Virtual reality in improving mining ergonomics

by P. Foster* and A. Burton†

Synopsis

Over the past decade there has been a great deal of research into the use of virtual reality (VR) and computer graphics in the mining industry. Much of this has led to developed applications including training simulators and accident reconstruction. One other area where there is considerable potential for virtual reality is that of mining ergonomics. This paper identifies those common ergonomic limitations associated with mining equipment that can be effectively modelled using VR techniques. From this, two simple models have been developed, namely (i) remote control continuous miner operation and (ii) free steered vehicle sight-lines, which demonstrate the practical use of VR in this area.

Introduction

Virtual reality (VR) has been applied in many sectors where safety and organizational complexity are key issues. This includes advanced manufacturing, the aviation industry, the nuclear industry, military applications, as well as the mining industry. In the mining industry typical applications of VR include the familiarization of new recruits and visitors with the mine layout, the rehearsal of emergency situations, accident reconstruction, and the training of equipment operators on 'virtual' machines (Hollands *et al.*, 2000[1]). One other area where there is considerable potential, but on which little has been done with respect to VR, is that of mining ergonomics.

It has been stated that over 90% of mining accidents involve human error. Recent studies have shown that one of the overriding issues lying at the cause of such accidents lies with ergonomic limitations in the design of mining equipment and machinery (Simpson, 1993[2]). All too often in the past, ergonomic issues have been overlooked in the design of mining equipment. Issues such as limited driver vision, poor control design and location, access and egress difficulties, and incorrect population stereotypes not only have a direct implication for safety but also for efficiency and performance standards.

Ergonomics

Ergonomics is the discipline that brings an understanding of human behaviour and capabilities to the design process. It helps us to understand human capabilities and limitations, and ensures that the design of equipment, working environments and information systems take these into consideration. The traditional framework used in ergonomics for the study of the relationship between man and equipment is the 'man-machine' interface. The main areas of consideration within this framework are as follows:

- Ensuring the man's sensor mechanisms (particularly sight and hearing) are allowed clear access to the necessary information sources
- Ensuring information is in a form that is clear, precise and easy to assimilate and process
- Ensuring that the man is in a position to control the equipment easily, quickly and with the required accuracy
- Ensuring ease of access to and egress from the workplace
- Ensuring a reasonable degree of physical and postural comfort, sufficient to avoid the rapid development of fatigue or the risk of musculoskeletal strain
- Ensuring that local environment factors do not exacerbate the problems above or are likely to cause any risks to safety or health.

Ergonomic limitations associated with the first three areas can be effectively modelled using VR. This corresponds to those limitations associated with the design and

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location of displays and controls and positions of sight-lines and illumination.

Common ergonomic limitations in mining equipment

Over the last two decades a great deal of work has been undertaken by mining research agencies in various countries on the ergonomics of mining equipment. In Europe, extensive research programmes into mining ergonomics have been funded by the European Coal and Steel Community. Much of the early research focused on the original design of mining machinery as ergonomic limitations are easier to deal with at this stage, while more recent studies have looked into improving the ergonomics of existing machines by retrofit. With this in mind, a great many of past research projects were studied, from which the following ergonomic limitations were identified, which could be modelled using virtual reality techniques.

Workplace design

- Limitations in the overall dimensions of drivers' cabs on FSVs and locomotives
- Poorly located controls, hoses, valves and other components that intrude into the cab
- Insufficient protection from external hazards (such as lagging, loose ducting and dust) entering the driver's cab through windows and doorways.

Design and location of controls and displays

- Lack of standardization of control layouts across similar types of vehicle often produced by the same manufacturer
- Inappropriate control stereotypes with movement-response relationships that contradict the expectations of the operator
- Lack of appropriate operating clearances and poorly designed handles
- Frequently used controls and emergency controls located outside acceptable reach limits
- Displays that are difficult to read or interpret and located outside the normal sight-lines of the operator
- Inappropriate display stereotypes, which confuse and lead to information error.

Illumination and operator's visual requirements

- Poor sight-lines caused by low seat heights and the location and orientation of the operator's cab on the machine
- Headlights fail to illuminate important visual attention areas.

From this, a number of scenarios were generated which were then modelled using virtual reality techniques. These included (i) remote control continuous miner operations and (ii) improving the sight-lines of free steered vehicles by retrofit. These two applications are described in more detail in the remainder of this paper.

