

Automated Tools to Be Used for Ascertaining Structural Condition in South African Hard Rock Mines

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Abstract—The use of automation in deep level hard rock mines has over the years been overshadowed by mechanized mining. However, more and more readily, the industry is starting to recognize the validity of considering automation as an option both in the mining operations and in the efforts to improve mine safety. If mines are safe, the belief is that more skilled labor will express interest in it unlike the way it currently is. The purpose of this paper is to discuss the possibility of using automated tools in the pre-entry examination or making safe exercise.

Keywords—making safe; pre-entry examination, electronic sounding device (ESD), thermal imagery, sonic beacons

I. INTRODUCTION

The condition of hard rock mines in South Africa is known to be both laborious and hazardous. It is therefore not uncommon for accidents to occur in the industry. The majority of accidents and therefore injuries are caused by the detachment and falling of rock fragments from unstable rock masses in underground mines [1]. The rock mass may be the hanging wall (or roof) or a side wall in a mine working area such as a haulage, panel or stope [2]. A significant portion of these rock fall accidents occur during re-entry into a workplace [3].

An investigation into the causes of fall of ground (FOG) accidents performed by Peake and Ashworth for SIMRAC in GAP202 and GAP055 revealed the primary cause to be inadequate examination, inspection or test [4][5].

Dickens [6], classified causes of hard rock mining accidents and found FOG to be the major contributor to the overall tally of mine accidents in the period of the assessment (May 2005 to March 2010).

For this reason, it is considered important to have a means whereby the integrity, i.e. the stability, of a rock mass can be assessed before mine workers can enter the mine working site and are exposed to potential injury from falling rock fragments.

The process whereby the integrity of the rock mass is being assessed is known as 'making safe' or pre-entry

examination and it is usually carried out after a blast and before other operations can commence.

II. MAKING SAFE

A 'making-safe' technique which has been in use for many years to assess the integrity of a rock mass in a mine working environment involves an experienced person tapping the rock mass with a pinch bar (steel sounding bar), listening to the sound generated and making an assessment of the integrity of the rock mass according to the sound which is heard [3].

The sound which is heard is caused primarily by the acoustic wave generated through vibration of the rock mass and other sources, for example the sounding bar, in the surrounding environment. The sound has a unique frequency distribution which must be interpreted in order for a determination of the integrity of the rock mass to be made [7].

Experienced miners familiar with this technique know that an intact rock mass, i.e. a rock mass which is sufficiently stable to be regarded as safe, will respond to the applied tapping with a relatively high frequency sound. A detached rock mass, i.e. a rock mass which is insufficiently stable to be regarded as safe, will respond to the applied tapping with a relatively low frequency sound [2].

This decision-making process is fully dependent on human interpretation and is therefore highly subjective. Errors can be made, attributed for instance to ambient noise levels, fatigue, inexperience and the hearing ability of the person making the assessment. A way to mitigate and minimize these factors is needed to improve safety [2].

While this exercise is extremely important to the safety of miners, it is often rushed and carried out inefficiently due to the fact that production can only commence after the area has been declared safe. Miners carrying out this exercise are often under a lot of pressure to complete the process and declare the area safe in order for operations to begin [1].

The making safe process is completed by remedying the potentially unsafe rock masses identifies, by either barring down the offending rock, supporting it with temporary support, or installing permanent support to prevent the rock

from dislodging and falling. Due to the amount of manual labour involved in the ‘making safe’ process as a whole, the miner can only efficiently operate for eight minutes before rest is necessary [8].

A consistent means of rock mass stability assessment, that is not as arduous as the current method, is therefore necessary to ensure that errors are kept minimal. Automation can therefore be used in the attempt to assist miners to effectively and economically conduct their tasks.

III. AUTOMATION

South Africa still has one of the biggest gold resources in the world, but it is at depth, which results in significant amounts of gold having to be locked up in shaft pillars and stability pillars, because blasting snarls up the ground conditions and creates dangerous seismicity. In the first steps towards the new mining paradigm, hard rock mines, especially gold, should strive towards:

- Eventually stopping all blasting;
- Creating people-less stopes; and
- Mining around-the-clock every day of the year in order to take full advantage of the country’s resources.

This plan will lead to mine workers being removed from the high-risk deep-level areas, ultra-deep resources being profitably accessed, and a competitive advantage opened up in deep mining. Most importantly productivity will be increased and safety improved [9].

A. Current Technologies

The CSIR has been working on technologies that can help alleviate the impact of danger involved in South African hard rock mines. Extensive research has been and is currently being undertaken to develop novel mining methods to assist in improving the safety of our mines through automation.

