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The Automation of the 'Making Safe' Process in South African Hard-Rock Underground Mines

S. R. Teleka, J.J. Green, S. Brink, J. Sheer, K. Hlophe

Abstract**: *In South African hard-rock mines, best practice dictates that the hanging walls be inspected after blasting. This process is known as 'making safe' and, although intended to save lives, it is both laborious and subjective. Pressure is placed on the barrer (inspector) to conduct the test quickly and efficiently, as daily operations can only continue after the area has been declared safe. The process involves the barrer tapping the potentially loose rock mass with a sounding bar, listening to and assessing the generated acoustics, and deciding whether it is intact or loose. For a loose rock mass, the barrer would either bar it down or support it. For the purposes of this report, only the inspection task of the 'making safe' process is considered. It is highly dangerous and limits the critical decision making to the experienced barrer. Fatality rates due to falls of ground (FOG) can be reduced by using a simple tool that will produce consistent results in the 'making safe' exercise.***

Index Terms**: *Fall of Ground (FOG), Hard-rock, Pre-entry Examination, Sounding.***

I. INTRODUCTION

Underground mining is the art of extracting minerals from deep within the earth's crust [1]. South Africa is a major mining country that boasts reserves in gold and platinum, which require mining at very deep levels. This is known as hard-rock mining and it is carried out in narrow tabular ore bodies with mining heights of less than 1.5 m. The challenge with deep level, hard-rock mining is the high stresses in rock masses, which lead to rock bursts and falls of ground (FOG). In an attempt to mitigate the prevalence of rock burst and FOG accidents, an assessment of the rock mass condition prior to entering a narrow tabular ore-body is carried out. This is usually carried out after blasting. Determining whether a narrow tabular ore-body is safe to mine in is thus both dangerous and highly subjective. The process is currently influenced by, inter alia, human factors such as fatigue, inexperience, hearing ability and pressure to execute the task quickly [2].Errors arising from these human factors can be made while trying to accurately characterize the rock mass under assessment. The accurate assessment of the stability or possible instability of a hanging wall and proper alerts to the worker/miner are critical to the safety of miners working in a narrow tabular ore-body.

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***** Correspondence Author (s)
S. R. Teleka, CSIR, Centre for Mining Innovation, P O Box 91230, Auckland Park, 2006, Johannesburg, South Africa, (email: rteleka@csir.co.za).
J. J. Green, CSIR, Centre for Mining Innovation, P O Box 91230, Auckland Park, 2006, Johannesburg, South Africa, (email: jgreen@csir.co.za).
S. Brink, CSIR, Centre for Mining Innovation, P O Box 91230, Auckland Park, 2006, Johannesburg, South Africa, (email: sbrink@csir.co.za).
J. Sheer, University of the Witwatersrand, Johannesburg, South Africa, (email: JSheer@wits.ac.za).
K. Hlophe, CSIR, Centre for Mining Innovation, P O Box 91230, Auckland Park, 2006, Johannesburg, South Africa, (email: khlophe@csir.co.za).

II. CURRENT 'MAKING SAFE' PRACTICES

A technique that has been in use for many years to assess the integrity of a rock mass in mine working environments involves a person tapping a rock mass with a steel sounding bar, listening to the sound generated and making an assessment of the integrity of the mass according to the sound heard. This sound is caused by the acoustic wave generated through the vibration of the rock mass and the sounding bar in the stope environment. The sound has a unique frequency distribution, which is interpreted to determine the rock mass integrity [6].

This process is known as 'making safe', and comprises two linked but separate steps, which are the detection of the hanging wall hazard and the remediation of this hazard. For the purposes of this paper, only the hazard-identification (assessment) step of the 'making safe' process will be explored. Making safe or pre-entry examination is conducted after blasting; this is a process where explosives are used to mine the ore. A significant amount of fall of ground accidents occur during re-entry into a workplace as the inspection and making safe procedures are carried out to stabilize the rock mass before work in that particular area begins [7].

