the years a number of accidents have been recorded in these Zambian mines due to perhaps the poor underground environmental monitoring methods which are either manual or outdated. It also appears from reports that standards of safety seem to have declined since privatization. This is evidenced from the increase in the number of mine accidents and fatalities. For instance the number of fatal accidents increased from nine in 2000 to about 80 in 2008 (Simutanyi, 2008) as shown in Table 1. It was established by Miller *et al.* (2006) that the major causes of mine accidents in Zambia were falling rocks and that policy interventions such as underground environmental monitoring techniques used had the greatest potential in reducing the accidents.

Environmental monitoring in underground mines: Environment monitoring in underground mines is an important exercise that would ensure safe working conditions for miners in the mines where many environmental factors like the amount of gas, water, heat, high humidity and dust need to be monitored (Hao *et al.*, 2008).

These environmental factors can cause harmful physiological effects including death. Ignited methane gas is a common source of explosions in mines or the more violent coal dust explosions. Gases in mines can also poison the workers or displace the oxygen in the mine causing asphyxiation (Kucuker, 2006; Terazawa *et al.*, 1985). Additionally, high temperatures and humidity need also to be monitored which may result in heat-related illnesses including heat stroke which can be fatal. Dusts should also be monitored for they can cause lung problems including silicosis, asbestosis and pneumoconiosis also known as miner's lung or black lung disease. For this reason, it is required that a complete monitoring of the underground mine environment should be done by sampling data at many different places within the mine. An acceptable environment overview requires high sampling data and this requires a large number of sensing devices.

Presently, methods of underground mine environmental monitoring in Zambia and elsewhere are conducted in a random and manual way due to the unavailability of specialized techniques for constructing an automated large scale sensing system. Using wires to connect sensing points to the processing server requires a large amount of wire deployment which is unfeasible because of poor working conditions and high maintenance costs underground. In addition, the wired communication method makes the system less scalable as the mining tunnels advances steadily and hence more sensing devices need to be deployed (Li and Liu, 2009). The purpose of this report is to present the findings of a case study of underground mine monitoring methods and their effectiveness in a developing country Zambia.

Table 1: Mine accidents and fatalities between 2000 and 2006

Years	Fatalities	No. of accidents
2000	9	399
2001	23	370
2002	17	284
2003	21	315
2004	19	350
2005	80	312
2006	18	270

MATERIALS AND METHODS

Methodology: A survey of Zambian underground copper mine environmental monitoring systems was undertaken and covered topic areas including, safety in underground mines, types of underground monitoring systems currently utilized and awareness of wireless sensor networks as tools for underground mine environmental monitoring. Survey questionnaires were sent to six underground copper mines on the copperbelt province of Zambia, representing 80% of the underground mines in Zambia and only 4 out of the 6 mines participated in the survey representing a 67% participatory rate. Twenty six survey questionnaires out of the forty that were sent to four mines were completed and returned representing a 65% response rate.

The questionnaire is divided into four sections; the first section contains questions on personal information of the respondents, the second sections contains questions on mine safety in general, the third section contains questions on underground mine environmental monitoring and section four contains questions on Wireless sensor networks as a potential tool for underground mine environmental monitoring. Attached to the questionnaire is a brief description of wireless sensor networks and their applications in underground mine environmental monitoring. The population is made up of employees in the safety and environmental departments of the six mines. Apart from questionnaires, interviews were conducted with heads of safety for Nchanga and Luanshya mines.

Profiles of study areas: The study covered six underground mines in Zambia. They are all located on the copperbelt Province of Zambia whose main economic activity is mining. These include Nkana in Kitwe, Nchanga in Chingola, Mufulira in Mufulira town and Luanshya in Luanshya town, Konkola mine in Chililabombwe and Chibuluma in Kalulushi.

Mufulira copper mine: It is situated in the northern part of the Copperbelt about 12.8 km from the Zambia Congo border and is located near Mufulira, Zambia, 50 km east of Chingola. The mine site is at an elevation of 1250 m above sea level.

The mine has three superimposed stratiform ore bodies; the largest has strike length of almost 5.5 km and depth of >2 km below surface. Mining is only done by underground mining methods. The deposit was discovered in 1923 and ore production commenced in 1933. There are three treatment plants at Mufulira, an onsite concentrator, a smelter and a refinery. Before September 1970 the majority of the mine's production was from various caving mining methods (Billany, 2006).