While the long-term plan is to stop blasting altogether, short-term mitigating efforts are required to ensure that current operations continue to run as safely as possible. This include minimizing the impact of blasting on the entire operation are required. Blasting introduces noxious fumes and increases the risk of rock falls associated with increased seismic activity [1]. Miners often have to wait for the work area to be ventilated before the pre-entry examination can be carried out. This delays operations and leads to non-optimal revenue generation.

Technologies that are immediately available can be used in the attempt to reduce the impact of blasting on the entire making safe exercise. These include but are not limited to smart-sensors and thermal imagery. These technologies can be used in conjunction with one another to improve their effectiveness in our application. These technologies will be discussed in more detail in the section that follows.

B. Thermal Imagery

Thermal imagery [10], [11] involves the identification of temperature difference between loose and intact rock masses.

The idea revolves around the principle that loose rock masses will be cooler than intact ones due to the fact that the heat flow from the host rock to the loose rock is interrupted by the crack that exists between the rocks. The cooler ventilation air therefore preferentially cools the loose rock mass [12]. The thermal camera is used to identify cool spots in the rock mass being assessed. These thermal images can be reflected through the use of projectors or other electronic equipment.

Although effective, the thermal imager only offers a 55° angle of view. This enables the camera to be effective in large excavations; however in confined areas such as stopes, it offers a limited view range. Stopes are typically 1 m high and at this distance, the angle of view only focuses a target of 500 mm across [12].

For instances where a ‘suspicious’ rock covers a large area that makes it difficult to delineate using one image, it is possible for a series of images to be stitched together to create a larger view. This image will then display a single image showing the temperature difference between the entire large ‘suspicious’ rock and the surroundings. The stitching is typically an automatic process that does not rely on human intervention.

Thermal imagery when used together with augmented spatial reality may enable the user to project augmented information onto real scenes. This can be achieved through the use of a projector mounted strategically near the camera.

Like virtual reality, augmented reality is becoming an emerging platform in new application areas for museums, edutainment, home entertainment, research, industry, and the art communities using novel approaches which have taken augmented reality beyond traditional eye-worn or hand-held displays. Spatial augmented reality consists of approaches that may exploit optical elements, video projectors, holograms, radio frequency tags, and tracking technology, as well as interactive rendering algorithms and calibration techniques in order to embed synthetic supplements into the real environment or into a live video of the real environment.

Wikipedia defines augmented reality (AR) as a term for a live direct or an indirect view of a physical, real-world environment whose elements are *augmented* by computer-generated sensory input such as sound, video, graphics or GPS data [13]. It is often achieved by placing a screen between the observer and the environment on which augmented data is added [12].

The CSIR is exploring possibilities of using AR together with the thermal camera to create a ‘safety torch’ that can be used in the pre-entry examination to immediately identify potentially unsafe rock masses.

C. Smart Sensors

The CSIR have developed a smart-sensor that is used to assist miners in the rock mass condition assessment. Miners testing for loose rocks and other anomalies in underground mining environments use a sounding bar to excite the ‘suspicious’ rock mass and make an assessment of the condition of the rock mass. The sensor which is known as the electronic sounding device (ESD) was developed to address the subjectivity involved in the pre-entry examination.

The device in its current form is mounted onto a miner's hard hat; it uses a microphone to capture the sound produced by the rock mass under assessment when it is tapped with a sounding bar. A neural network model is used to train the device to simulate the conventional cognitive process of the miner. This is accomplished through the implementation of a neural network which accepts as its input the audio signal from the sounding bar hitting the rock. The neural network then delivers an audio cue to the operator to indicate its judgement.

The method of operation of the ESD is as follows [2]:

- Capture the acoustic signal generated by the tapping of the rock mass;
- Derive a frequency distribution for the captured signal;
- Process the frequency distribution data by means of a neural network model trained to apply adaptive intelligence to assess the input data; and
- Output a signal from the neural network model which is indicative of the integrity of the rock mass.

Additional explanation of how the ESD operates is depicted in Figure 1.

It is important for the device to be rugged and portable such as to allow it to be incorporated into the design of an automated device. The device needs to be as close to the tapping sound for sufficient clarity and resolution of the recorded signal. An automatic tapping device is necessary such that the quality of the produced sound remains consistent.

