Mine motion monitoring

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Whether underground or at the surface, unanticipated earth movement can pose particularly hazardous conditions on mines. Risks include the endangerment of lives, destruction of property and damage to valuable, specialised equipment.

Fig. 1: Google Earth image of the opencast mine.

Fig. 2: Google Earth images close to the failure indicate that there is still ground motion.

Today's open-pit mines are far deeper than before. Because rock mass strength at these vast scales is difficult to evaluate, massive slope failure can occur with little warning. Monitoring therefore plays a critical role in early detection, minimising risk and safeguarding resources.

Experts Jami Girardl and Ed McHugh note the importance of devices that facilitate accurate monitoring and advance warning of imminent failures; observing that "examination of slopes for failure warning signs is the most important means of protecting exposed mine workers and equipment." Furthermore they highlight the unpredictable nature of slopes, stating that "even the most carefully designed slopes may experience failure from unknown geologic structures, unexpected weather patterns, or seismic shock."

Traditionally a monitoring survey network consists of target prisms placed on areas surrounding anticipated instability on the slopes, working in conjunction with one or more non-moving control points acting as fixed survey stations. The angles and distances from the survey station to the prisms are then measured on a regular basis in order to establish a history of movement on the slope.

Traditional techniques for positional monitoring using these optical measurements are able to detect changes that are typically measured over long periods to expose trends in an object's motion. The interval between measurements is based on the specific project requirements and can vary from a few hours to several months. Such long intervals between measurements leave much room for error, making it difficult for geotechnical engineers to correlate suspected ground movement with rapidly changing factors such as temperature, ground water levels, or seismic activity.

Using a global navigation satellite system (GNSS) significantly improves the frequency of measurements, while achieving similar precisions to that of optical systems. Continuous observations and position updates are typically received every second (1 Hz). This dense data enables the geotechnical engineer to correlate position measurements with events recorded by other sensors such as inclinometers, extensometers, piezometers and so on.

In 2008, Trimble Navigation introduced a new product to the GNSS industry; specifically designed to help GNSS Network Operators track their CORS (continuously operating reference station) GNSS antennas. The new technology now enables operators to know immediately whether their network solution is being compromised by a shifted antenna – whether by an abrupt shift caused by vandalism or plate tectonics, or a slow-moving long-term trend such as subsidence or ground movement.

Fig. 3: The four stations transmit the GPS data to a repeater station on the headgear of the mine.

Fig. 4: New challenges arose as the distances that the wireless network was required to cover increased.

Fig. 5 and 6: Directional antenna at TIM installation 2,4 GHz, 15 DBi gain antenna 30° x 30° beamwidth.

The corresponding software package, Trimble Integrity Manager, automates all aspects of GNSS methods for monitoring CORS antennas, including the post-processed and RTK techniques. Additionally, it adds new methods including a rapid motion detection tool that is capable of real-time movement detection of 3 cm/s, or faster, over thousands of kilometres. Essentially, what previously required expensive repeat site visits can now be observed autonomously 24 hours a day, seven days a week, year round; using real-time communications, providing truly complete data for structural motion analysis.

The software makes available three different techniques for monitoring slope stability, namely: server-based RTK, rapid motion detection and post-processing. The server-based real-time kinematic (RTK) technique differs from traditional single-baseline RTK because it computes positions that are based on simultaneous observations from multiple points. This solution is calculated on the server rather than on the receivers, with the advantage being that there is far more computing power on the server, which makes ambiguity resolution almost instantaneous over distances of up to 35 km.

When using the server-based RTK, motion of a few centimetres can be detected within seconds of the receiver moving. Tilt sensors can also be connected to each GNSS antenna and correlated with the 1 Hz observations from the GPS receivers. This additional information is then streamed to the software in real-time. When detected motion goes beyond what is expected, the system can be programmed to alert a system operator's desktop or mobile devices.

