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# Mapping utility infrastructure via underground GPS positioning with autonomous telerobotics

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ABSTRACT

This paper presents technology applications from the autonomous mining and construction industries in tunnel and underground environments as applied to critical large diameter utility infrastructure. A self-contained inertial navigation system for the positioning and mapping of underground infrastructures is a significant development in tunnel profiling, 3D referencing and gyro/laser surveying; a key service offered by the results of this project. The underground positioning relies on a network of satellites placed to surround an area of interest, with a range of up to 2 km through soil or rock with accuracy better than 3%, enabling accurate positioning of underground assets. The robotic mapping system has the capabilities to accurately map tunnels, pipes and conduits, in detail and sequentially transfer the data collected into popular engineering CAD systems. A specialized military grade inertial referencing system (IRS) linked to multiple scanners provides high precision profiling while measuring roughness, deflection, ovality and positioning. The IRS component is linked to multiple laser scanners supplying high precision profiling while being driven forward. Laser scanning collects hundreds of data points per second linked to an accurate position through the IRS. All data is collected to on-board computer hard drives and transferred to the engineering office via memory storage systems or directly by wireless networks set up within the pipeline. Combining sectional scans with positioning and altitude data in real time creates 3D maps for surface referencing, a valuable service for pinpointing underground infrastructure problem locations in relation to surface features enabling informed risk management decisions.



## 1. Introduction

In 1986 Inco Limited began to embark on a project to create the mine of the future. The intent of this program was to radically change the underground mining process. This change would see a mine transformed from manual operation to the equivalent of a robotic manufacturing assembly line to develop tunnel and produce broken ore for processing. This idea came about after extensive benchmark studies of the manufacturing business and in particular understanding the key performance indicators of safety, quality and performance.

While the idea for robotic mining was simple, several key technology changes would be required to make this a reality. The key requirements were:

- Wireless network technology with extremely high bandwidths to handle video transmission;
- Compact high capacity on-board mobile computing systems;
- Advanced sub-surface positioning and navigation systems for mobile platforms, and;
- Robust mining robots that could be connected to control centres to support teleoperation from surface or other locations.

This program called the "Mining Automation Program" or MAP was a comprehensive multifaceted undertaking that proved quite successful with the building of the first pilot-scale robotic mining operation at (Inco Limited, 2000) in 1999 based on Baiden's Ph.D. thesis (Baiden, 1994).

This paper will focus on the commercial results of a single aspect of this work, the "advanced sub-surface positioning and navigation systems". This paper will provide a brief history of the work and the results that have that have been obtained since the ideas were conceived. Two areas have been focused onto allow the building of the sub-surface positioning and navigation systems. The first has been in perfecting the use of inertial (INS) equipment underground and the second (patented) work is the conception and building of the equivalent of subsurface Global Positioning Systems (GPSs). This paper will focus on the inertial work only.

The creation of a commercial sub-surface positioning product by Penguin has focussed on building teleoperated reconnaissance

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robots that contain an accurate positioning INS for geospatial referencing that are or can be tied with other sensors for distance measurement. To date efforts have focussed on laser scanning however the platform is able to handle any sensor package needed such as sonar, ground penetrating radar and various other probes.

## 2. Sub-surface INS

The original INS work at Inco began several years ago following a CANMET project to attempt to locate drill rigs and in-the-hole bits (Inco Limited, 1991). In this project, one of the objectives was to locate the drill rig in real time to support setting the rig up for drilling. The process used had three known survey points marked on the rock walls and a laser mounted on the drill rig with azimuth and dip sensors. The attempts to use this technology proved somewhat successful but not practical due to the iterative nature of the calculation and the lack of fine machine controls.

