Virtual geologist – creating photo-realistic 3D models of underground mines with instant Mine Modeller

Stephen Se, Dave Parry and Roy Jakola
MDA, 9445 Airport Road, Brampton, Ontario, L6S 4J3, Canada
[sse, dave.parry, roy.jakola]@mdacorporation.com

Abstract

Geological assessment of active mine faces enables ore grade control, geological modelling and exploration planning. Monitoring of the mine advancement at every drill-blast-muck cycle allows for effective production management. However, geological assessments are performed infrequently due to the need to travel to active mine faces, and detailed surveys to map the mine progress are performed at the end of the month.

Instant Mine Modeller (iMM) is a portable ruggedized stereo-vision system that creates photo-realistic three-dimensional models of underground mine faces on-site. The 3D models are generated automatically within minutes and can be viewed underground and annotated with geological information. The overall ore percentages of the face are calculated automatically for grade control. Annotated 3D models are located in the mine coordinate system and can be imported into mine management systems. iMM allows for daily monitoring of the mine progress and geology, and for re-visiting the mine virtually as it existed.

iMM has been deployed in an underground hard rock mine for 18 months, and it effectively brings the underground work face into mine management offices enabling the right decisions at the right time. iMM has demonstrated benefits to various mine processes including grade control, geological mapping, 3D photo-realistic as-built and production volume.

Introduction

Geological assessment of active mine faces enables ore grade control, geological modelling and exploration planning. Monitoring of the mine advancement at every drill-blast-remove cycle allows for effective production management. However, geological assessments are performed infrequently due to the need to travel to active mine faces, or do not have enough information to best understand the geology. Detailed surveys to map the mine progress are not performed at every cycle due to survey costs.

MDA has developed the instant Mine Modeller (iMM), which is a portable ruggedized stereo-vision system that automatically creates photo-realistic 3D models of underground mine faces on-site. Figure 1 (left) shows a 3D model reconstructed at an underground mine cavity. Geological annotation has been overlaid on the 3D model and these 3D geological features can be exported into mine management software to model the ore body better. Rock mass fracture characterization and structural mapping can also be performed on the 3D model. iMM has demonstrated benefits in:

- Geological mapping
- Grade control
- Daily production volume
- Daily as-built model of advancing work faces
- Geotechnical data
- Better and more timely data for decision making

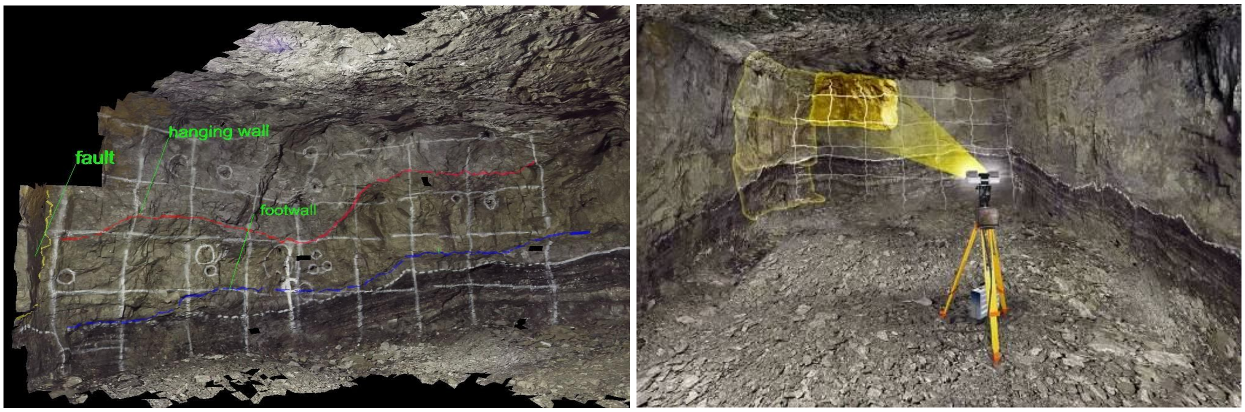

Figure 1 3D model of underground mine overlaid with geological annotation (left) and iMM operation concept (right)