Nkana copper mine: It is located 1 km south-west of Kitwe a town in the centre of the Zambian Copperbelt Province is one of the largest mines in Africa. The mine is both underground and open pit and it has been in operation since 1932.

The copper and cobalt at the mine is mined from three sources and these are Mindola Shaft in the north, the Central Shaft in the centre and South Ore body shaft in the south. The major mining method used at the three sources is vertical crater retreat. Sublevel open-stopping and sublevel caving methods are also used at lighter scales (Del Castillo *et al*., 2002).

Nchanga copper mine: It is Located 30 km South East of Chingola and approximately 75 km North West of Kitwe on the South West margin of the Kafue Anticline on the Copperbelt Province of Zambia. Copper mining at Nchanga mine started in 1939, first as an open pit mine and later underground mining was introduced. The Nchanga deposit is one of the most significant ore systems in the Zambian Copperbelt and contains two major economic concentrations of copper and cobalt (McGowan *et al*., 2006).

Chibuluma copper mine: It is located near the town of Kalulushi about 10 km to the South West of Kitwe one the biggest town on the Copperbelt Province of Zambia. The area where the mine is situated has generally a flat topology withelevations above mean sea level of 1220-1300 m.

The mine began production in 1955 as a self contained unit producing copper concentrates which were treated at the mine concentrator. However, the concentrator was closed in 1991 and the ore has been treated locally. The Chibuluma South deposit which is being mined currently was discovered in 1969. Chibuluma was the first mine to be privatised being acquired by a Metorex consortium a South African company in October 1997 with ZCCM/Zambian Government retaining a 15% share (Kabemba and Southall, 2010).

Konkola mine: It is located in the northernmost of the Zambian Copperbelt mines in a town called Chililabombwe about 100 km from the city of Kitwe. The mine has two existing shafts systems that have been managed as separate mines. Underground haulage connections between the two mines were developed mainly for cross tramming and dewatering purposes.

Both shafts are used for servicing and for hoisting ore and waste. The underground ore arising from Konkola is treated in the Konkola concentrator situated close to one of the shafts. This shaft material comes directly into the plant while the shaft materials are trucked to the plant. The concentrator has the capacity to process 2.4 million tons per annum.

Luanshya copper mine: It is located 2 km east of Luanshya town on the copperbelt Province. The mine operates an underground mine, a smelter and concentrator. The mine was opened in 1943. Since its privatisation in 1997 the mine has since changed ownership 6 times. Currently the mine is being run by a Chinese mining company known as China Non Ferrous Metals Mining Company, CNMC.

The company acquired the mine for US$ 50 million after the original owners pulled out of the mine in January 2009 citing low copper prices on the international market. The Chinese firm acquired 85% shares in the mine pledging to invest over US$ 400 million in re-capitalization and construct a state of the art leach plant at a cost of US$ 300 million at Luanshya mine. The company resumed the operations at the mine in December 2009.

RESULTS

Demographics of respondents: From the demographic results of the survey, the majority of the respondents (58%) fell within the age range of 40-55 years. Probably reflecting their age, a higher percentage of 80.8% were not university graduates withonly 19.2% indicating that they had a first degree.

Some 15-20 years ago Zambia had few university graduates. The mines employed school leavers who were trained on the job. The age also gives an indication that the majority of the respondents had worked for many years and were nearing retirement. This age group could have a relatively higher level of biasness

Table 2: Demographics of the respondents

Mining company	Age 25-40 (%)	Age 40-45 (%)	Qualifications High school-diploma (%)	Qualifications Degree and above (%)
Luanshya	25	75	75.0	25.0
Chibuluma	50	50	87.5	12.5
Mufulira	67	33	67.0	33.0
Nkana	43	57	85.7	14.5
Total	42	58	80.8	19.2

in terms of safety in the mines and would want to protect the integrity and the face of the company. Table 2 shows the demographics of the respondents.

Mine safety: The survey reviewed that underground mine accidents had continued to happen despite the improved safety measures adopted by the mines. Table 3 shows the comprehensive results. About 69% of the respondents confirmed that mine accidents were recorded in the mines in the past 5 years. This is despite 88% of the respondents indicating that the safety measures were adequate.

A study by Hayumbu *et al*. (2008) which assessed the exposure to dust as part of an epidemiological study to ascertain the risk of non malignant respiratory diseases among Zambian copper miners showed that 59 and 26% of Mufulira and Nkana Mine samples, respectively were above the calculated U.S. Occupational Safety and Health Administration permissible exposure limit (Birch and Noll, 2004).

