Extracting more value from mine data using virtual reality and scientific visualization techniques

*Vasak, P. and #Suorineni, F. T.

*MIRARCO - Mining Innovation, Enhanced Visualization and Optimization Group
933 Ramsey Lake Road Sudbury, Ontario, Canada. P3E 6B5 Email: pvasak@mirarco.org
#MIRARCO, Geomechanics Research Centre, Sudbury, Canada.

Abstract:

MIRARCO has pioneered the application of large-screen, stereoscopic, virtual reality technology for the mining industry since 2001. The technology is used to evaluate trends in the data to gain insight and understanding at all stages of mine development; from exploration, earth modeling, resource modelling, mine planning and infrastructure layout to the display and visualisation of mine monitoring data. The application of novel scientific and engineering visualization technology provides the means for technical professionals (geologists, engineers, etc.) to gain better understanding and insight from their data.

The Laurentian University virtual reality laboratory (VRL) provides the research platform for developing new technology ranging from exploration drillhole location and optimization to mine safety issues such as rockbursts in deep mines. The technology has matured to the point where the research innovations are currently being transferred to the mining industry. Two case studies are presented, the first focuses on optimal drillhole placement for mineral exploration and the second focuses on the installation of a VRL at the deepest mine in the Sudbury Basin to better understand and mitigate rockbursts in deep mines.

It is not the quantity or quality of the data, but rather the quality of the decisions that are made based on the data that makes scientific and engineering visualisation techniques in stereoscopic 3D an invaluable resource.

1 Introduction

The RAND report on the critical technologies for the mining industry recognises that it is the knowledge management benefits of new IT technology that will provide the greatest benefit to the industry (Peterson et al., 2001). In fact, most leading mining representatives interviewed for the report stated that "although mine operations are generating more data, such information is rarely well utilized." The major challenge is first to separate the important information and only then decide on how to use it. An often cited solution for

simplifying the complex data interpretation is the use of simple graphical interfaces that are easy to comprehend by all levels of mine personnel, since, as one particular respondent elegantly stated: "Data is not as interesting as insight", (Peterson et al., 2001). It is these underlying principles that form the basis for new scientific and engineering visualization techniques in mining.

Although mining has large datasets, the lack of structure and data standards creates obstacles to integrated evaluation. The benefits of developing advanced visualization applications are clearly highlighted in the National Science Foundation review of visualization technologies for science (Munzner et al., 2006). The discipline essentially requires a means of quickly identifying trends and anomalies, and reliance on the human's visual analysis capability still remains one of the most effective means of identifying anomalies. Our goal is to develop alternative views of the world in order to maximize the use of human perception and pattern recognition.

A number of mining researchers have applied principles of virtual reality to develop tactical applications such as safety training applications, and line of sight for equipment design. These applications relied on the modelling of real objects such as tunnels and vehicles to improve the effectiveness of training.

The foundational research work that MIRARCO is pursuing using virtual reality, attempts to modify our perception of transient data to better understand the complex dynamics of mining. Using virtual reality as a means of improving the scientific process, MIRARCO has worked with leading mining companies to develop a unique approach to data integration, review and vetting. Collaborative Immersive Virtual Reality (CIVR) (Kaiser et al., 2002) has been used to:

- Improve the effectiveness of exploration projects
- Optimize location of drifts and cross cuts to minimize drift damage
- Optimize mining production sequences using genetic algorithms
- Develop underground support criteria
- Review underground planning and layout scenarios
- Environmental assessment and flow modelling

This paper focuses on the innovations in scientific visualization for exploration drilling and mining-induced seismicity (focus on safety) in an immersive, stereoscopic virtual reality (VR) environment. The latter has been adapted to an on-site VR facility at the deepest mine in the Sudbury Basin, and provides the mine operator with the strategic and tactical advantages provided by the innovations in data visualization and collaborative interpretation with the following benefits:

- Improved identification of hazardous work areas, to formulate better re-entry policies and allow better planning of workforce allocation

- Installation of more effective support systems to strategic areas of elevated risk

- Better understanding of the overall response of a mine to extraction also facilitates mine planning and design

- Placement and design of key underground infrastructure

- Assisting in reducing production costs and thus in enhancing profitability

2 Innovations in Data Processing

Proper use of VR and scientific visualization represents a fundamental paradigm shift in how we collect, store, process and interpret multi-terabyte datasets, previously the domain of enterprise database managers. According to a recent article in the "A Generation of New Technology" (GNT) website, "Worldwide spending on hardware, software, and services for 3D visualization, simulation, and training in the defence and government segment will reach $16.5 billion in 2010, and grow to $20 billion by 2015" (GNT, 2010). This foretells that the paradigm change will happen in all industries in the near future since many technological advances and innovations come from advanced defence research.

