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Advances in Drill Rig Deployed Radars

Tim Sindle[1], Carina Kemp[2]

1. Mr Tim Sindle, ARCO/CRC Mining Imaging Lab, USYD, Australia, t.sindle@usyd.edu.au
2. Dr Carina Kemp, GeoMole Pty Ltd, Australia, carina@geomole.com

ABSTRACT

The deployment of geophysical instruments in underground mining is a rarity. The primary reason for this is that the implementation is often seen as cumbersome and time consuming by geologists and mine managers alike.

This paper explores the recent improvement in deploying borehole radar in hard rock mines. Firstly the paper examines the minimum gear needed to complete the task to simplify logistics. It then looks at the processing of data collected by borehole radar deployed on a core drill rig. The non-ideal stop-start motion of the deployment presents issues in the data quality. With the aid of an onboard accelerometer and a time logging based procedure, these quality issues are addressed by examining three different algorithms to process the data. The strengths and weaknesses of each are discussed, before concluding that an intelligent combination of velocity and statistical methods will reliably produce smooth “winch like’ data.

Key words: Drill Deployment, Borehole Radar, Accelerometer.

INTRODUCTION

Geophysics techniques have proved over time to be reliable and useful for gaining insight into difficult geological situations to anticipate problems and increase the efficiency of mining operations.

However, despite the quality of the results, if any technique cannot be easily and reliably implemented in various mining situations it will have limited effectiveness and is unlikely to become a mainstream mining technology.

Borehole radar is one such technology. When first implemented in South African mines in the late 1990’s a survey crew consisted of about a hundred kilograms of gear and a number of highly trained personnel. Holes were surveyed using long bi-static (separate transmitter and receiver) probes, coupled to optical fibre cables. Large winches with built in data acquisition deployed the tools.

While quality data were captured and further trials run (Simmat 2005), logistics was always difficult. The time taken to freight gear to remote survey sights sometimes took more time than the actual surveys. Transporting heavy and bulky items down South African gold and platinum mines (which operate using shafts, chair lifts, and tracked mining) caused numerous problems. It was a common occurrence for equipment to be damaged or mislaid and if a single hole had to be surveyed it would take seven days to get required equipment in and out.

The other complexity is in the actual deployment. Steeply dipping holes (greater than 30^o) are easily gravity fed surveyed using a winch. However, horizontal holes and up holes provide a challenge where cables and pulleys have to be used. These are often tricky to install, are subject to twisting and blocking with only minor borehole cave-ins, and have a maximum reliably repeatable deployment length of around 200m for narrow holes. Often the survey will not reach the drilled depth of the holes.

METHOD AND RESULTS

Survey Gear Minimization

The first step was to minimise the technology to the point where it can be carried by one person, on chairlifts, in deep mines. GeoMole^{TM} monostatic iqua radar meets this requirement, being a single stick radar, with a length of 1.6m and weighing in at 3kg.

The winch deployment method was then examined. Winches are bulky, require battery power, and are easily jammed by mining dust and grease. There are also accuracy issues with the stretch of the deployment chord, as even a stretch of 1% can mean many meters over the length of the borehole. The logical replacement for the winch was the drill rig that drilled the hole in the first place.

As normally the radar is deployed using a non-conductive dyneema^{TM} chord this added some complications. Any metal surrounding the radar interferes with its antenna radiation pattern. This was solved by spacing the radar 4.5m away using three light weight 1.5m non-conductive spacer rods.

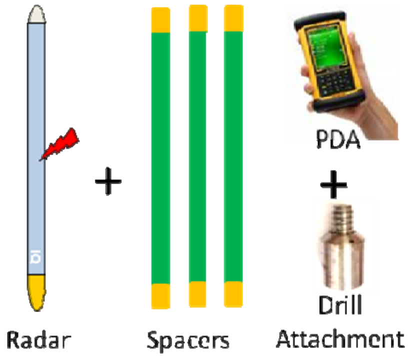

Figure 1. Borehole Radar Field Survey Kit.

The kit could simply be reduced to a radar probe, 3 spacers, a handheld PDA, and drill attachments. These radars are designed to be deployed on core drills, by either pumping, or pushing the tool down the hole.