To scan for unexpected motion, the software incorporates a rapid motion engine, which is able to detect movement over distances of hundreds of kilometres between reference stations. The software "learns" the normal behaviour of a monitoring point and creates a model (referred to as a filter) of its typical or expected movement. Once again, when observed motion goes beyond what is expected, the system can call attention to the irregularity through e-communication.

For deeper analysis, the software package provides a post-processing engine. With this

Figs. 7 and 8: The GPS receivers and wireless access points are powered by solar power.

Fig. 9: If the objective is to detect millimetre movement or trends, this becomes virtually impossible when utilising a mobile installation.

tool, data collected over long periods can be computed to calculate position changes with a precision of 3 mm. By selecting and refining larger datasets, a detailed picture of the ground behaviour can be determined.

The software facilitates simple incorporation of Trignet, the network of CORS available in South Africa. This allows operators to ensure that the reference stations, which are chosen as the stable points are in fact situated on stable ground or bedrock. As the software is able to compute baselines over hundreds of kilometres this is a premium option.

The trial

In February 2009, a Trimble Integrity Manager trial set was installed on an open cast mine in South Africa. The objective being to detect sudden movement, as well as trends. On this particular mine, sudden movement is defined as 5 – 10 cm and a trend is sub cm. The pit under observation is 1600 m in diameter and over 800 m deep. What is particularly interesting about the case site is that a failure did occur a number of years ago, as is evident in Fig. 1.

Closer inspection revealed that there is still ground motion, as can be seen from the Google Earth images close to the failure (Fig. 2).

Installation

The trial set comprises five components: communication, GPS equipment, power supply, monumentation, and Trimble integrity manager software.

Trimble personnel deduced that the most effective communication solution for the site was to employ a 2,4 GHz Wi-Fi, which linked into the mine's local area network (LAN). The corresponding equipment was industrial-grade wireless 802,11 b/g Access Points with YAGI directional antennas. In consultation with the mine's geotechnician, four stations were chosen for monitoring. Three of these stations are located on the edge of the pit and are titled: "Edge", "Failure" and "Office", a further station in the pit is titled "Vent".

The concept is that these four stations transmit the GPS data to a repeater station on the headgear of the mine as illustrated in Fig. 3. The GPS data is then transferred to the mine's LAN system, before being streamed to the server in the office, which is running the software. The distances between the stations are Edge to Repeater, 1820 m; Failure to Repeater, 1670 m; Vent to Repeater, 564 m; and Office to Repeater, 66 m.

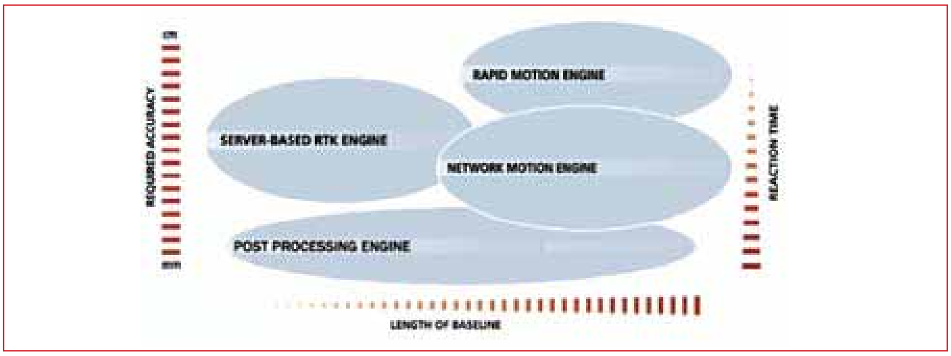

Fig. 10: The relationship between the various engines in regard to precision required, baseline length, time to alarm, and level of reported information required.