From an engineering practice perspective, the current paradigm shift from spreadsheet calculations (represented as graphs or charts) to an immersive, multi-dimensional representation where scientific visualization techniques provide the insight into the vast multi-disciplinary data sets is as evolutionary in its impact as was moving from the slide rule to the hand-held calculator, or subsequently, the move from the programmable hand-held calculator to the spreadsheet on personal-computers. The geoscientist and engineer now have a new tool in their arsenal to gain better insight into the complex world that is the rock mass. This shift also provides an important opportunity since VR and immersive projection systems

not only allow very large datasets to be quickly assessed and explored, but also provide an increase in the dimension of the data that can be represented.

2.1 *n-Dimensional Geospatial Data*

Data in the spatiotemporal geographic information system (GIS) sense can be ordered into three main domains (Hogeweg, 2000): (i) The spatial domain represents the physical location (in a defined coordinate system), (ii) The temporal when it occurs and (iii) The thematic, it has some characteristic properties. Data in each domain can be stored and analyzed independently, i.e., they can be stored in different tables in a relational database management system (RDBMS). However, it is more common to apply analytical techniques combining two domains as independent variables, e.g., the more common techniques applied to mining data in the data domain cube are:

- Geostatistics which uses the spatial and thematic domains.
- Animations to show changes to an object, generally movement or motion.
- Topological (relationship) changes over time; and
- Property and geometry variations with time.

True spatiotemporal analysis includes the dependency of all three domains, for example, mining-induced seismicity, by its nature, demonstrates this close dependency – event location is linked to the excavation of the rock mass, and has characteristics of the damage mechanism. The latter depends on stress changes, rock type and strength, various scales of structures and the mining history, amongst others. Therefore, spatiotemporal analysis techniques provide the best insight from the data. However, this is rarely done in practice, partly due to the lack of suitable technology. Innovations in n-dimensional scientific visualization are rapidly increasing our ability to do what was thought impossible just a decade ago before the advent of 3-D modelling software.

2.2 *Scientific and Information Visualization*

Modeling software also provides visualization capabilities, however, the advantage of scientific visualization is that it uses the geometric (easting, northing, elevation) data as a structural support for thematic (property) data. The goals between the modeling visualization and scientific visualization are also different; the former is used to create data and

information, whereas the latter is used to explore datasets to find new trends and likages, and develop new knowledge. Most scientific visualization software rely on the concept of filters being applied to a dataset to extract or highlight knowledge. These filters can be connected into a visualization pipeline which, once correctly defined, can be applied to any number of datasets. This approach is particularly well suited when integrating data from multiple sources, or when having to review multitudes of similar datasets.

Scientific Visualization relies more on the exploration of datasets that have been generated by simulation software, whereas mining tends to rely on inferred datasets based on observational data. Examples of this type of inferred data are most exploration datasets where large volumes of space must be "defined" based on limited drill hole (or geophysical) datasets.

Another key difference lies in the use of the time as a fourth dimension. While many scientific fields of study model the change in a process or object over time, the modeling of time still remains rather limited in mining is quite elusive. Despite these fundamental differences, both disciplines require a means of quickly identifying trends associations and anomalies. Relying on the human's visual analysis capability still remains one of the most effective means of identifying anomalies. Our goal is to develop alternative views of the world, in this case a virtual representation, to maximize the use of human perception and pattern recognition, and thus enable better insight by all for enhanced strategic and tactical decision making.

3 Integrated Multi-Dimensional Models

The value of applying appropriate scientific visualization techniques in a virtual reality setting is highly dependent on the quality and continuity of data collected at the mine site. It is often taken for granted that the data collected and the models generated from it (in reality interpretations) conform to high standards. However, more often deficiencies and errors become glaringly apparent when visualized in a multi-dimensional platform, and VR makes for an efficient first-pass quality control system. Improving data collection systems and applying strict quality control should be a continuing concern for all mining operations. Three significant projects carried out by MIRARCO that utilize the new data integration and scientific visualization paradigm, are discussed in this section.