Analyzing Drill Deployed Data

The next significant challenge was to gain data of the same quality as if it were deployed by a winch. Speed controlled winch deployment is optimal for this application as it gives a smooth, evenly spaced radar time section whilst the drill rig deployment is the antithesis; continually pushing, stopping and changing rods in a jerky manner as described by Bray et al (2007). The process for pump-down drill deployment simply involves the following steps: retract three 3 m rods, pump the radar and spacers down attached to the core barrel to the end of hole, and pull the rods back out of the hole at a slightly slower rate than normal. Pushdown is similar, except the radar is first directly attached to the front of the rods and the rods are then inserted into the hole before being retracted as described above.

To complicate matters, there is a large variety of drill rigs available, from the Boart LM75's (which can push a 3 m rod in two even pushes) (Boart, 2006) to the small pneumatic Kempes that only have a pull of 30-70cm. Figure 2 shows a set of radar captured radar data, whilst deployed on a Boart LM 75 drill rig. The stepped jerky nature of the data is clearly visible. The nature of this data makes interpretation hard as one cannot be sure if the structure being imaged is stepped, or if it just poor data quality. There are other artefacts including the stationary period while the driller was on a break between trace 440 and 480.

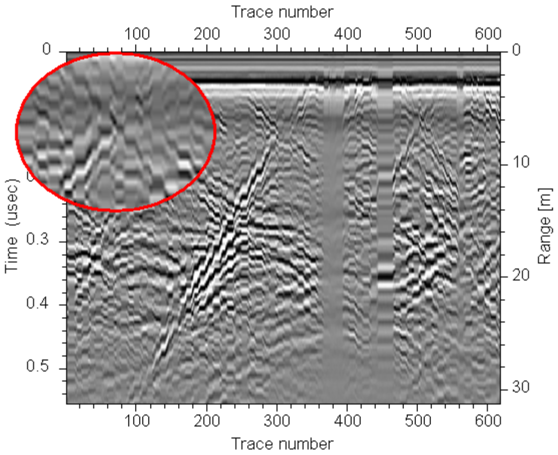

Figure 2. Raw radar data using Boart LM75 diamond core drill rig. Time along the borehole is on the X-axis and range from the borehole on the Y-axis.

To track accurately the motion of the drill rig a computerised logging procedure was implemented. This process involves pressing the 'MOVE', 'STOP' and 'ROD-CHANGE' buttons on a PDA following the motion of the drill. These events are then accurately time stamped and recorded for later data processing.

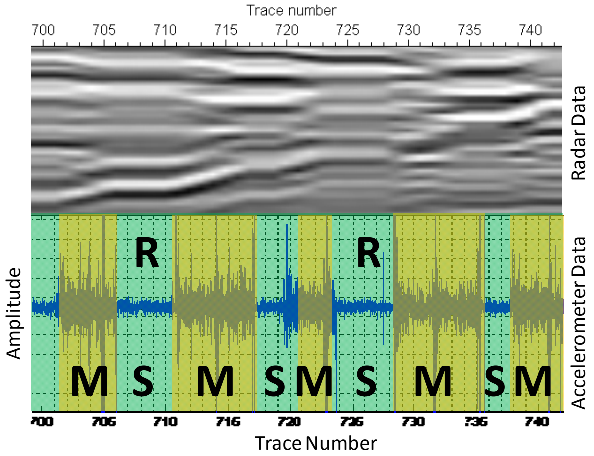

Figure 3. Graphic showing the zoomed in raw radar data (above), accelerometer data (below), and log time stamps (M = Moving, S = Stopped, R = Rod Change)

Figure 3 shows an example of the time logging, together with the accelerometer data, and a close up section of radar data. Radar image reflections change while the probe is moving and stay the same while the probe is stopped. The data is processed by selecting just the moving traces, and then later re-spacing the time based data according to distance using the rod changes as distance markers. This differs slightly from Bray et al (2007) as the stationary traces are not stacked and added but disregarded as this information is already contained in the previous moving trace. Qualitative data analysis confirms this.

This method of logging has many benefits, as it works with any drill, and can cope with the unexpected issues that often arise including; rig maintenance and mechanical issues while surveying, varying rod lengths, and borehole flushing.

Manual input, however, is open to surveyor error. Subsequent processing is time consuming as all the input data has to be checked. This can be seen in Figure 3, where the 3rd 'move' is clearly logged one trace late. The processed data as seen in Figure 4, has none of the jagged reflectors seen in Figure 2 and the radargram becomes easier to interpret.