Related systems

There are a number of sensor systems available for 3D modelling of mine faces at both underground and open-pit mines, including photogrammetry packages and laser scanners. Photogrammetry systems capture high resolution images using off-the-shelf digital SLR cameras and the software processes the images to recover the 3D information. Commercial systems available include:

- Sirovision from CSIRO[1]
- 3DM Analyst from ADAM Technology[2]
- ShapeMetriX3D from 3G Software & Measurement[3]

Typically, a reference object and a survey point are required in the scene to scale and geo-reference the 3D model. These systems only collect the images on-site, and the images need to be post-processed afterwards on surface to generate the photo-realistic 3D models.

Laser scanners collect a dense 3D point cloud by measuring the time-of-flight of the laser. Laser scanners have a long operating range and high accuracy at long range. Commercial systems available include:

- I-Site 4400 from Maptek[4]
- ScanStation2 from Leica[5]
- ILRIS-3D from Optech[6]

However, laser scanners are typically heavy, expensive and difficult to ruggedize for underground use. Apart from producing a point cloud, these systems can also offer the option of photo-realistic texture draping. As some of them are geared towards open-pit mining, they may not incorporate lighting.

Principle of operation

iMM is based on instant Scene Modeller (iSM), previous R&D work at MDA to automatically create photo-realistic 3D models of unknown scenes quickly using handheld stereo camera [Se and Jasiobedzki, 2006]. The original motivation of this work was for planetary rover exploration. With iSM, the planetary rover can localize itself and can create a photo-realistic 3D model at the same time. iSM has

---

[1] http://www.sirovision.com/
[2] http://www.adamtech.com.au/
[3] http://www.3gsm.at/
[4] http://www.maptek.com/products/i-site/index.html
[5] http://www.leica-geosystems.com/corporate/en/HDS-Laser-Scanners-SW-Leica-ScanStation-2_62189.htm
[6] http://www.optech.ca/prodilris.htm

also been used in forensics applications such as crime scene modelling, and can improve situational awareness for military applications such as Improvised Explosive Device (IED) detection.

iMM is a ruggedized commercial system developed for underground mine work faces. To allow automatic image acquisition and ensure full scene coverage, the camera head is mounted on a motorized pan-tilt-unit and moves to pre-programmed positions automatically, capturing a sequence of stereo images. The image acquisition typically takes a few minutes for a typical heading, covering the mine face, side-walls and the back. A diagram illustrating the operation concept is shown in Figure 1 (right).

Mine surfaces provide rich texture for feature extraction and stereo matching. Each stereo image is processed and produces a dense 3D point cloud. All the individual 3D point clouds obtained from each stereo image are stitched together automatically. A triangular mesh is obtained from the point cloud and colour images are subsequently draped onto the mesh to produce a photo-realistic 3D model.

Using an integrated laser rangefinder and the motorized pan-tilt-unit, iMM back-sights to survey stations to localize itself in the mine and place the 3D models in the mine coordinate system. By measuring the camera location relative to survey stations for each scan, the 3D models are geo-referenced in the mine coordinate system and appear in the correct location on the mine map.

Unlike the other photogrammetry packages, iMM models are available on-site within minutes from acquisition and contain full metric information, without the need of a reference object in the scene. Geological information can be annotated on the 3D models at the work face. All information can be uploaded to a computer network and imported into the mine management software system.