3.1 *Exploration and Geology models*

Building a proper 3D deposit model is a complex procedure that requires a multidisciplinary geosciences approach, since large volumes of space must be interpreted or "filled-in" based on limited data (surface maps, drill holes, geophysics, geochemistry, structural geology, etc). Knowledge and understanding of the deposit type, depositional environment, major orogenies, and other factors leading to the current day ore distribution and structural geology provide guidelines to the experienced practitioner to build a proper site-specific 3D deposit model. Thurston et al. (2005) describe the modeling procedures and data treatment for the "Integrated 3D Geoscientific Deposit Modelling Project" for Canadian Shield lode gold, and volcanogenic massive sulphide deposits in the Ontario portion of the Abitibi greenstone belt. For such a large undertaking, the Laurentian University VR laboratory was used for model validations by industry, consultants and academia.

The key point is that before we attempt to attribute geomechanical properties to the rock mass, we first must understand the lithological intricacies (variations) and structural relationships. Communication in an immersive, stereoscopic setting facilitates consensus from various experts to build the best model based on currently available data and knowledge. In addition, data and interpretation gaps are typically found and addressed in the VR sessions to improve future models, resulting in improved data collection and auditing strategies.

3.2 *Mine Map Overlays (MMO)*

"Mine map overlays for excavation performance assessment in burst-prone mines" is a chapter in the Canadian Rockburst Support Handbook (MRD, 1995) addressing the practical handling of geological and geomechnaical information to identify potential burst-prone conditions underground. The procedure requires the following layers of information:

- Mine stope and infrastructure layout (the geometry).
- 3D geology model (the geology).
- Rock properties including UCS, elastic properties and density attributed to each unit (the geomechanics).
- 3D elastic stress model (the stress).
- Seismic record with calibrated scaling relationship for ground motion (ppv) estimation (the damage); and

- Ground support tables for various support systems including peak load, ultimate displacement, and total energy absorption (the capacity).

Despite the comprehensive list of analyses, the MMO is highly reliant on the operator providing good quality 3D geological and rock property information and the availability of a properly sequenced 3D stress model, items that are readily provided without considerable time and effort. However, with current 3D modeling, visualization and database technology, the listed items can be easily integrated into a mine geomechanics model. Examples of other geomechanics data analysis for underground excavation using VR are given in Henning et al. (2003). The point is that each mine may have unique rock mechanics problems that may require various types of analyses generated by specialized software or interpretations generated by expert consultants often using simulations. We now have the technology to take the various sources and evaluate them in one common model. It is not sufficient to generate a report with tables and figures alone; the mine operator now requires the data, models and interpretations in a spatiotemporal GIS relational database format to allow the operator and experts to gain the required insight to make the proper high-level decisions to ensure safety and profitability of the operation.

3.3 *Seismic Excavation Hazard Maps*

A seismic event records a physical rock mass damage occurrence, the result of which may not only pose a safety threat to underground personnel but may also have severe financial implications. New innovations in data trends analysis, particularly extracting the spatial orientation of seismic event clusters and tracking blast-induced and mining-induced in time series, analogous to tracking the aftershocks of earthquakes, were introduced about five years ago (Vasak et al., 2004; Kaiser et al., 2005). However, these have remained in the academic domain due to lack of suitable n-dimensional scientific and engineering visualization tools.

In general, stress-induced seismicity follows the mining front as new stopes are excavated and diminishes as an area becomes mined out and stopes are backfilled. However, structure-induced seismicity may recur in a mined out area at a later stage of mining. The implication is that hazard (and risk) conditions are not static, but change over time as mining progresses. More specifically, remote mining areas may trigger seismicity in other areas that cannot be accounted for by stress considerations alone. Keeping track of the past (history), current and

potential future (forecast) hazards is the key for advancing a coherent risk assessment and risk management strategy at rockburst prone mine sites.

The actual data integration, visualization and assessment can be quite complex and conscious attempts must be made to simplify the data representation by reducing the dimensionality in novel ways that still ensure data integrity, clarity and usefulness for insight. Current commercial 3-D modelling packages lack this sophistication and often fail as integrated data visualizers since they only layer the information without drawing correlations between the multiple layers.