The study also showed that the mean intensities of respirable dust exposure at Mufulira and Nkana were 0.992 (range 0-7.674) and 0.868 mg m^{-3} (range 0-6.944), respectively while the mean intensities of respirable quartz at Mufulira and Nkana were 0.143 (range 0-1.302) and 0.060 mg m^{-3} (range 0-0.317), respectively. These results indicate a weak dust monitoring system at these mines which may increase the risk of non malignant disease in many miners.

WSNs awareness: WSNs are new and emerging systems especially in developing countries like Zambia. Very few people have heard or seen these systems. Table 4 shows that only 22% had some knowledge in as far as WSNs were concerned. After going through a write up attached to the questionnaire about WSNs and what they can do and where they can be used. Almost all the respondents 91% appreciated them and indicated that they would not hesitate to recommend their implementation to management. Below is a description of what wireless sensor networks are and some of the existing research in underground mine monitoring using WSNs.

Wireless Sensor Networks (WSNs): Recent advances in wireless communications have motivated the development of extremely small, low-cost sensors that possess sensing,

Table 3: Accidents and safety measures

Mining company	Accidents in past 5 years Yes (%)	Accidents in past 5 years No (%)	Safety measures adequate Yes (%)	Safety measures adequate No (%)
Luanshya	37.5	62.5	86	14
Chibuluma	62.5	37.5	75	25
Mufulira	100.0	0.0	100	0
Nkana	100.0	0.0	100	0
Total	69.0	31.0	88	12

Table 4: WSNs awareness

Mining company	Have knowledge Yes (%)	Have knowledge No (%)	Recommend to management Yes (%)	Recommend to management No (%)
Luanshya	12.5	87.5	87.5	12.5
Chibuluma	0.0	100.0	87.5	12.5
Mufulira	67.0	33.0	100.0	0.0
Nkana	50.0	50.0	100.0	0.0
Total	22.0	78.0	91.0	9.0

signal processing and wireless communication. A wireless network consisting of a large number of small sensors (called wireless sensor network, WSN) with low power transceivers can be an effective tool for gathering data in a variety of environments (Ilyas and Mahgoub, 2006; Raghavendra and Znati, 2004). Theoretically, the number of sensor nodes deployed in the environment to be monitored is unlimited. Sometimes some sensor nodes may act as data sources on one hand and act as relaying stations on the other hand where they are expected to receive and forward data from adjacent nodes.

There is also one or more particular sensor nodes that act as base station and represent the data sink in the network. The job of the base station node(s) is to receive and aggregate all the data generated within the network. In addition, the base station establishes a communication link to a data logging unit or a remote site (e.g., control centre), using standard wired or wireless communication technologies like a Wireless Local Area Network (WLAN) (Bischoff *et al*., 2009). The sensor nodes deployed are normally equipped with specific sensors tailored to their measurement tasks. Each sensor node has the capacity of detecting a number of parameters in the environment such as acoustic, seismic, light, temperature, etc.

However, each sensor can sense only one modality at a time. A sensor in a WSN uses some energy in form of a signal and converts it into a reading for the purpose of information transfer. The sensors are normally powered using a battery and their bandwidth for wireless communication is limited. Therefore, energy efficient Wireless sensor networks systems are needed for less consumption of the limited energy from sensors. Moreover, the unattended nature of sensor nodes and the hazardous sensing environment prevents manual battery replacement. For these reasons, energy awareness becomes the key research challenge for sensor network protocol design (Soe, 2008). The utilization of a WSN to implement the underground environmental monitoring

Table 5: Environmental Monitoring Methods in Zambian underground mines

Mining company	Parameters to be monitored		
	Dust and gas	Temperatures and humidity	Seismic events and falling rocks
Luanshya	Detection tubes Taking dust levels using tools such as the Electrostatic precipitator and the Konimeter which determines snap samples of dust in the underground environment By using gas testers to monitor the gases	An ordinary thermometer A hygrometer which is fitted with two bulbs namely wet bulb and dry bulb The difference in the reading between the two bulbs, gives the wet bulb depression which indicates the degree of relative humidity in the atmosphere	Using a level machine which checks the ground movement
Chibuluma	Using portable detection meters Carrying out air survey underground and checking the emissions from moving machines underground with glass tubes containing substances that detect poisonous gases	Using the wet and dry bulb thermometer. (A man goes round reading the thermometer and gives advice on how to control the dust and the heat)	Using a pinch bar probing on the rock to detect if the ground condition is good or bad
Mufulira	By using continuous gas detectors called miniwains and spot sampling equipment called a drager pump that goes with drager tubes. Elf gravimetric sampling pumps are also used	By using a Whirling hygrometer. The results gotten are fed on the relative Humidity chart to determine the humidity	Seismic events are monitored by using a seismic detector connected to a series of cables and sensors
Nkana	By giving detectors to some miners when going underground and they return them after coming back from the underground	Using the wet and dry bulb thermometer to monitor the temperature and humidity in underground environment	Non