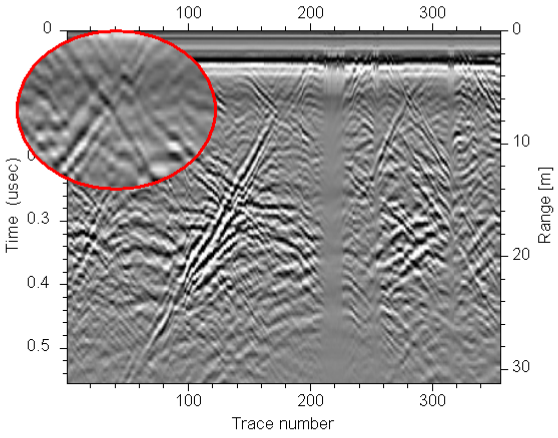

Figure 4. Radar Data processed using time log data.

Automatic Algorithm Development

Working towards a more user independent solution, MEMS (Micro Electro Mechanical Systems) accelerometers were built into the radars and data was captured for various drill rigs, in differing situations and mining environments. The goal of this is to develop an algorithm that could recognise the difference between moving and stopped data and process this radar data automatically. The ultimate objective was a radar that 'knew' how far it was down a hole with no user input. A number of different algorithms were trialled including:

- Statistical deviation measurement.
- Fourier spectrum analysis.
- Velocity integration calculations.

Statistical Standard Deviation

When examining the captured accelerometer data from the forward (along the borehole axis) channel, it is clear that there is a difference between the moving and stopped profile, as shown in Figure 3. The statistical standard deviation (1) of the acceleration was calculated for each trace (2 seconds, 170 samples), and this is displayed as a bar chart at the top of Figure 5. A threshold level was then applied to select the traces where the probe was moving and this data are shown in Figure 6.

$$s = \left(\left(\frac{1}{n-1} \right) \sum_{i=1}^{n} (x_i - \bar{x})^2 \right)^{\frac{1}{2}} \qquad (1)$$

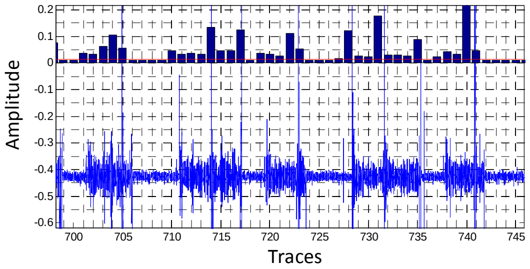

Figure 5 Accelerometer and standard deviation data, showing the threshold that determines between moving and stopped data

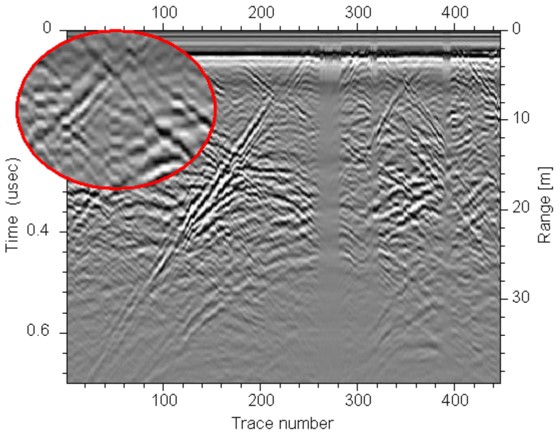

Figure 6. Radar data processed using accelerometer deviation information.

Although this data are easily clear enough to be interpreted, and almost automatically processed, it does suffer from the effects of random acceleration events. These include events where the probe has been stopped, but the vibrations transmitted along the drill string cause the algorithm to select erroneous stationary traces. Such events include; the chuck hitting the front of the drill platform during a pullback cycle causing an acceleration spike, the flushing of the hole mid survey (necessary in saline water), and the increase in background vibration as the probe nears the drill rig.

Fourier Spectrum Analysis

This method involves computing the Fourier transformation of the acceleration data for each radar trace and looking at the power in various regions. Figure 7 details the frequency spectrum for 4 traces that give a good representation of the overall data. Each trace is selected at a different point of the drill pullback cycle. Looking at this image it is possible to detect the difference between some moving and stopped traces by examining the higher frequency content. However, drill vibrations, particularly sharp impulse type shocks, cause wide band energy gains. It is not useful therefore to look at a particular frequency band and this method was abandoned.