Visualization without the proper technology to identify and link n-dimensional patterns within the data has little benefit for decision makers. This concept is illustrated in Fig. 1, which shows a snapshot of seismic events at a particular time of the mining sequence. Traditionally, this data is represented as a point cloud that may have a colour attribute and provides little insight. Here the seismic and microseismic data is enhanced by representation as a series of surfaces, lines, iso-surfaces, shapes, sizes and colours. Each has a prescribed role in a 3-D stereoscopic visualization environment and patterns, not distinguishable in the 2-D image, become apparent to the observer in a VR room which enhances the insight and understanding of the complex problem. However, this is still relatively complex and requires a strong scientific or engineering background to fully comprehend the relationships and trends.
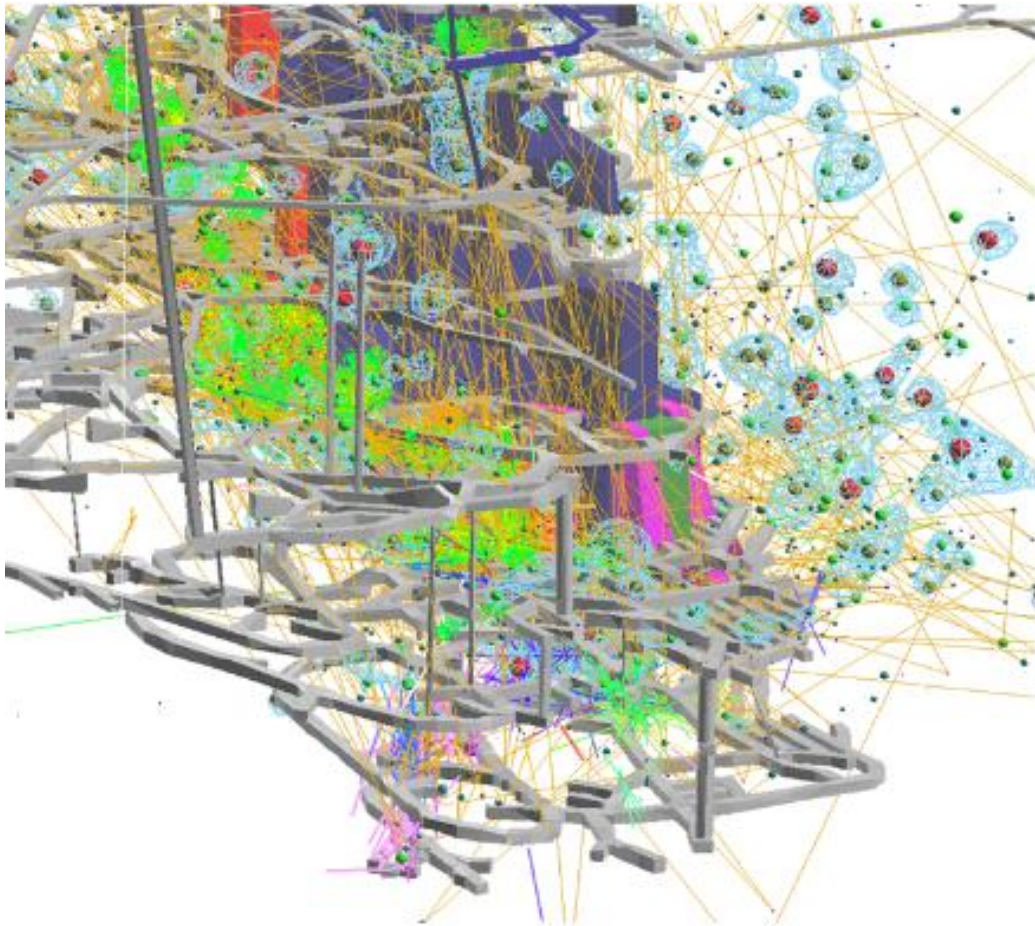
Fig. 1. Seismic data processing and interpretation showing time (linkage lines) and source parameter relationships (colour/size) between mining induced seismic events – This is the expert's viewpoint.