Remote control continuous miner application

The increasing use of remotely controlled continuous miners (CMs) has led to a number of incidents and fatalities world-wide. A number of studies have looked in detail at this type of operation (e.g. Pitzer, 2000[3]; Talbot and Rushworth, 1998[4]) and identified that many of these problems are related to a combination of poor operator positioning and inaccurate assessment or perception of risk. In these operations there are two categories of hazards associated with ergonomics:

- Those associated with the operator and his positioning (a function of sight-lines as he will position himself where he can see the cutting). These include:
  - Being struck by other moving machinery in the vicinity (such as shuttle cars operating behind the CM)
  - Being struck by falling or flying objects, such as falls of roof from unsupported ground or lumps of rock being projected by the cutting head
  - Exposure to health hazards such as dust and noise.
- Those hazards associated with the use of the remote controller such as being struck by the CM when incorrect controls are activated or controls are activated in the wrong direction.

Based on this information, a VR model was developed in order to demonstrate the hazards and risks associated with remote control operation. The model in detail encompasses a continuous miner with a 3.3 m cutting head operating in a single entry heading of dimensions 4.5 m width and 3 m height (typical of coal mining operations in the UK). A bridge conveyor is fitted to the rear of the CM, which feeds to shuttle cars. The depth of cut is 1m and the cutting procedure is a double pass cycle i.e.:

- Position the CM on the right-hand side of the roadway
- Raise the cutting head and 'sump' half a metre from top to bottom
- Repeat the above so that a total cut depth of 1m is obtained
- Reposition the CM on the left-hand side of the roadway
- Repeat the above cutting cycle so that a total cut of 1 m is taken.

The user controls the continuous miner using a hand-held controller simulating the remote control unit and moves around the virtual world using a separate joystick.

In order to model risk, a number of risk indicators are shown on the model that show the level of risk of the significant potential hazards that affect the CM operator. These hazards are:

- Being struck by the CM
- Being struck by the FSV/shuttle car
- Being struck by rib/roof fall
- Being struck by flying rocks.

The level of risk shown by the risk indicators is based on the operator's positioning within the virtual world. A series of risk regions has been programmed into the model and if the operator positions himself within such a region, the level of risk changes. For example, the risk region for the hazard of being 'struck by flying rocks' is taken as a radius from the front centre of the machine as the source of this hazard is the cutting head. The relationship between the radius and the risk is given according to the dimensions in Table I.

Table I

Flying rock: dimensions of risk regions

Radius	Risk level
10 m	0
9 m	0.5
8 m	1
7 m	2
6 m	3
5 m	4
3 m	5

Figure 1 shows a view from the CM simulator looking back down the roadway showing the CM, approaching shuttle car, and the different risk indicators

As the operator moves around the virtual world in real time, the levels of risk to which he is exposed are recorded and can be analysed separately. The risk scores obtained can be compared for different cycles and times of operation and used as the basis for a comparative risk assessment between stand-off and on-board operation, as well as different cutting cycles. The results of this comparative risk assessment show that for the majority of the standard cutting operation described above, the operator has a total risk of 'medium' or above on the 'total' risk indicator for about 70% of the time of the cut. The higher risk locations where the operator was positioned included:

- ➤ Close to the cutter head in order to see the far top corner for each pass
- ➤ Standing on the tight side of the machine to get a better view of the upper corners of the cut
- ➤ Next to the cutter head while cleaning and levelling the floor at the end of each pass
- ➤ Behind the CM and near the shuttle car while backing the CM away from the face before tramming it from the right to the left-hand side of the roadway.

In terms of risk assessment, what this model shows is that remote control operation exposes the operator to different hazards and risks from those on on-board operation. As this assessment is qualitative, and if the number of hazards and magnitude of risk were the basis of any comparative risk assessment, it could be argued that remote control operation is 'more risky' then on-board operation. However, in reality the difference in risk is dependent on site-specific conditions, the standard of training and the operator's awareness of these hazards.

Whilet the overall aim of generating this model was to study the lines of sight and operator positioning, one obvious additional application of the model is for operator training, particularly as operators are generally trained 'on the job'. This allows operators to be made aware of potential hazards and risks in the virtual environment as a direct part of their training. This aspect is to be further studied in a follow-up to this project.

FSV sight-lines application

Free-steered-vehicles (FSVs) are used in UK coal mines to transport material and equipment in underground roadways. The very nature of the operating environment imposes major design constraints, which prevent the vehicle from meeting optimum ergonomic guidelines (Boocock *et al.*, 1994[5]). One of the major ergonomic limitations that governs the safe use of FSVs underground is poor visibility from the operator's position. Such problems are affected by a number of factors such as the low vehicle height, the centrally positioned cab, the design of the protective canopies, the positioning of headlights, and the types of load being carried.