The pre-entry examination assessment is one of the most critical exercises undertaken in underground hard-rock mines because mines rely on it to ensure that the work area is safe. Most mines specify that no one should enter a work area before it is declared safe [8]. This puts pressure on inspectors, as operations rely on the speed and efficiently they can carry out the examination. For this reason a rushed and inaccurate assessment is often made. 'Making safe' is also laborious because the object used to perform the assessment is often heavy and the environment hot and humid. Miners who carry out this exercise together with the remediation measure of barring down can often only work for eight minutes before rest becomes necessary [9].

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A way to mitigate errors and human factors involved in the 'making safe' process is required in the attempt to reduce fatal rock fall incidents. Green shows in his paper that automation in the form of robotics has the potential to improve mine safety [10].

The CSIR has developed a signal processing tool, Figure 1, that is equipped with a microphone to capture the acoustics generated through the tapping of a suspicious rock mass. The tool is known as the electronic sounding device (ESD) and uses a neural network to assess the heard acoustics and give audio and visual feedback to the operator. The ESD is used together with other electronic devices to automate the 'making safe' process.

Figure 1. The CSIR developed ESD.

This process can potentially be automated in two stages:

1) Stage 1 involves the automation of the tool in order to remove subjectivity and variation in the assessment of the hanging wall and will ensure that the process is highly repeatable.

2) Stage 2 of the automation would make it possible to execute the assessment portion of the 'making safe' process without human involvement, using an autonomous platform. This assessment can be undertaken during the delay between blast and re-entry caused by the presence of noxious fumes, dust and gases, and the increased seismicity, that are harmful to humans [10]. In this way mine operations will be able to resume sooner than is the case with the current 'making safe' process.

The implication is that future examination techniques will include remote assessment. Miners will still be required to bar or support potentially unsafe areas but the automation of the entry assessment will enable them to do so with a clear idea of unsafe areas.

III. JUSTIFICATION

The motivated for this work is from a desire to improve mine safety in South African hard rock mines.

A. Mine Fatality Rates and Causes

An assessment of fatality rates in South African mines over the five years May 2005 to March 2010 reveals that the majority of underground hard-rock mining accidents are caused by FOG accidents. "FOG" refers to incidents that involve the collapse of a hanging wall. Figure 2 shows that uring the period under assessment, 837 accidents occurred in the South African mining sector, with hard-rock mines (platinum and gold) contributing over 77% (633) of the total. FOG accidents contributed over 35% of the total hard-rock mining sector accidents, as shown in Figure 3. This paper examines the possibility of using automation to improve the 'making safe' process, and hence mine safety.

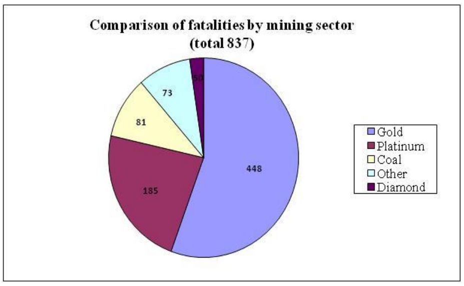

Figure 2: Fatalities by mining sector as classified by Dickens [3].

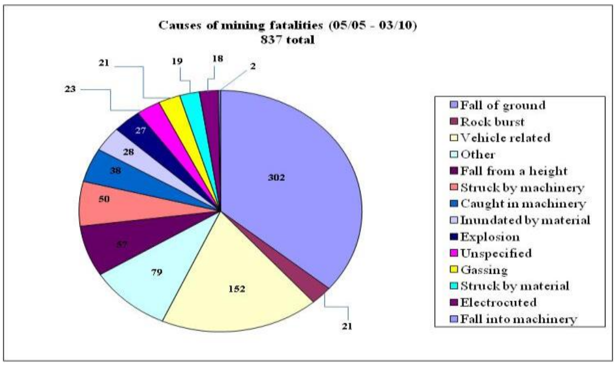

Figure 3: Causes of mining fatalities as classified by Dickens [3].

Figure 4 shows the causes of FOG accidents, ranging from seismic events to inaccurate identification of unsafe areas after the entry examination.