To produce a practical and useful tool for the mine operator, the complexity of the data processing must be further reduced to produce the final geospatial and temporal visual representation that we use for the seismic excavation hazard maps (SEHM) data visualization tool. Local hazard ratings are calibrated and established according to their impact on mine infrastructure, and are visually displayed as shown in Fig. 2. The hazard map is 4-dimensional, since it can represent discrete periods of time and shows the changes in hazard with the mining schedule. Forecasting, based on prior historical trends is plausible since future representations can be determined by the mine stoping sequence and rock mass failure migration based on local mine conditions.
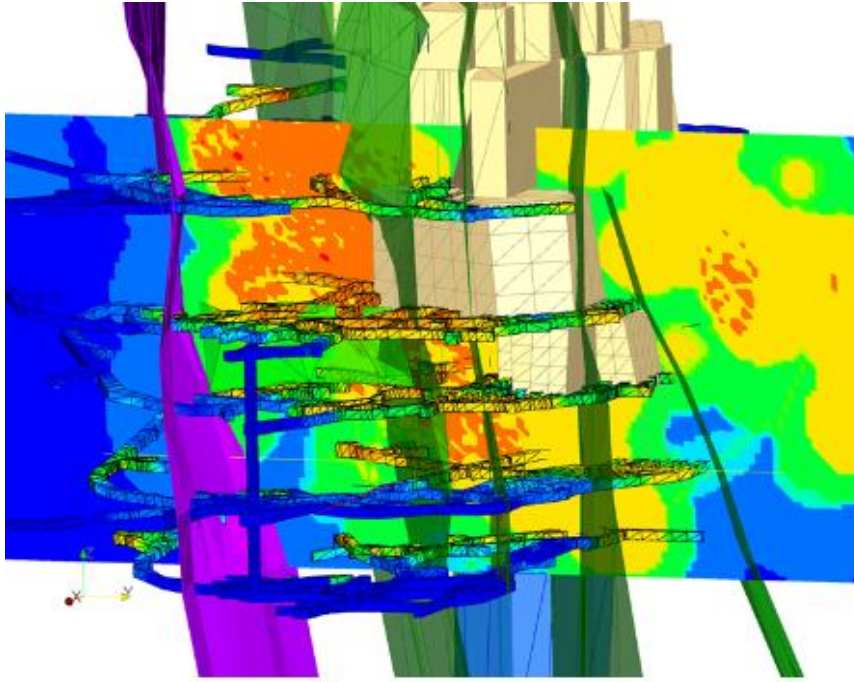
Fig. 2. ParaviewGeo visualization of the Seismic Excavation Hazard Map showing a section and hazard projected onto mine excavations. This is the mine operator's viewpoint.

3.4 *Seismic Excavation Hazard Maps in VR*

Seismic Excavation Hazard Map logic is now implemented as a near-real-time excavation hazard system at the deepest mine in the Sudbury Basin. Due to the complex integration of large datasets from various sources, the high dimensionality (space and time are a minimum requirement) and complex spatial processing, a specialized visualization platform is required, especially for large screen stereoscopic visualization capability.

As a not-for-profit R&D company, MIRARCO is mandated to transfer new knowledge and innovation through innovative applied research, software tools, and the transfer of knowledge. A new open source visualization and data integration package called ParaviewGeo has been released to the exploration and mining industries (paraviewgeo.mirarco.org). It is based on ParaView (http://www.paraview.org), a scientific visualization software platform developed to run on distributed and shared memory parallel systems specifically for the integration and visualization of large, complex datasets. ParaViewGeo allows the practitioner to have access to, and ability to view and interpret large datasets and is the platform for the SEHM data integration tool at the mine site.

The seismic hazards are calculated for the rock mass volume, but can be represented in terms of iso-surface contours, or more traditionally as plans and sections (shown in Fig. 2) or the data can be projected onto any other geometric object such as geological structures (e.g. faults), mine stopes or drifts (also shown in Fig 2.) A simple colour scale (blue = cool, low hazard to red = hot, high hazard) represents the hazard scale.

4 Exploration in VR

This technology is ideal for representing the underground as a model since we physically cannot see beyond the ground surface or into the rock mass itself. Finding an orebody using geophysical and probing (drilling) methods is analogous to finding a tumour in a human body by using various scanning technologies and recreating a fully 3-dimensional representation that surgeons can use to operate precisely.