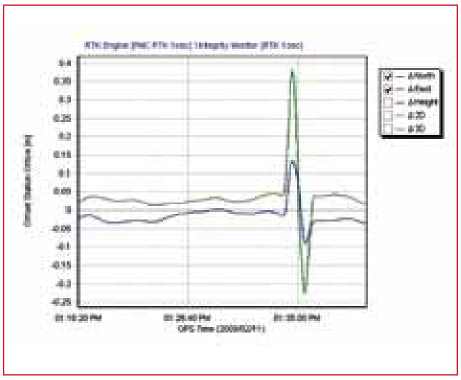

Fig. 11: To demonstrate the movement that can be detected, one of the stations was intentionally rocked from one side to the other.

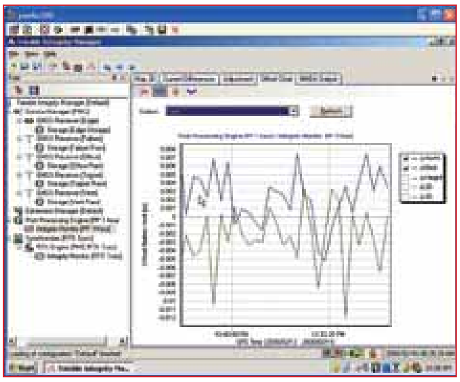

Fig. 12: The data is relatively erratic due to the fact that the GPS antenna was not yet mounted on a permanent monument.

The demise of this setup:

- The mine does not allow wireless networks to link in to any part of its network as this poses a potential security threat, despite any measures taken to secure the wireless network.
- Several thousand volts travel through the mine headgear each time the cage travels up or down the shaft, creating an electro-magnetic

Fig. 13: A similar trial was conducted on a different mine using a more permanent structure.

Figs. 14 and 15: The antenna was first cranked down on the tripod and then in the opposite direction.

wave which interferes with the wireless network reception at the repeater station

Plan B

- In order to address the security issues encountered, a wireless network independent of the mine's network was developed.
- The repeater station was moved off the headgear to an alternate repeater station, "Lookout" point, and from there the signal was repeated back across the pit to the computer housing the software at the geo-tech office.

New challenges arose as the distances that the wireless network was required to cover increased. The inter-station distances were now: Edge to Lookout, 1360 m; Failure to Lookout, 1880 m; Vent to Lookout, 2040 m; Office to Lookout, 2430 m; and Lookout to TIM, 2660 m. To increase this range additional directional antennas were installed as shown in Figs. 5 and 6.

GPS equipment

The Trimble NetRS receiver was selected for the trial, because it has the advantages of being a CORS with low power consumption, direct Ethernet connectivity and variable power input (11 – 28 V DC external power). For a more permanent installation, a GNSS receiver with Glonass capability would be recommended, particularly for the station "Vent" down in the pit, thereby providing better satellite coverage at higher elevations.

Power supply

The GPS receivers and wireless access points are powered by solar power. The NetRS receiver with antenna consumes 4 W of power, the wireless access points require 7 W, and the solar controller, a further 2 W; giving a total power consumption of 13 W x 24 hrs = 312 WHrs. Taking these factors into consideration, in addition to the amount of sunlight available at this latitude, it was decided to use a 125 W solar panel, charging 2 x 12 V 102 Ah batteries.

Monumentation

The monumentation provided by the mine proved to be one of the biggest obstacles. The intention had been for the monumentation to be mobile, so that the stations could be moved to monitor areas where movement was suspected. The primary problem being that, if the objective is to detect millimetre movement or trends, this becomes virtually impossible when utilising a mobile installation as demonstrated in Fig. 9.

A possible solution would be to construct permanent pillars on the points to be monitored, thereafter mounting the GPS antenna directly onto the pillars. The rest of the installation could remain on the metal structure.

The software

The three core functions of the software are:

- *Detection:* the initial step in understanding motion-related issues is to recognise change within the network. The software observes network conditions in real-time to detect both rapid and long-term change.
- *Alarming:* however infrequent, when significant events arise, administrators need to know about any potential issues expediently. With configurable alerting options, the software notifies administrators of these significant events, as they arise, via email and/or mobile devices.
- *Measurement:* in determining the method of response to a significant event, an administrator must first have at hand sufficient data to gauge the severity of the situation. The software provides precise measurements before, during, and after the events occur.