Hardware

iMM hardware is ruggedized for the harsh underground mining environments by using stiff polyurethane enclosures. The system is sealed and can handle water and dust in typical underground mines. Figure 2 (left) shows the iMM system consists of the following key components:

- Camera head with the stereo camera, LED lights, laser rangefinder and motorized pan-tilt-unit. The stereo camera captures left and right colour images to recover the 3D depth information. The LED lights provide the necessary illumination underground for up to 8m. The laser rangefinder is used for back-sighting existing survey station for localization. The motorized pan-tilt-unit is used for pointing the laser to the survey station and for pointing the camera at different pan and tilt angles to capture the images.
- Ruggedized Underground Computer (RUC) with battery and power conditioning. This electronics unit hanging underneath the tripod also has USB and Ethernet ports as well as a battery level indicator. The ruggedized computer is fanless and placed inside a sealed enclosure.
- Standard survey tripod and tribrach for levelling
- Wireless touch-screen as shown in Figure 2 (middle) that allows the user to remotely control the RUC and annotate the 3D model via Wi-Fi.

iMM hardware is designed for ease of use. There is only one cable harness connection between the camera head and the computer unit to facilitate set-up underground. The motorized pan-tilt-unit allows automatic and complete coverage of the entire heading. The LED lights will be turned on at full brightness only during image capture to save power, and will be switched off or at low brightness at other times. The battery can last for a typical shift and batteries can be swapped at the face if needed. The wireless touch-screen offers the flexibility for the user to stay close to the mine face during geological annotation. Figure 2 (right) shows a geotech performing geological assessment on a 3D model using the wireless touch-screen.

Figure 2 Motorized camera head on a tripod and Ruggedized Underground Computer hanging beneath the tripod (left). Hand-held wireless touch-screen (middle). Geotech annotating geological information onto a 3D model using the wireless touch-screen (right).

Software

The iMM software operates on the Ruggedized Underground Computer (RUC) during underground operation and on a Surface Computer (a typical Windows PC) for visualization and post-processing. Both the RUC GUI (Graphical User Interface) and Surface Computer GUI have undergone several iterations taking into account the feedback from the users at the test mine.

RUC GUI is designed for use with the touch-screen. Therefore, it has large buttons and the fields can be populated with drop-down boxes as much as possible to avoid typing on the touch-screen. Moreover, the left hand side of the GUI shows the key steps and guides the user through the process step-by-step. The GUI is self-explanatory and designed for operator ease of use with minimal training and learning curve.

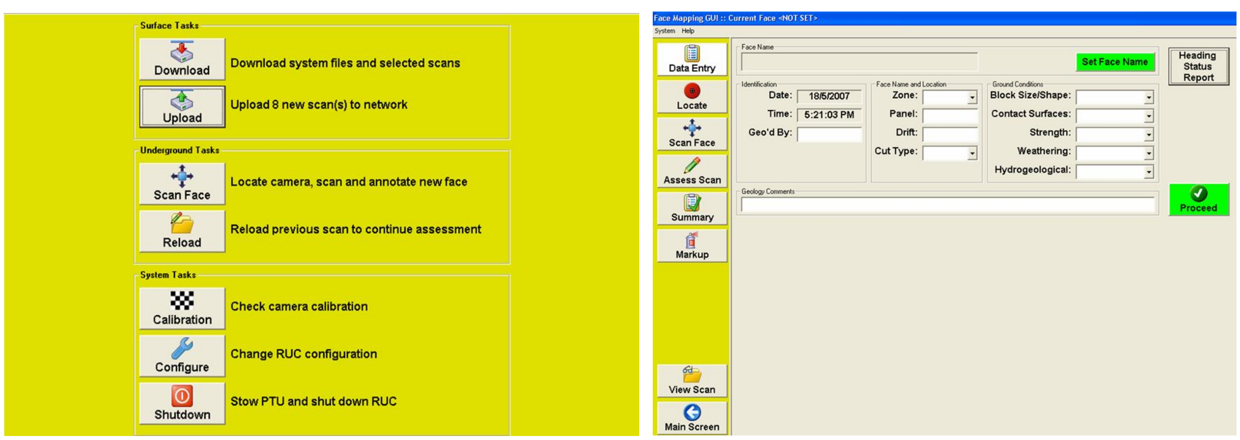

Figure 3 First RUC GUI screen to select different tasks (left) and the data entry screen (right).