MIRARCO used a portable VR system at the Prospectors and Developers Association of Canada (PDAC) convention in Toronto, Canada in 2008 to highlight eight junior mining companies' mineral properties. The forum provided both mining experts and non-experts (public and financial investors) a unique view of the actual mineral deposit as they sit underground. By integrating the mapping, geophysics (surface and inversion model), drilling and the resource model, the full potential of the deposits were readily grasped using stereoscopic virtual reality. Fig. 3 shows two views of one of the prospect properties presented at PDAC 2008.
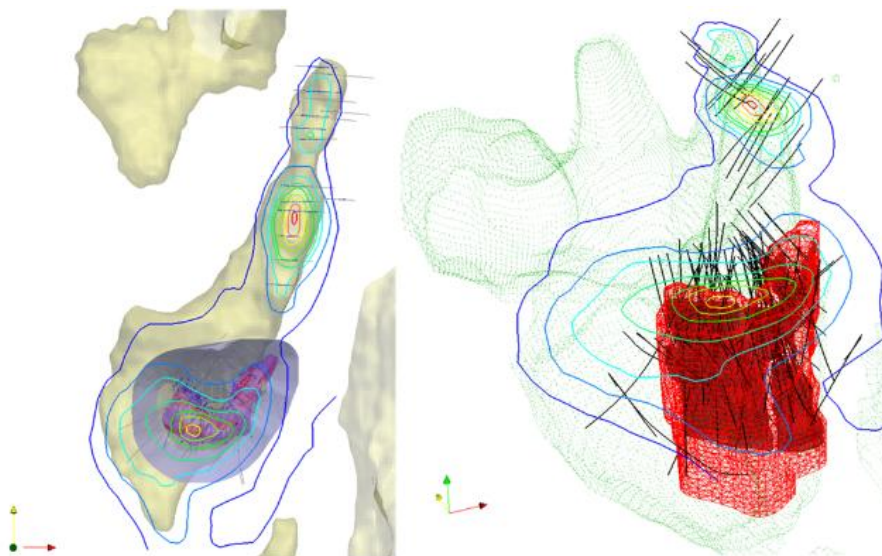
Fig. 3. Two views of a potential mineral deposit showing underground models developed from exploration data.

Apart from displaying the raw data (drillholes), interpreted models and potential mine plans, the information can be displayed for specific purposes. As shown in Fig. 4, the measured resource from the block model is at the highest existing drillhole concentration. To improve the bankable resource, the gaps highlighted as inferred (yellow surface) must be strategically drilled to maximize the benefit while minimizing the drilling costs, e.g., the number of drillholes and the total footage drilled. The red drillholes are laid out in an optimized pattern that uses the exiting layout and maximizes the volume of influence (e.g., the surfaces shown on the middle four planned drillholes) to capture the largest possible volume of inferred resource.
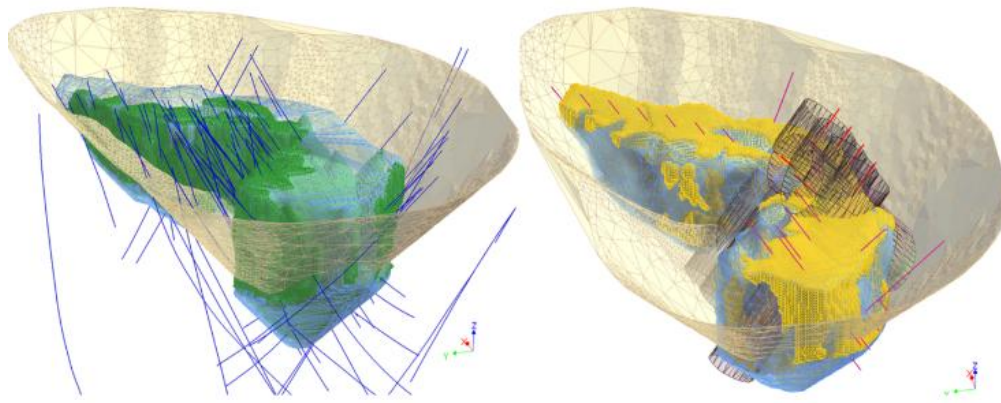

Fig. 4. Using drillholes and block model to upgrade the resource. The green surface represents the measured resource and the yellow, the inferred. Existing drillholes are blue and planned are red.