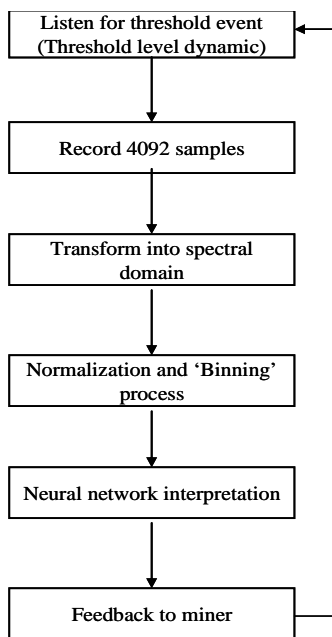


Figure 1. ESD Software flowchart.

The ESD is capable of recording a tapping sound, storing it, transforming it into the frequency domain, normalizing and

grouping the resulting information for the neural network stage, and subsequently interpreting the signal [2].

IV. TESTING AND VALIDATION

The ESD was validated in a process that consists of two steps, which are training and testing. The ESD units were trained and tested to function in four different reefs.

A. Training

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 few months to accumulate samples from various reefs.

The recordings from each reef were added together and all 'unknown' readings removed to optimize neural network training. This process yielded a total of 699 useable recordings for each of the reefs

B. Testing

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

TABLE I. ESD TESTING CONDITIONS

Reef	Conditions		Samples	Barring Incidents
	Ground	Ground water		
1	Intact	Dry	94	17
2	Crushed and fractured	Dry	100	1
3	Solid and intact	Moist	97	44
4 (2 panels)	Crushed fractured	Dry,	95,	10,
	Crushed	Moist	50	16

In all cases there was little background noise, except for reef 2 where the noise level was considerable. All tests were conducted during the pre-entry examination.

C. Results

The testing process resulted in com 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 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 II. ESD TEST RESULTS

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

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 II 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 make-up 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.

V. DATA FUSION

The CSIR is currently investigating possibilities of using the safety torch in conjunction with the ESD and other technologies. The method of operation will be as follows:

- Use localization to establish the position of the area under assessment;
- Identify risky areas through the use of thermal imagery (the safety torch);
- Delineate unsafe areas by using the ESD to identify potentially unsafe areas; and
- Correct the condition of the rock mass where necessary.

In order to establish the position of the testing device in the mine, it is necessary to implement a form of localization. A means of representing the localization information in a way that it can be easily interpreted is also necessary.

Fusing sensor data becomes possible only if the location of the data capture points is known. The CSIR is using simple ultrasonic beacons [14]. These beacons will provide the position of the safety data collected, which will enable construction of a safety map.

The safety map will enable inspectors visualize the condition of the rock mass prior to entering and conducting the examination. This will help reduce the safety risks involved in the rock mass assessment as the person conducting the examination knows high risk areas prior to testing.

It is believed that a risk known is a risk reduced and therefore it is imperative that the information displayed on the map can be easily interpreted by all users, hence the augmented reality view.

Although beacons only really allow for 2D positional data reporting, augmented reality requires 3D views of the area under assessment for ease of interpretation. The signals from the beacons can be converted into 3D data through conversion using artificial neural networks.

VI. FURTHER WORK

In order to achieve complete automation that will enable the deep level mining industry to stop blasting altogether, small steps need to be covered. Each step in the process will lead to more information being readily available to optimize systems that will be incorporated into the final system.

It is necessary to further investigate other automation techniques and methods in order for best solutions to be selected.

Automation can be suggested for use in high risk areas such as to save people's lives. It is in no way intended to replace miners working in areas that allow for profitable human mining. All technologies presented in this paper allow for both human and artificial interaction.

The best option would be to initially adapt it for use with human intervention. Adapting the device into one that can be used for full automation should then be much simpler as the one that includes human intervention will serve as a technology demonstrator.

Further work has to be done on establishing definitive causes of high unsafe errors in areas that have intact ground conditions. More samples need to be collected in such areas such that a more effective neural network model can be derived.

It is believed that automation will speed up the making safe process and therefore help optimize revenue.

A means of converting 2D beacon positional data into 3D data that can interface with spatial augmented reality will be explored further.

VII. CONCLUSION

Although machines are rigid and unable to adjust, automation will optimize the making safe process in that the condition of the rock mass will be properly characterized in shorter periods.

Subjectivity involved in the pre-entry examination will be removed as artificial intelligence is rarely affected by age, noise, sight etc. In the event that the equipment gets old/outdated, the problem can almost always be easily and effectively remedied in no time.

Automation used with human interaction will remove exclusivity from the pre-entry examination as anyone who can interact with the equipment can conduct the examination.

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