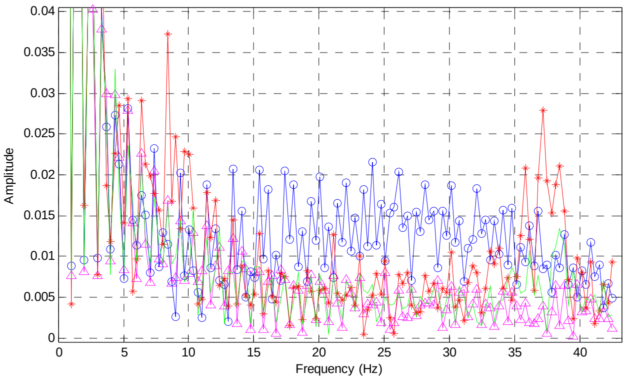

Figure 7. Frequency spectrum for 4 accelerometer traces. Stopped (Magenta ▲); Stopped with drill shock (Blue O); Start of Move (Red *); Constant velocity move (Green -).

Velocity integration calculations

Basic physics tells us that the integration of acceleration gives velocity but in such a noisy environment, where the tool is continually bumping along the borehole wall, and affected by drill vibrations, this data are filled with spurious accelerations and accurate velocity is hard to gather.

There is the added issue of the variation of measured acceleration with dip, due to gravity, adding a constant offsets which become integrated. However, the slowly changing offset variation and the acceleration pulses that come from movement differ in frequency by an order of magnitude. A high pass filter can be effectively employed to distribute the velocities around zero. Then the mean representation of the velocity for a two second trace can be calculated and displayed as in Figure 8, where positive are moving data and negative stopped data.

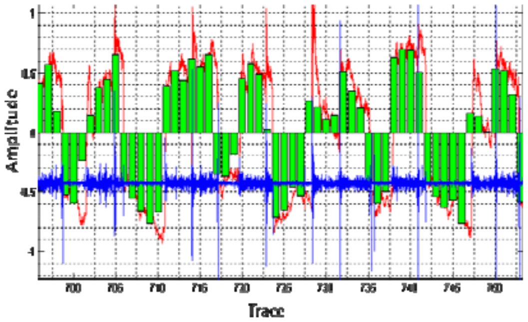

Figure 8. Filtered instantaneous velocity (red), mean velocity per trace (green bar), actual acceleration (blue)

This method copes well with the sharp drill shocks and vibrations as they often have equal positive and negative direction. It also captures the start and stop of the movement well. However, particularly violent jerks where the accelerometer is limited by bandwidth and range can cause a trace to be lost. An example of this in the otherwise clean data is show in Figure 9 around trace 120.

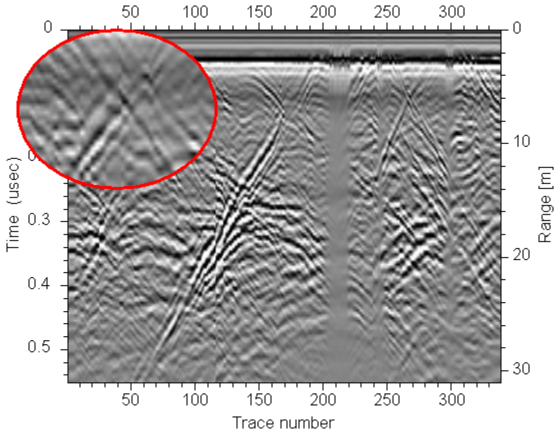

Figure 9. Radar data processed by velocity analysis.

CONCLUSIONS

Drill deployed radars have reached the technological level where they can be run with minimal disruption to normal work flow.

Different algorithms to process automatically the resulting data have been analysed, and although each has its strengths and weakness a combination of a time log together with statistical and velocity methods will result in smooth “winch quality” images being produced. The exact nature of this algorithm is currently being investigated. The ultimate aim of a tool knowing its own position automatically is theoretically possible, but only within well defined constraints, and there will always be the unknown events on the drill rig that can cause inaccuracies.

Development in this area continues, with some of the currently tested developments including doubling the sample rate and minimising dead time, to get the best quality data and reduce the survey time, and dependence on slow drill deployment.

The above progress makes it possible for quick data turnaround from survey to seamless integration of BHR data into mine planning packages, to enable day to day mining decisions to be made using such tools.

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