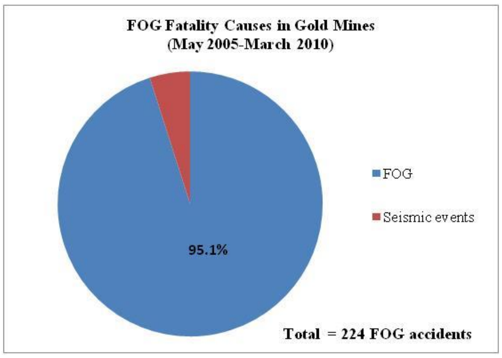

Figure 4A: An assessment of the causes of FOG accidents in gold and platinum mines.

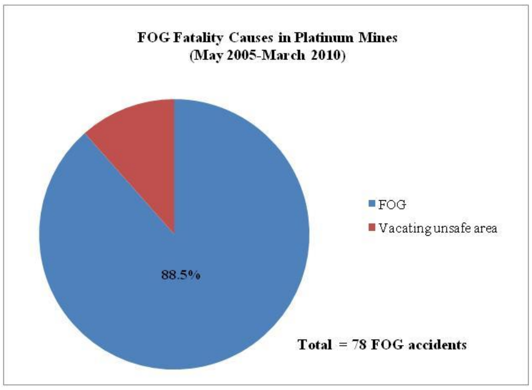

Figure 5B: An assessment of the causes of FOG accidents in gold and platinum mines.

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Figure 5 shows the number of FOG accidents from May 2005 to September 2010, averaging 5.3 accidents per month. For the last seven months under assessment, an accident rate of 3.85 per month was recorded.

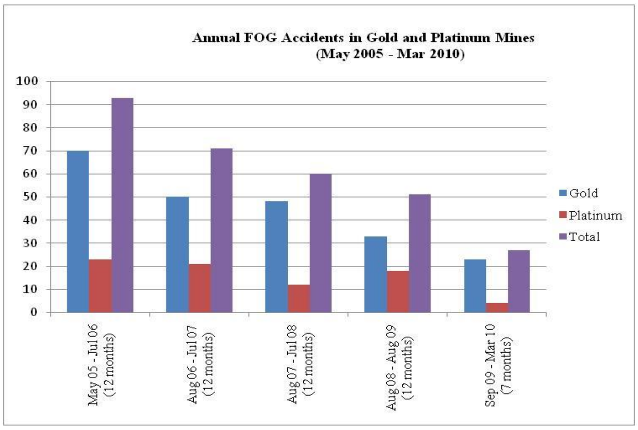

Figure 6: Annual FOG fatalities in gold and platinum mines.

Although there is an overall decline in the FOG accident fatality rates over the time period discussed, the unpredictability of rock mass collapse implies that further mitigating actions are necessary.

B. Causes of FOG Accidents

From the data collected over five years May 2005 to March 2010, three main causes of FOG accidents were identified and a discussion of each follows [3] [4].

Poor Identification of 'Unsafe' Areas

The typical process of inspection starts with a visual inspection to identify potentially unstable areas. Thereafter an assessment of rock mass stability is carried out on the candidate areas. Remedial action, which could be barring down, temporary or permanent support, or no action is carried out based on the assessment result. Potentially unsafe areas could be un-assessed if they are visually unlikely candidates. To avoid FOG fatalities that result from workers not being aware that the area they are entering is unsafe, a way to identify/mark unsafe areas is needed. The automated device under discussion will include this as a specification.

Seismic Activity

Causes of seismic events that lead to FOG are varied. They may include the shift of the rock mass, blasting, the change in rock mass condition or a knock on effect of an event in a different part of the mine. Research has identified changes in rock mass condition as one of the significant contributors to FOG accidents [4]. Due to the mining depths, rock formations in hard-rock mines have been exposed to enormous forces. The mining process creates a void that releases the stress and these changes may lead to seismic events.

Ineffective Assessment

Ashworth and Peake found ineffective assessment to be the primary cause of FOG accidents [5]. The human factors involved in the 'making safe' process include fatigue, hearing ability and experience. Fatigue affects most people involved in laborious exercises – such as working in confined, warm and humid environments. The layout of the stope area is usually only 1 m high with a 30 m long panel and dips that range from 8° for platinum to 20° for gold mines. This constitutes an environment where fatigue is unavoidable.