Figure 3 (left) shows the first screen of the RUC GUI with options for the user to select surface or underground tasks, including data upload/download from the network. Figure 3 (right) shows the data entry screen, in which the user enters the zone, panel and drift information as well as ground conditions from drop-down boxes. The left hand side panel guides the user to the next step which is localization. Figure 4 shows the latest mine map with survey locations that would be displayed for the user to select at least two survey stations to back-sight. The GUI can zoom into the work area of the map automatically based on the zone, panel and drift information entered. The user can then back-sight each selected survey stations one by one using the red laser beam from the laser rangefinder.

The next step is to scan the mine face. For the scan coverage, the user can choose a pre-configured setting for a typical scan or configure the pan and tilt angles. iMM then performs image acquisition and generation of photo-realistic calibrated 3D models automatically. The user can then assess the 3D model with geological annotation, as a grade control tool. The geotech can draw the hanging wall, footwall, fault lines and contact lines. Different colours are used to indicate different annotation. Each of the regions can then be assessed and given an estimate of the ore percentages. The overall ore percentage for the face is calculated automatically and compared with a cut-off percentage, to indicate whether it is an ore or waste face and hence whether or not development should continue. Examples of 3D scans with geological assessment are shown in Figure 5.

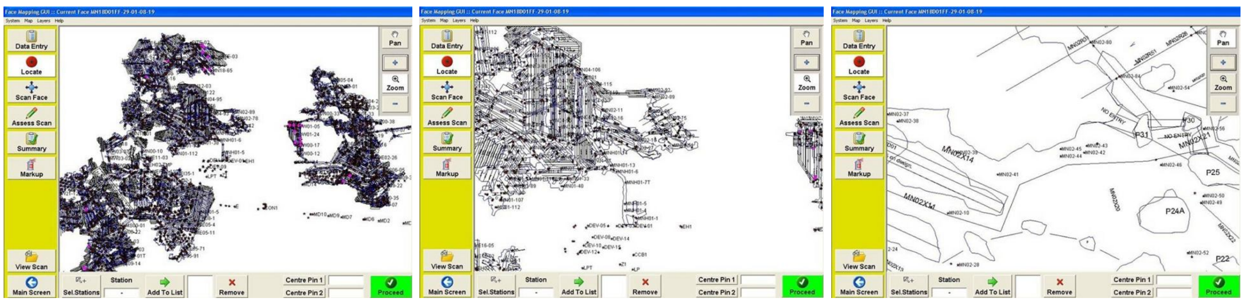

Figure 4 RUC GUI displays the latest mine map with survey locations and can zoom into the work area to allow the user to select survey stations for back-sighting.