This near success led to looking at alternative technologies due to the potential significant improvement in mining cost and performance this concept identified. The iterative nature of the trial led to investigation of technologies that would eliminate this problem. Completion of the investigation led to inertial positioning technology. Selection of INS technologies proved to be challenging due to expansive nature of mine workings and lack of re-referencing technologies such as GPS. At this point, high accuracy INS technology was focussed on after an investigation of the technologies available. The US bureau of Mines (USBM) was working with INS technology for coal cutter control with limited success (Schiffbauer, 1997). The INS unit is shown in Fig. 1. While this success was limited, the technology appeared to have promise for underground machine control of all types.

Based on this initial report and discussions with USBM personnel the idea of providing survey quality information for construction appeared feasible. A Ring Laser Gyro was procured to support experimentation and attempt to improve the accuracy.

Once a Ring Laser Gyro was procured, a test bed was developed as shown in Fig. 2. This unit consisted of a mobile carrier, Ring Laser Gyro, two laser scanners and a computer platform for processing the data. The concept is shown in Fig. 2 where one laser scanner is mounted horizontally and the other vertically. In the figure, the line in the centroid of the tunnel represents the INS position. This unit was tested in the field in 1995. At the time only a single laser scanner was able to be linked to the INS using estimated algorithms.

**Fig. 1.** Honeywell Ring Laser Gyro.

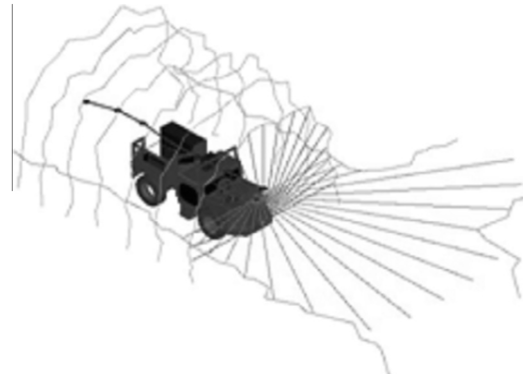

**Fig. 2.** Mapping and surveying machine concept.

Results of these initial tests are shown in Figs. 3–5. The first output graphic, Fig. 3 is a 3D side view of the tunnels surveyed. At the time, the mapping system gathered laser measurement data by stopping at specific distances giving accurate scans of rings and inertial position data so the information could be plotted. This is represented by the rings in the upper portion of the figure. The lower portion of the figure shows the rings jointed together to creating a solid surface.

Fig. 4 shows the same data looking along the tunnel. The scans shown are on 1.5 m intervals and a total of 25 scans were collected. Again in this view the scans were fitted with surfaces to give an idea of the profiles.

Fig. 5 shows a plan view of the underground survey in northing and easting UTM coordinates. The dark dots represent the data of the rock wall in the tunnels while the light dots show the INS coordinate.

While the information gathered was reasonably accurate is was not precise enough for surveying for construction. In 2003, our team began to categorize the INS technology more completely. Filion reported in his M.Sc. thesis (Filion, 2006) that improvements survey quality could be achieved if timing loops could be improved. Following on from the Filion work Penguin began a series of developments that improved the accuracy dramatically. The accuracy improvement work developed specific information on the timing of the "Honeywell Ore Retrieval and Tunnelling Aid (HORTA)" and the laser scanners. This work resulted in improving data collection synchronization.

## 3. System development

The research has evolved as commercial applications needed different functions. The first requirements needed were finding lost drill holes in mines, second was the need for rapid, accurate geospatial location and mapping of an entire mine and finally the need

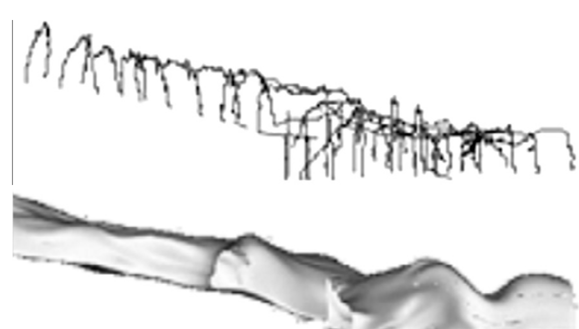

**Fig. 3.** Side view of the laser scanned distance measurement of tunnels.

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