The sounding bar used to test the wall stability and subsequently bar down unsafe rocks is typically a 25 mm hexagonal mild steel bar that weighs 4.3 kg for a 1.2 meter model and 6.96 kg for the 2 meter long version. The mine conditions together with the weight and size of the tool used in the 'making safe' process make it difficult for miners to continue working for prolonged periods.

Another factor that may affect workers involved in the 'making safe' process is hearing ability. Loss of hearing may be linked to mine operations such as blasting, drilling and other duties that induce noise levels above 85 db (which is deemed unsafe, if continuous over extended periods of time (8hr shifts).

In addition to the human factors mentioned above, procedural, work practice, and competence issues contribute to ineffective assessment [4].

IV. PROPOSED AUTOMATION OF THE 'MAKING SAFE' PROCESS

A. The Design Stages

The full automation of the device will be undertaken in three stages. The three stages are:

1) Stage 1: Build a hand-held device that can be used by a miner to accurately characterize the rock mass under test. The device should enable testing from a safe distance and remove subjectivity from the 'making safe' process.

2) Stage 2: Make the device referred to in Stage 1 smarter by automating the wall-approach and representation of unsafe areas on a map using an underground localization system [11].

3) Stage 3: Mount the device onto a safety platform and incorporate the capability to link into other sub-systems of the platform, such as AziSA [12] [13] [14].

This paper addresses Stage 1 of the project with the design and manufacturing of the initial prototype. Our automated device is known as the "wall stability assessor" (WSA). This will be incorporated into existing technological devices. The device will have the design objectives as indicated below.

B. Design Objectives

The main objective of the work of Stage 1 is to help reduce the prevalence and therefore the impact of FOG accidents in South African gold and platinum mines.

1) To achieve this main objective a number of interrelated elements were identified and itemized in order to simplify the design process.

2) To remove the subjectivity involved in the process by implementing a device that will offer accurate assessment of the rock mass integrity.

3) To remove 'specialty' from the 'making safe' process by introducing a device that will be light and easy to operate by all miners.

4) To incorporate proper and consistent classification of the rock mass under assessment.

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To introduce the demarcation of potentially dangerous areas both for immediate and long-term data use (Stage 2).

From the design objectives, five functions were identified as follows:

Function 1: Extend from the safe area

The safe area is classified as the area that has a clear escape route if rapid evacuation is required and could be a side panel or a supported stope area [8]. The maximum length of the current tool is typically 2 m. A telescopic section is used to allow the device to extend to 2 m. The decision of whether to extend or not will be made by the operator depending on where he or she is standing in relation to the test area.

Function 2: Approach the test structure

A 10 mm proximity sensor is used for this application, which implies that the proxy sensor will detect the surface when the device is 10 mm away from the rock mass. In this way testing can be conducted from a known and consistent position every time.

Function 3: Excite rock mass under evaluation

Apply sufficient impact force to the structure or rock mass under assessment to ensure that an acoustic signal is generated that is loud enough for the ESD to make an assessment. A solenoid is used to apply such impact. This will be refined through the involvement of pulse-width modulation and other relevant electronic control in stage 2 of the project.

Function 4: Feedback system

Capture the sound produced by the wall excitation tool. The ESD records the sound generated by the normal sounding bar [2] with a Linux single-board computer. The acoustic frequency response of the rock mass to the impact is analyzed and classified as safe or unsafe based on expert training of a neural network classifier. On the basis of the output, the operator has the option of whether to re-test, demarcate as unsafe or proclaim the area safe.

Function 5: Demarcation of unsafe rock

In order for workers entering a work area to be aware of potentially unsafe areas, a means of demarcating these areas is necessary. A reflective paint spray can will be used to identify such areas. To automate this process, a mechanical lever connected to a solenoid will be used to activate the spray can in order to demarcate potentially unsafe rock mass. Demarcation is at the discretion of the operator, as is explained elsewhere in the text.

C. Controllers

One switch for the excitation mechanism and another switch for the spray mechanism are included in the design. Two LED lights to indicate the position of the individual switches will be used. These switches are connected to the power supply as appropriate.