5 Conclusions

It is not the quantity or quality of data, but rather the quality of the decisions that are made based on the data that makes scientific and engineering visualization in an immersive, collaborative virtual reality environment an invaluable resource.

The VR visualization technology developed at MIRARCO, Laurentian University is enabling innovations in planning and design through an enhanced ability to visualize overall impact of various factors in a complex environment. The VR technology is transitioning to the mine site and early adopters of the technology include:

- Goldcorp, Red Lake Virtual Reality Studio, Canada, 2004

- Timmins Public Library (multi-use), Canada, 2006

- Rio Tinto, Kennecott Utah Copper, USA, 2007

- Golder-Mirarco virtual reality studio, Toronto, Canada, 2008

- Xuzhou Coal, China, 2008

- Vale Inco, Creighton Mine, Sudbury, Canada, 2009

The future is clear, as the age of the visual scientist and engineer draws near, new innovations in processing and interpreting complex integrated data sets is required as the mining industry deals with complex issues from exploration for new deposits to mining at great depth. The future potential and impact of stereoscopic virtual reality is highlighted on the Prospectors and Developers Association of Canada's (PDAC) "Mining Matters" website, a student resource highlighting the career opportunities in the mining industry.

High-level management evaluation of exploration and mining risks as well as developing potential strategic and tactical mitigation measures in the immersive, collaborative virtual reality facility will ensure safe, profitable and reliable mining for the future.

It is up to the current generation of mine managers to put the infrastructure, hardware and software technologies in place to ensure that the mining industry remains relevant to society for the future.

7 References

GNT (A Generation of New Technology). 2010. http://us.generation-nt.com/research-markets-spending-hardware-software-services-press-2183281.html

Henning, J.G, Cotesta L. and Kaiser, P.K. (2003), "Geomechanics Design of Underground Excavations Utilizing Virtual Reality", *4th International Conference on Computer Applications in the Minerals Industries (CAMI),* 8-10 September 2003, Calgary, Alberta.

Hogeweg, M. (2000), *Spatio-temporal visualisation and analysis*, MSc. Thesis: 10-32, University of Salford, UK.

Kaiser, P.K, Henning, J, Cotesta, L. and Dasys A. (2002), "Innovations in mine planning and design utilizing collaborative immersive virtual reality (CIVR)", *104th CIM Annual General Meeting*, Vancouver, BC, 7 p.

Kaiser, P.K., Vasak, P., Suorineni, F.T. and Thibodeau, D. 2005. New dimensions in the interpretation of seismic data with 3-D virtual reality visualization in burst-prone mines. Keynote Address, *6th International Symposium on Rockburst and Seismicity in Mines*, Perth, Australia, 17 p.

MRD (Mining Research Directorate), "Canadian Rockburst Research Program 1990-1995", *Rockburst Research Handbook*, CD-ROM Version, CAMIRO Mining Division, Available at: http://www.camiro.org/mining_products.htm

Munzner, T., Johnson, C., Moorhead, R., Pfister, H., Rheingans, P. and Yoo, T.S. (2006), "NIH-NSF Visualization Research Challenges Report Summary", *IEEE Computer Graphics and Applications*, Vol. 26, pp. 20-24.

PDAC, (2004). *Giving mining a high-tech dimension of reality*, Mining Matters website, http://www.pdac.ca/miningmatters/pdf/article-virtual-reality-and-mining.pdf

Peterson, D.J., LaTourrtette, T. and Bartis, J.T. (2001), *New Forces at Work in Mining: Industry views of Critical Technologies*, RAND, Science and Technology Policy Institute, Santa Monica, California, pp. 33 – 52.

Thurston, P.C., Cotesta L., Hawson C.A. and Vasak, P. (2005), *Ontario Geological Survey Open File Report 6168: Descriptions of Modelling and Coordinate System Conventions for the Integrated Three-Dimensional Deposit Modelling Project*: Discover Abitibi Initiative, 84 p.

Vasak, P., Suorineni, F.T., Kaiser P.K. & Thibodeau D. (2004), "Hazard Map Approach Using Space-time Clustering Analysis of Mining-induced Microseismicity", *CIM-AGM*, Edmonton, 8 p