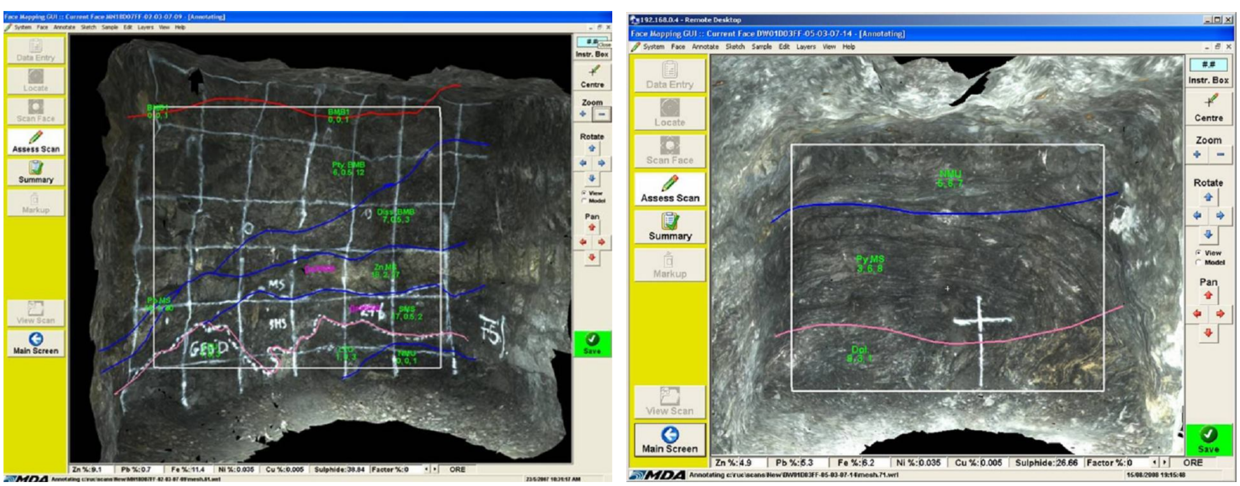

Figure 5 Examples of 3D scans with geological assessment in the RUC GUI. The overall ore percentages for the face are shown at the bottom.

On the surface, the Surface Computer GUI is used to browse all the 3D models on the network for visualization and post-processing, as shown in Figure 6 (left). The 3D models are grouped based on the mine drift by default but can also be sorted by date. The user can browse and select which 3D model to visualize. It connects to a SQL database that keeps track of all the models and their relevant information. The various functionalities are grouped on the right hand side, including geology functions, survey and database functions. Multiple consecutive 3D models can be viewed together to show how the drift advances, as shown in Figure 6 (right). Volume between consecutive faces can be calculated to estimate how much ore has been taken from each round.

The Surface Computer GUI caters for different groups of people at the mine, including mine geologists, surveyors, mine engineers, management, etc. The mine geologists can review 3D models with geological annotation done underground by the geotech. The 3D geological features can be exported into mine management software for 3D geology block modelling. The use of 3D information is important to be able to follow and predict the ore body better. The SQL database can be updated through the GUI to indicate the face status. The planned and actual volume can be obtained on a daily basis to calculate dilution. The 3D models can be used for planning the exploration and monitoring the tunnel advancement.

Apart from the geological annotation, the photo-realistic 3D models can also be imported into mine management software for visualization. As the models are already geo-referenced in the mine coordinates, they would appear in the correct location in the mine map, as shown in Figure 7 (left). Multiple consecutive scans can be shrink-wrapped together to obtain a watertight mesh, preserving the side-walls, ground and the back. The shrink-wrapped models resemble the actual survey as-built in Figure 7 (right) and can be used for daily mine as-built update.