D. Power Supply

A sufficient power supply that lasts for the required period of one shift, which is typically 8 hours, is incorporated into the design. Ten 1.2 V cells are connected in series to make up the 12 V, 2.7Ampere-hour required by the two solenoids.

E. Enclosure

An appropriate enclosure of sufficient thickness and International or Ingress Protection (IP 65) rating is used in the design. The IP Code reflects the degree of protection as "IP" followed by two digits. The first digit shows the extent to which enclosures are protected against particles and protection to others from enclosed hazards. The second digit indicates the extent of protection against water [15]. IP 65 means that the contents of the enclosure are protected against dust and water jetting [16].

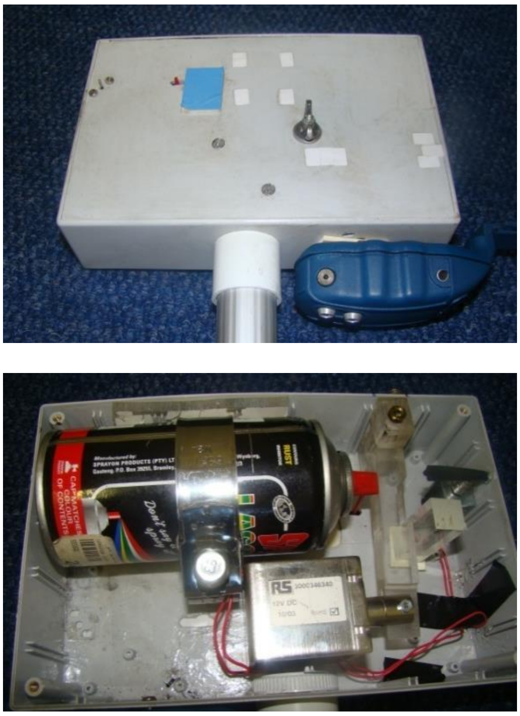

Figure 7: Prototype WSA head – wall exciter (solenoid); spray nozzle extender; enclosure; ESD; mechanical lever; solenoid for the spray mechanism.

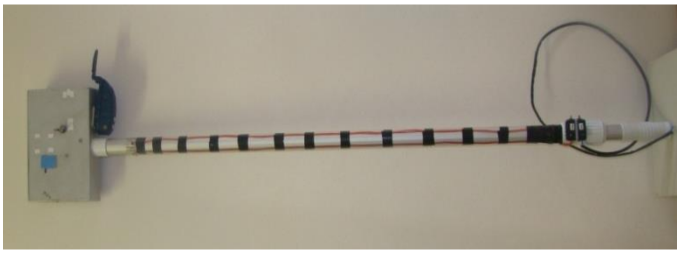

Figure 8: Prototype WSA.

V. VALIDATION OF THE FEEDBACK SYSTEM

The feedback component (ESD) of the WSA) has been tested in a gold mine setting to test its efficacy. The process of using the ESD

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Reef	Judgement correlation success	Cautious errors (%)	Unsafe errors (%)	Ground conditions
Reef 1	76.47	11.77	11.76	Intact
Reef 2	78.38	16.21	5.41	Crushed, fractured
Reef 3	78.40	7.80	13.80	Intact
Reef 4	89.19	6.76	4.05	Crushed
	78.48	16.46	5.06	Crushed, fractured

occurs in two phases of validation, designated as Training and Testing. The ESD units were tested in their function on four different gold containing reefs.

A. *Training*

Reef	Testing area	Conditions		Samples	Barring incidents	Noise level during test
		Ground	Ground water			
Reef 1	Panel	Intact	Dry	94	17	little background noise
Reef 2	Stope	crushed and fractured	Dry	100	1	a lot of background noise
Reef 3		solid, intact hanging wall	moist	97	44	relatively quiet period
Reef 4	Panel 1	crushed, fractured	Dry	95	10	little background noise
	Panel 2	crushed	moist	50	16	relatively quiet

To train the ESD, a specific variant on the ESD design was created to record the audio samples and allow the operator to indicate whether the recorded sample should be labelled as an example of a 'safe', 'unsafe' or an 'unknown' indicating sound. These training ESDs were used by mine personnel over a number of months to accumulate samples from various reefs. The recordings from each reef were combined and all 'unknown' readings removed to optimize neural network training.