system benefits from rapid and flexible deployment (Zhao and Guibas, 2004). Additionally, the multi-hop transmitting method conforms to the tunnel structure and provides more scalability for system construction (Li and Liu, 2007).

Existing work: WSNs research was initially mainly driven by military applications which included battlefield reconnaissance and surveillance, nuclear, biological and chemical attack detection. In the recent past a lot of research has been done in the civilian applications of WSNs in different fields. The applications include but not limited to environmental monitoring, home automation, health applications, production and inventory and delivery control.

A number of researches have also been done on the use of WSNs in underground ground mines especially coal mines to ensure safe working conditions for the miners. Mohanty (2006) proposed a WSN system for the location of trapped miners and monitor Environment conditions such as temperature, carbon monoxide level, presence of methane or other undesirable gases along the rescue path. Kennedy (2006) proposed a low-rate wireless sensor personal area network standard for underground or confined space, high-integrity safety and emergency applications.

A system that establishes a self healing wireless network in underground mine environments to maintain communication in the remaining connected network was proposed. Li and Liu (2009) designed what they called a Structure-Aware Self-Adaptive WSN system, SASA. SASA is able to rapidly detect structure variations caused by underground collapses. SASA is also able to accurately report locations of collapses to detect and reconfigure displaced nodes, thus maintaining system integrity. A WSN system that uses a unified wireless mesh-networking infrastructure to locate, trace and manage mobile assets and people as well as monitor different environmental conditions was proposed (Bandyopadhyay *et al*., 2009).

Monitoring methods: To ensure a complete and inclusive monitoring of the underground environment, data sampling need to be carried out at many different locations within and without the underground mine. Current methods of underground mine environmental monitoring in Zambian mines are mainly conducted in a random and manual way. Table 5 shows the methods used to monitor the underground environments in the Zambian mines.

The environmental monitoring in the underground mine is done in such a way that the environmental and safety staff at the mine will go to selected places in the underground mine and they would call out their instrument reading and all the output values would be recorded manually and they would be compared with the average values for the time indexed weather station or reference instrument data.

To establish biological responses of workplace particles and their association with adverse health effects on miners, samples for analysis are collected by choosing sampling stations that are representing the distinct exposure zone and that are close to the workplace where miners are operating (Chen *et al*., 2004).

DISCUSSION

The research reported here illustrates on a large scale, the need to improve monitoring methods in underground mines particularly in developing countries. The research supports the argument that the current monitoring methods which are manual are not adequate because accidents that can be avoided by simple monitoring methods are still being recorded. WSNs are promising tools that would reduce to larger extent the accidents that occur in underground mines.

WSNs are capable of continuously monitor the underground environment making them safe for the miners to work in. The research shows that the mining companies in Zambia are willing to adopt the use of WSNs in monitoring underground mine environments. Underground mine environmental monitoring if properly implemented would drastically reduce the number of accidents that happen in underground mines all over the world.

The research that carried out in Zambia about underground mine monitoring reviewed that very little is being done by the owners of the miners to ensure a safe working environment for the miners. This is evidenced by the type of methods currently being used by most underground mines to monitor the working environment. Apart from assessing the current underground mine monitoring methods, it introduced the use of WSNs as potential tools for the monitoring purpose. The idea was welcomed by all the mines visited. The head of safety at Nchanga through an interview indicated to us that management had encouraged them to computerize their operations and that using WSNs would be welcome.

CONCLUSION

The study revealed that all the mines visited, uses manual monitoring methods or wired sensors to monitor environmental conditions underground. The study also revealed that the current methods are not very effective and a number of accidents that could have been avoided were recorded in the past 5 years. The safety departments and the environmental departments which were the targeted respondents in all the 4 out of the 6 mines that participated unanimously welcomed the idea of introducing WSNs as monitoring tools for environmental conditions in underground mines.

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