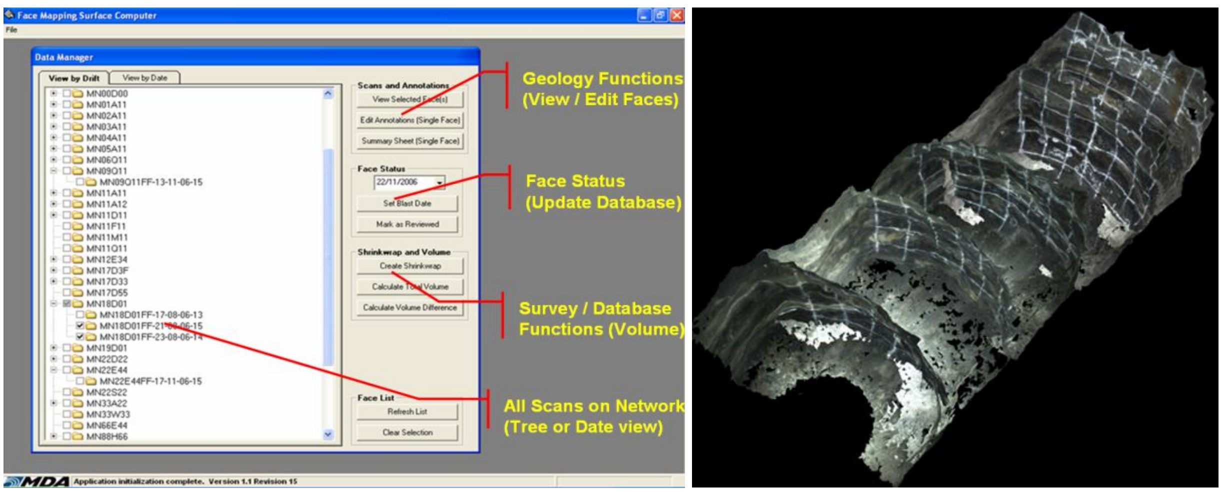

Figure 6 Surface Computer GUI for 3D model browsing (left). Multiple photo-realistic 3D models from consecutive scans of a heading as the drift advances (right).

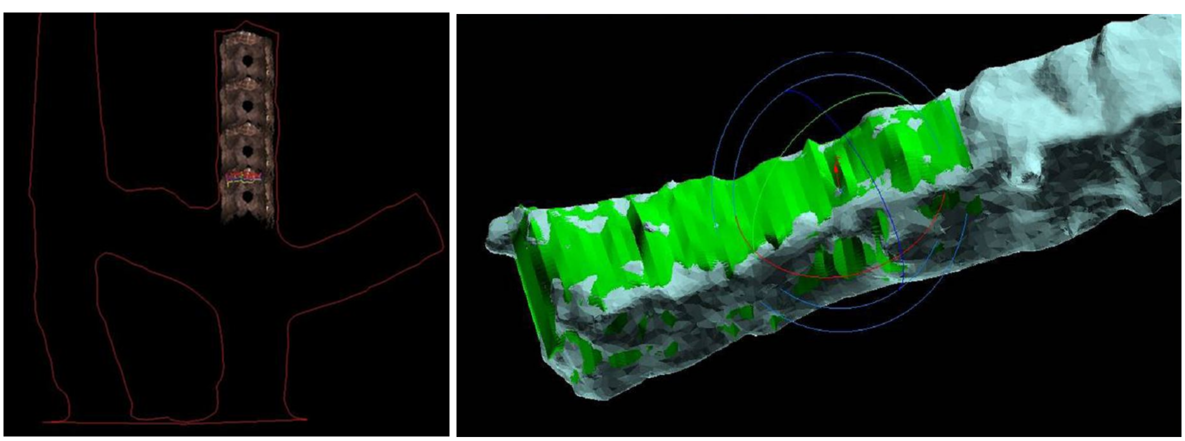

Figure 7 Geo-referenced 3D models overlaid on mine map (left). Shrink-wrapped model can be exported into mine management software to compare with as-built (right).

Operation procedure

At the beginning of a shift before going underground, the geotech will connect iMM to the network on the surface and it will automatically download the latest mine data from the network including the latest mine map and survey stations. Relevant previous 3D models can also be selected and downloaded for visualization underground if desired.

Then, the geotech can visit multiple underground work faces during the shift. At each underground work face, after the face has been scaled by the prep crew:

- Set up and level iMM.
- Enter drift information and ground conditions.
- Localize iMM by back-sighting: The map will be zoomed into the vicinity of the current location automatically based on the drift information provided.
- Scan the face and create a 3D model: The user can configure the range of pan and tilt angles. iMM will acquire the stereo images and generate the 3D model automatically.
- Perform geological assessment and annotations: The overall grade of the face is automatically calculated to indicate whether the face meets the cut-off percentage to advance further.
- Indicate centre line: iMM can indicate the centre line by sweeping a vertical red laser beam onto the face. This allows the geotech to check for any deviation from the mine plan.
- Shut-down and pack up iMM to allow the drilling crew to proceed.

At the end of a shift back on the surface, the geotech will connect iMM to the network and the new scans will be uploaded automatically to the network. The other mine staff can view the 3D models and annotations right away.