The software consists of four different motion detection engines. In selecting a computation engine, a number of project-specific factors are considered such as baseline length and time to alarm. The chart in Fig. 10 demonstrates the relationship between the various engines in regards to precision required, baseline length, time to alarm, and level of reported information required.

One of the main products of the software is report generation. Reports are created with the report generator function. Reports can be pulled manually in order to document a specific period of interest, or scheduled to run automatically at desired intervals. The report generator queries an underlying SQL database to report on connection details, data storage, individual monitoring modules and system properties. Reporting options can be customised to any requirements through SQL programming.

For the installation under trial, the server-based real-time processing engine and the post-processing engine were utilised. The adjoining Trignet station was included in the monitoring network and used as the fixed, stable point. This was easy to implement by using the NTRIP mount point provided by Trignet and streaming the station to the software.

The server-based RTK engine

The most rapid form of motion detection is provided by calculating RTK at the server at a 1 s update rate. It can be used on baselines of up to 35 km. The baselines are computed

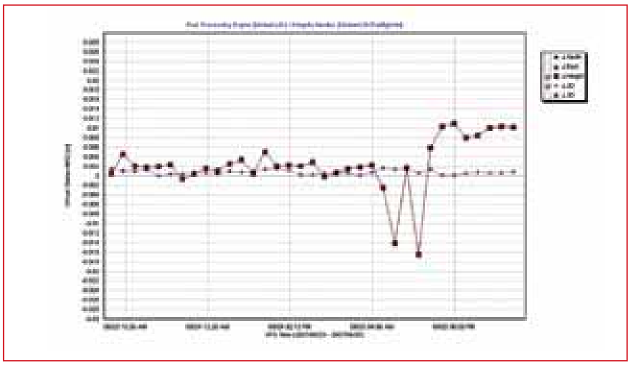

Fig. 16: The movement at the millimetre level can clearly be seen.

to an accuracy of better than 5 cm. This is ideal for detecting sudden movement often associated as the precursor to a failure. In this trial, the movement of the four monitoring stations was calculated relative to the fixed Trignet station, at a distance of about 5 km.

The post processing engine

The delay required to arrive at post-processed data is rewarded by extreme accuracy, where baselines can be calculated down to the millimetre level. Post-processing is very valuable in measuring long-term drift, and assessing cyclical or seasonal movement, making this the ideal engine for determining movement trends. In this trial the baselines were set up to be calculated at hour intervals, once again from the Trignet station, located about 5 km away.

Results from the trial

The graph (see Fig. 11) was generated using the RTK Engine. To demonstrate the movement that can be detected, one of the stations was intentionally rocked from one side to the other. This movement is accurately detected as it occurs, which is clearly evident in the graph.

The graph in Fig. 12 is generated by the post-processing engine. The data is relatively erratic due to the fact that the GPS antenna was not yet mounted on a permanent monument, but on the unstable metal structure shown in Fig. 9.

A similar trial was conducted on a different mine using a more permanent structure as shown in Fig. 13. In this trial, vertical movement was simulated to demonstrate how the software and graphs would react. The antenna was first cranked down on the tripod (see Fig. 14 and 15) and then in the opposite direction. The movement, at the millimetre level can clearly be seen in the graph in Fig. 16.

Conclusion

GNSS receivers can successfully be used in conjunction with Trimble's Integrity Manager software to detect ground movement on open-cast mines. By utilising two of the software's motion engines, sudden movement can be detected at the centimetre level, as well as movement trends at the millimetre level. The alarming module can be used to warn of possible failure and, because all of the data is stored in an SQL database, this database can queried and reports can be generated, keeping interested parties on the mine informed at all times.

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