This process yielded a total of 699 useable recordings from the reefs as follows:

Reef 1: 376 recordings;
Reef 2: 162 recordings;
Reef 3: 119 recordings; and
Reef 4: 42 recordings.

B. *Testing*

The tests were conducted on different reefs and at different ground conditions as shown in Table 1 below.

Table 1: ESD Testing Conditions

C. *Results*

The testing process resulted in comprehensive performance results of the ESD in various ground conditions, different ground water conditions, and on four different reefs.

In the summation of the results, it is important to keep in mind what is being measured and what it is being measured against. No truly objective measure was made of whether the rock mass that was being sounded was truly safe or unsafe but, rather, the readings rely on the subjective measurement of an experienced operator. Therefore, the performance of the ESD is measured against the judgment of the operator and the correlation between the two judgments is the measure of success.

Table 2: ESD Testing Conditions

The correlation mismatches between the ESD and an experienced operator can be divided into cases where the ESD was overly cautious (i.e. the ESD predicted an unsafe rock mass where the operator judged it safe) and where the ESD made a potentially dangerous error (i.e. the ESD predicted a rock mass safe where the operator judged the rock mass to be unsafe). Table 2 above shows that the increase in unsafe errors correlates to the ground conditions of the testing area. Higher unsafe errors are observed for areas where the ground conditions are described as 'intact' and 'stable'. Possible solutions to minimize unsafe errors include sampling more recordings during the training process in these areas and then evaluating whether increased exposure increases the efficacy of the neural network model. It is suspected that the makeup of the rocks in an area with intact ground conditions may deliver a different frequency response from those in a crushed and fractured ground condition.

VI. FOG ACCIDENT MITIGATION

A. *Other Techiniques*

For the past 100 years, little change has been experienced in the South African deep level platinum and gold mining methods [17]. Mining in South Africa is still perceived to be a very dangerous and hazardous job. The CSIR together with industry recognizes that efforts need to be taken to make mining safe and attractive to a new generation of miners. In order to achieve this, research into better mining methods through the use of technology is required. A shift in focus is therefore imperative in improving hard-rock mining conditions.

Extensive research has been and is currently being undertaken to develop novel mining methods to assist in improving the safety of our mines. Methods such as using thermal imagery [18], [19] and electronic sounding [2] to determine the condition of the rock mass have been explored. Thermal imagery involves the identification of temperature difference between loose and intact rock masses. The idea revolves around the premise that a loose rock mass will be cooler than an intact one due to the fact that the heat flow from the host rock to the loose rock is interrupted by the crack. The cooler ventilation air therefore preferentially cools the loose rock mass [20]. Although effective, the thermal imager only carries out an assessment in a narrow field of view.

The CSIR has patented a method and apparatus for testing installation quality in a grouted anchor system (U.S. Pat. 7,043,989 B2). This apparatus is known as In-Situ Bolt Integrity Testing (ISBIT). This is a process according to which the rock mass integrity is established through the testing of

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the support anchor bolt/tendon [21]. This method is not appropriate for our application, as it can only be implemented after the loose rock mass has been supported.

VII. Conclusion

Automation will speed up the process of ‘making safe’ in the sense that seismic threats after blasting and the presence of gases do not affect machines. Seismic threats and the presence of gases typically delay the ‘making safe’ process by approximately 4 hours, which is the time required for seismic activity to settle and for ventilation to take effect.

If the pressure and haste are removed from the ‘making safe’ process, it is believed/anticipated that the prevalence and impact of FOG accidents will be reduced. Removing subjectivity from the process will lead to consistent and accurate assessment of the rock mass integrity. The WSA will ensure that the fatigue involved in the ‘making safe’ process is removed due to it being light and easy to operate.

