Extracting more value from mine data using virtual reality

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The application of virtual reality technology for solving complex problems in the mining industry is rapidly evolving with improvements in computer hardware support for virtual reality and innovations in scientific visualisation techniques.

Originally developed for use in the oil and gas industry, the technology is best suited for multidisciplinary evaluation of information at all the stages of the mining cycle. The technology is used to evaluate trends to gain insight and understanding at all stages of mine development; from exploration, geological and resource modeling, mine planning and infrastructure layout to the display and visualisation of mine monitoring data.

The application of novel scientific and engineering visualisation technology provides the means for technical professionals (geologists, engineers, etc.) to gain better understanding and insight from their data. For the past decade, the Laurentian University Virtual Reality Laboratory (VRL) has provided the research platform for developing new technology ranging from exploration drillhole location and optimisation 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.

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 [1]. In fact, most leading mining representatives interviewed for the report stated that “although mine operations are generating more data, such information is rarely well utilised.” 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”, [1]. It is these underlying principles that form the basis for new scientific and engineering visualisation 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 visualisation applications are clearly highlighted in the National Science Foundation review of visualisation technologies for science [2]. 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 maximise 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. However, we pursue a data-centric approach to virtual reality that attempts to modify our visual perception of transient data to better understand the complex dynamics of mining in the following fields:

- Improving the effectiveness of exploration projects
- Optimise location of drifts and cross cuts to minimise drift damage
- Optimise mining production sequences using genetic algorithms
- Develop underground support criteria
- Review underground planning and layout scenarios
- Environmental assessment and flow modeling

This article focuses on the innovations in scientific visualisation 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 visualisation 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

Innovations in data processing

Proper use of VR and scientific visualisation 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 market Study by Acadia Research Group, titled "Opportunities in 3D Visualization, Simulation, & Training 2010-2015: Defense & Government", the forecast is that the "Worldwide spending on hardware, software, and services for 3D visualisation, simulation, and training in the defense and government segment will reach $16.5-billion in 2010, and grow to $20-billion by 2015" [3]. This foretells that the paradigm change will happen in all industries in the near future since many technological advances and innovations come from advanced defense 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 visualisation 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.

**n-Dimensional Geospatial Data**

Data in the spatiotemporal geographic information system (Fig. 1) sense can be ordered into three main domains [4]: (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 analysed 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
- 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 visualisation are rapidly increasing our ability to do what was thought impossible just a decade ago before the advent of 3-D modelling software.

**Scientific and information visualisation**

Modeling software also provides visualisation capabilities, however, the advantage of scientific visualisation is that it uses the geometric (easting, northing, elevation) data as a structural support for thematic (property) data. The goals between the modeling visualisation and scientific visualisation 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 linkages, and develop new knowledge.

Most scientific visualisation software relies on the concept of filters being applied to a dataset to extract or highlight knowledge. These filters can be connected into a visualisation 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 visualisation 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. 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 maximise the use of human perception and pattern recognition, and thus enable better insight by all for enhanced strategic and tactical decision making.

Integrated multi-dimensional models
The value of applying appropriate scientific visualisation 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 visualised 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. Two novel applications, the first for resource exploration and the second for mining, that utilise the new data integration and scientific visualisation paradigm are discussed in this section.

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 from 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. [5] 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 any 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.

VR 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.

A portable VR system was used 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.

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. 3, the measured resource (green surface) from the block model is at the highest concentration of existing drillholes, whereas, the inferred resource (yellow surface) occurs where insufficient drillhole coverage occurs. To improve the bankable resource, the gaps highlighted as inferred must be strategically drilled to maximise the benefit while minimising the drilling costs, e.g., the number of drillholes and the total footage drilled. The red drillholes are laid out in an optimised pattern that uses the exiting layout and maximises the volume of influence (e.g. the surfaces shown on the middle four planned drillholes) to capture the largest possible volume of inferred resource.

Seismic hazard model

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 for a mine. 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 seven years ago [6, 7]. However, these have remained in the academic domain due to lack of suitable n-dimensional scientific and engineering visualisation 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, visualisation 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 3D modelling packages lack this sophistication and often fail as integrated data visualisers since they only layer the information without drawing correlations between the multiple layers.

Visualisation 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. 4, 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 3D stereoscopic visualisation environment and patterns, not distinguishable in the 2D 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.

The Seismic Excavation Hazard Map (SEHM) 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 specialised visualisation platform is required, especially for large screen stereoscopic visualisation capability. A new open source visualisation and data integration package called ParaViewGeo was developed to handle the integration of large exploration and mine datasets. It is based on ParaView (www.paraview.org), a scientific visualisation software platform developed to run on distributed and shared memory parallel systems specifically for the integration and visualisation of large, complex datasets. ParaViewGeo allows the geoscience and geo-engineering practitioner to have access to, and the 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. 5) 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. 5) A simple colour scale (blue = cool, low hazard; red = hot, high hazard) represents the hazard scale.

Conclusions

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

Novel VR visualisation technology enabling innovations in mine planning and design through an enhanced ability to visualise the overall impact of various factors in a complex environment. The VR technology is transitioning to the mine site and early adopters of the technology in North America include:

- Goldcorp – Red Lake Virtual Reality Studio, 2004
- Timmins Public Library (multi-use), 2006
- Kennecott Utah Copper, Rio Tinto, 2007
- Creighton Mine, Sudbury, Vale, 2009

The stereoscopic hardware enables the use of more advanced software applications, particularly if the use of the added dimension provided by the stereo display is not “wasted” by projecting three-dimensional data, but leveraged to display hyper-dimensions. These dimensions can be used to create a link between space and time and to provide a means of evaluating and exploring the effects of uncertainty on measured and synthesised data.

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 related to mining at greater depth.

Acknowledgements

This article was compiled from two mining conference papers, the first in Toronto, Canada (Vasak and Dasys, 2009 [8]) and the most recent in Tarkwa, Ghana (Vasak and Suorineni, 2010 [9]).

The ParaViewGeo tool is an innovative development through a research project funded in part by the Northern Ontario Heritage Fund (Canada), and is made available to the entire mining and geological community at [http://paraviewgeo.mirarco.org](http://paraviewgeo.mirarco.org).

References


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