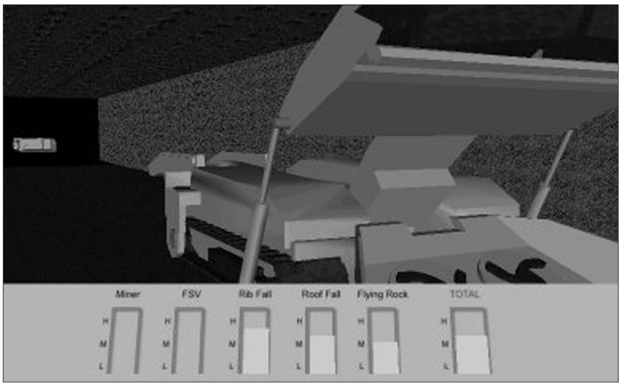


Figure 1—View of CM simulator showing CM, shuttle car and risk indicators

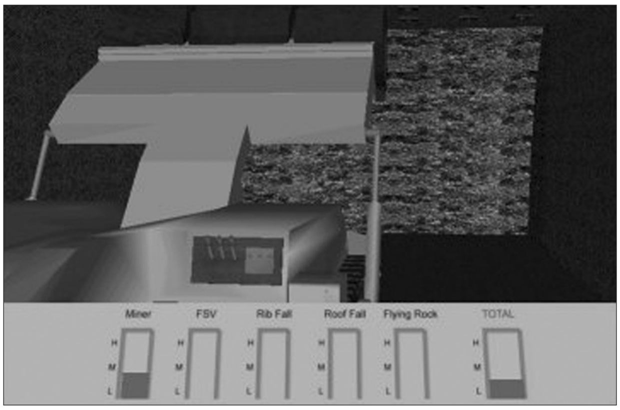


Figure 2—View of CM simulator looking forward

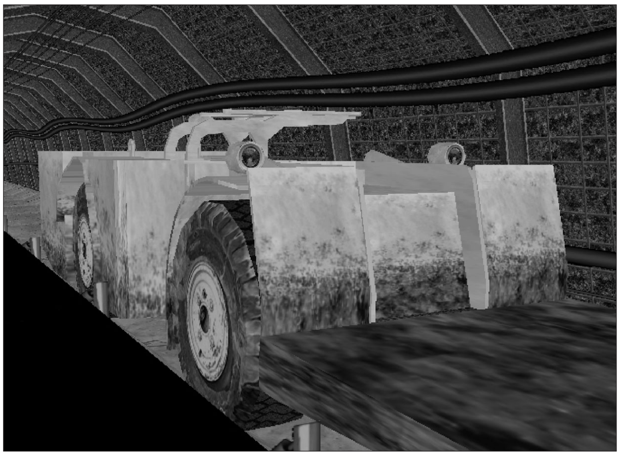


Figure 3—Virtual free steered vehicle

Past research funded by the ECSC (Rushworth *et al*., 1995[6]) has shown that improvements can be made to the ergonomics of FSVs by a number of retrofit improvements. Such retrofits can be undertaken by mine owners and operators on existing machines, and this is important as new FSVs may not be readily purchased with the contraction of the UK mining industry. In the 1995 project the ergonomics of a number of machines were examined. Three machines were then selected and used to evaluate and demonstrate the practicality of a wide range of retrofit ideas that ranged from simple, relatively inexpensive solutions to more fundamental changes. Among these retrofits were a number of improvements that were specifically made for the purpose of improving sight-lines. The actual benefits, in terms of improved visibility, were realized after the improvements had been made. In this project VR would be used to demonstrate the benefits of these retrofits in the virtual world before any modifications take place. It would also reintroduce mine operators to the concepts of retrofits due to limited exposure of the original project.

Following discussions with members of the 1995 project research team, it was agreed that the following potential retrofit improvements be modelled in the virtual world so as to evaluate their effectiveness in improving sight-lines:

- Raising the height of the supporting canopy (from 0.8 m to 1 m above the seat position)
- Modifying the driving position by raising the seat approximately 0.1 m and moving the cab wall behind the driver backwards 0.075 m
- Modifying the shape of the front near-side mudguard by reducing the clearance over the tyres from 0.15 m to 0.05 m and cutting back the leading edge of the mudguard by 15°
- Modifying the mounting arrangements of the front headlights from the front mudguard to under the canopies
- Reshaping the engine cover by chamfering the near-side top edge some 0.15 m across and 0.15 m.