Demarcating potentially unsafe areas to all who enter the work area will empower workers to take responsibility for their wellbeing by vacating these areas and/or taking proper action to minimize the risk. Automation will not only enhance the process but also save time, as mine operations will be able to resume sooner than is currently the case. This will allow for mine operations to resume sooner than is currently possible. A reduction in time taken will also reduce the pressure on mine workers.

The project will proceed with stages 2 and 3. Stage 2 involves the acquisition of geopositioned data through the use of an underground localization system (beacons). Once the position is captured, a capability to interface with the AziSA system will be built into the device. Stage 3 also includes the ability for the WSA to be mounted onto an autonomous mine safety platform (robot) for full automation. It is imperative that the WSA has the capability to interface with all the systems involved in the final automation of the ‘making safe’ process.

Acknowledgment

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AUTHOR PROFILE

S.R. Teleka
I completed undergraduate studies in Mechanical Engineering at Central University of Technology and University of Johannesburg and currently pursuing an MSc Degree with University of the Witwatersrand (Design and Implementation of a Wall Stability Assessor).

Joined CSIR in 2003, led the mechanical testing laboratory of the Consulting and Analytical Services for six years before moving to Centre for Mining Innovation in 2010. Research at the centre has been directed towards mining safety and has joined the Novel Mining Methods which focuses on mining robotics as a possible solution to the safety risks facing the South African hard-rock mining industry.

Education

NDip Mechanical Engineering, Central University of Technology, 2003.
BTech Mechanical Engineering, University of Johannesburg, 2005.
GDE Mechanical Engineering, University of the Witwatersrand, 2011.

Publications peer reviewed conference publications

1. Teleka R, Green J, Brink S, Sheer J, *Automated Tools to be used for Ascertaining Structural Conditions in South African Hard Rock Mines*, **RobMech 2011**, Pretoria South Africa, 23-25 November 2011.
2. Teleka R, Green J, The Automation of

the 'Making Safe' Process in South African Hard-Rock Underground Mines, **Cars&Fof 2011**, Kuala Lumpur 25-28 July 2011.

J.J. Green

I completed undergraduate and postgraduate Degrees in Mechanical Engineering at the University of Stellenbosch before a 10 year career at DebTech, the research arm of DeBeers. In June 2009 I joined the CSIR's Centre for Mining Innovation to investigate the use of robotics in the development of an autonomous continuous mining system for South African narrow tabular ore bodies. I have had a number of publications since then and is currently the Chair for the Robotics and Mechatronics Conference of South Africa (ROBMECH) to be held in November 2012, where he is supporting mining robotics as a major research opportunity for South Africa. I also organise a mobile robot competition with a mining theme that is held in conjunction with the conference to encourage tertiary institutions to work in this field.

Education
Bing – Batchelor of Engineering, Mechanical, Stellenbosch University 1996.
Ming – Masters of Engineering: Mechanical, Stellenbosch 2002.

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8. Dugal Harris, Narendra Viranna, Graeme Hill,Jeremy Green, *Integrating Two Spectral Imaging Systems in an Automated Mineralogy Application*," **3 rd Robotics and Mechatronics Symposium**, CSIR, November 2009.

Achievements
CSIR Excellence Award for Mentoring, 2010.

S Brink

I joined the CSIR in 2008 after graduating from North West University. Research work was predominantly in the implementation of the AziSA standard in various deep-earth mine environments. This involved the design of sensors, aggregators andmulti-kilometre stope-to-surface communication networks. Concurrent work was done on the Electronic Sounding Device (ESD), which aimed to simulate a human's auditory recognition of dangerously loose rocks during the entry-examination phase that occurs after blasting in a mine stope. Current work is in the Personal Area Safety System (PASS), which aims to be an early-warning tool for use by individuals or teams in an underground environment. Integration of the ESD with a thermal-band visual inspection forms part of the PASS system, and promises to increase the effectiveness of tools previously developed.

Education
B.Eng Electronics,
B.Sc Computer Science & Mathematics, pursuing M.Eng (Process Control)

Research
Focussed on technology demonstrators in underground technologies: AziSA integrated mine sensor system, Electronic Sounding Device, Personal Area Safety System

Achievements
CSIR Excellence Award for Outstanding Contribution by a Team, 2010.

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