The RUC GUI software and the operation procedure have been designed to fit into the workflow at the test mine. The software is modular and can be adapted to other workflow easily. While iMM is currently a tripod-mounted system, a vehicle-mounted option is also viable. Moreover, the operation procedure is streamlined to minimize the effects on the other processes of the mine cycle. The total time spent at each work face is around 45 minutes including 15 minutes of geological assessment. A mobile vehicle-mounted version can potentially streamline the time spent at the work face to as little as 10 minutes. Annotations can be done off-line, allowing the drill jumbo to begin its work.

Applications and benefits

Photo-realistic 3D models are useful for survey and geology applications in underground mining. Currently, mining companies only survey the mine at month end to keep track of the mine advance. With iMM, the mine map can be updated after each daily drill/blast/ore removal cycle to minimize any deviation from the plan. In addition, the 3D models can also allow the mining companies to monitor how much ore is taken at each blast. Surveys can catch up later and are not restricted to completing their work at month end.

Geological mapping are typically not carried out by geologists at every drill cycle as the cost would be prohibitive. This does not allow monitoring of the ore content or adapting the mine exploration plan to local conditions. iMM workflow can be integrated with a crew that is already on-site to collect the 3D models daily so that geologists can visualize the mine faces virtually on the surface. The 3D information collected by iMM enables a number of applications and benefits, as summarized in Table 1.

The detailed specifications of iMM are as follows:

- The operating range for localization is < 25 m and the 3D modelling operating range is from 2 m to 8 m.

- The 3D model accuracy is < 4 cm at 8 m and the localization accuracy is < 10 cm at 20 m.
- The data acquisition time for a typical scan is 5 minutes and the 3D model creation time for a typical scan is 5 minutes.
- The camera head weight is 7.9 kg and the Ruggedized Underground Computer weight is 8.1 kg.
- The battery life lasts for a typical 8-hour shift and the battery can be replaced in minutes.
- The operating temperature is from 0 to 50 degree Celsius.
- The system has CE certification. It is ruggedized and can handle water and dust in typical underground mine conditions.

Table 1 iMM applications and benefits

Applications	Benefits
Grade control tool	• Calculates ore percentage automatically • Facilitates better geological assessment • Allows geologists to review geological interpretation
Geology mapping tool	• Allows re-visiting faces virtually to re-assess analysis • Improves geological prediction using photo-realistic 3D models • Improves overall mine productivity • Creates a permanent visual record
Daily production volume	• Provides a daily volume of production • Reduces dilution by comparing instructed to actual
Daily as-built update	• Provides daily update, rather than month-end • Allows visual monitoring of daily production progress • Allows early recognition of deviation from plan
Survey line	• Automatically provides an accurate centre line for the next round • Eliminates the need for month-end as data is available daily

Conclusions

iMM has been tested in several underground mines and is currently commercially available. A number of units have been delivered to an underground hard rock mine and have been deployed for production use for 18 months. Both iMM hardware and software have been designed for operator ease of use with minimal training and learning curve. iMM has effectively brought the underground work face into mine management offices enabling the right decisions at the right time. iMM has demonstrated benefits spanning across many mine processes from grade control and geological mapping to 3D photo-realistic as-built and production volume.

The current workflow requires the geotech to perform geological annotation underground at the work face, as the geology at the test mine is difficult to identify visually. Depending on the mine geology, geological assessment can potentially be done virtually on the 3D models by geologists on the surface.

While the current geological assessment is done manually by human, future work includes incorporating X-ray fluorescence technology with iMM, which would allow quantitative analysis of elemental concentrations and 3D distribution on-site automatically.

References

Se, S. and Jasiobedzki, P., Photo-realistic 3D Model Reconstruction, Proceedings of IEEE International Conference on Robotics and Automation, ICRA 2006, pages 3076-3082, Orlando, Florida, May 2006.