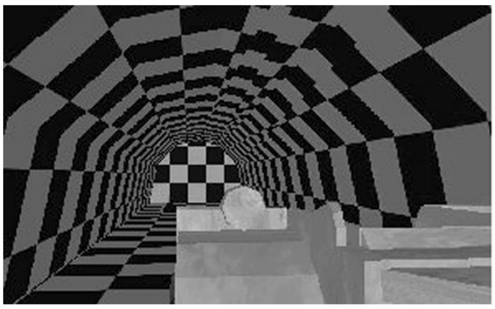
The model allows the FSV sight lines to be viewed in either a virtual mine environment or as a grid of 1 m squares. These squares allow sight lines to be plotted and potential improvements to be quantified. Eye positions are also included for the 5th, 50th and 95th percentile sized operator within the model.

As an example in Figure 4 below, the diagram on the left shows the forward sight lines for an average height operator (i.e. 50th percentile). The diagram on the right shows the sight lines for the same sized operator if the seat were raised upwards by 0.1 m and back by 0.075 m. It almost doubles the forward distance that can be seen.

For all the potential retrofits, and for the three anthropometrical dimensions, a series of sight line plots has been developed. Figure 5 below shows the plotted sight lines for an average height miner before (hatched) and after (shaded) all the retrofits have been undertaken. The hatched area represents the floor region that cannot be seen by the operator before any retrofits and the shaded area the region that cannot be seen by the operator after all the above retrofits have been undertaken. As can be seen, the improvements are considerable.

The improvements in sight-lines for an average height operator for (a) chamfering the engine (b) repositioning headlamps and (c) raising the seat are shown in Figure 6. The estimated costs of these individual retrofits are (a) £2000 (b) £1500 and (c) £2300, and so in terms of cost benefit, repositioning the headlights is the greater. The retrofit of modifying the front mudguard had no effect on the sight lines at all.

From this model and in particular from the sight line plots, mine operators and engineers can actually visualize and evaluate the potential benefits of retrofit improvements before they commit themselves to the expense of modifying their vehicles.



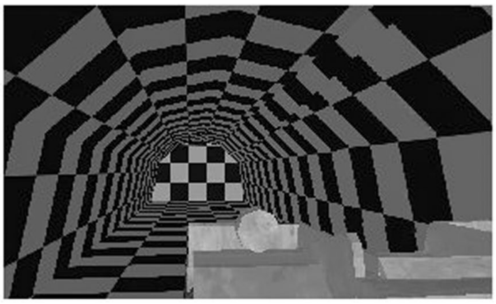


Figure 4—FSV Sight lines on metre square grids before and after seat retrofit

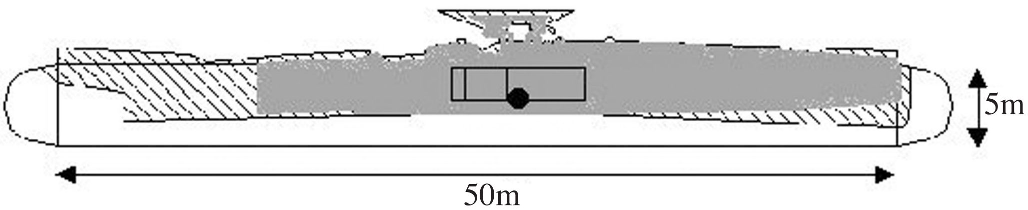


Figure 5—Sight ine plots before (hatched) and after (shaded) all retrofit improvements

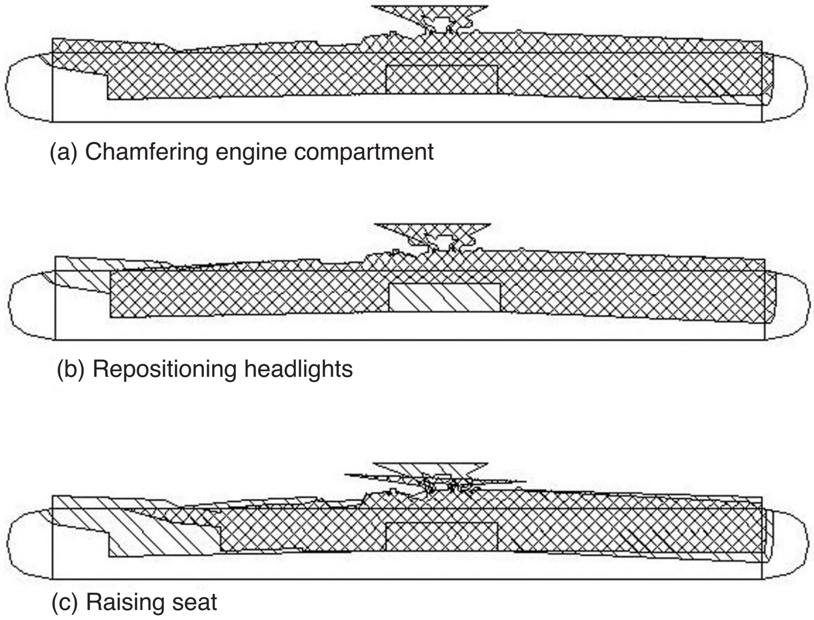


Figure 6—Sight line plots from individual retrofits

Conclusions

The models described within this paper have shown that virtual reality can be used to develop simple, yet practical applications related to mining ergonomics that in turn have the potential for improving health and safety.

- ➤ In the CM model, the risks associated with the personnel positioning of remote operation can be determined and used as the basis of a comparative qualitative risk assessment, as well as in operator training. This allows operators to be made aware of potential hazards and risks in the virtual environment.
- ➤ In the FSV model, the sight line plots allow machine manufacturers and mine operators to see directly the restrictions from these vehicles, as well as being able to visualize the improvements that can be brought about by retrofitting. These improvements in sight lines have a direct implication for improved safety as a greater area can be seen by the driver.

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Platinum industry adopts uniform safety training*

The platinum industry has taken a major leap forward on the safety front by opting for universal Safety Health and Environmental (SHE) induction training.

Impala Plats and Anglo Plats are party to the universal safety approach, having agreed, after in-depth investigations, to select KBC whose core offering is generic induction, legal and environmental outcomes based, SHE training programmes.

The decision to go the generic route was taken by the platinum industry's Bushveld Safety Forum, established two years ago to provide a platform for discussion and management of safety challenges in this key sector.

The rationale behind the joint training initiative was fourfold. Firstly, as a key industry, the platinum industry has SHE obligations to workers, trade unions, shareholders, investors and the international market.

Secondly the contractors and suppliers involved in the platinum industry are fundamentally the same. It therefore made economic as well as practical business sense to avoid duplication of effort, cost and time in providing generic safety training services to the industry.

Thirdly, in terms of outside contractors, the platinum industry's management is responsible for the legal and safety liabilities of contractors allowed on site at a platinum facility. This scenario is unique to the platinum sector.

Finally it's necessary to ensure that South African platinum producers comply with international safety legislation and the Mine, Health and Safety Act and the Occupational Health and Safety Act have been couched in overall compliance with international norms and are broadly recognized as being among the world's best.

The generic approach ensures a single standard using training content co-developed with detailed input by the stakeholders says KBC MD Michael Kruger.

Having been essentially designed by the industry itself in a collaborative process, the resultant courses are tailor-made to the industry's needs, technically and legally

They comply with international standards and all applicable local legislation and are premised on the principle of good practice and a flexible approach to managing accident and incident exposure and risk

Certification in terms of the induction courses is transferable from site to site and remains valid for a year. The courses are constantly reviewed in conjunction with the Bushveld Safety Forum, taking into account practical experience as the needs of the industry evolve in safety terms

While training has traditionally been one of the most conservative, change-resistant fields, the courses recognize the emphasis on learner participation and 'edutainment' in the interests of better results and greater effectiveness with the active involvement of the learner on the basis of guided discovery.

High-level training is provided by cost effective, self-paced, interactive Computer Based Training (CBT) programmes accessible anywhere and at anytime. In a sense, this is 'Just in Time' learning.

KBC has also developed mobile training centres for the platinum industry on the premise that training should be available wherever the need arises.

The courses are aligned with SAQA requirements and can be used for credits of SAQA qualifications, ultimately embracing the highest level of such qualifications. Clients have access to an interactive, SAQA aligned database on their learners that is either stand-alone or web enabled

Benefits flowing from the generic approach include access to appropriate, in-depth expertise which could not justifiably have been created in-house, accurate management of SHE related budgets and the delegation of most day-to-day responsibilities in terms of SHe compliance.

For further information call Michael Kruger, Managing Director, KBC at (011) 792-9129 or 083 655 4087 michael@kbconsulting.co.za. ◆

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