Mining with Robots

by Rick Wilkins

Slope stability monitoring (a form of deformation monitoring) in open pit mines has improved since the introduction of advanced surveying technology. Five Leica Geosystems (Atlanta, Ga.) robotic total stations controlled by A. Chrzanowski & Associates Ltd.'s (ACA, Fredericton, New Brunswick, Canada) ALERT software have effectively aided deformation monitoring duties at Highland Valley Copper's open pit mines in British Columbia, Canada. The 24/7 operation of the tireless "robotic surveyor" has allowed extraction schedules to be extended into the night, dramatically increasing production while maintaining safe environments.

Monitoring the safety of personnel and equipment in an open pit mine has traditionally been accomplished through visual inspections and manual measurements. Although still acceptable ways of monitoring, each of these tasks requires dedicated personnel and daylight hours.

The laborious task of manually measuring targets with a traditional total station takes hours and lends itself to blunders. Due to the time required to observe and process dozens of targets, a high-frequency monitoring program was not feasible. At best, areas deemed high risk could be observed weekly with a reduced set of targets, while lower risk areas were observed monthly.

The turnaround time for retrieving monitoring results by use of a total station for the mining engineers, who need the information in a timely manner to revise production plans or to take remedial measures to avoid rock mass failures, was longer than desired. Also, cracks and fissures can go unnoticed during manual inspection until it is too late. A more efficient system was required to increase the monitoring frequency and extend the monitoring activities into the previously unavailable nighttime hours.

Survey Instrument and Software Solutions

In an open pit environment, long sightlines of 1,000 m or more are common, as it is often next to impossible, due to the extraction activities, to place an instrument close to the wall being monitored. The geological structures of some of the pit walls at Highland Valley Copper dictated the need for daily displacement determination accuracies of 5 mm or better—very demanding requirements for such long lines of sight.

Robotic total station technology aids mine safety and efficiency in British Columbia, Canada.

Automation of the monitoring measurement tasks required reliable high-precision robotic total stations that could automatically identify retroreflector targets. Further, in an open pit mine environment, a "passive" automatic target recognition (ATR) total station, in which the target is merely a prism that returns a transmitted signal back to the instrument, makes monitoring much more feasible, as there are hundreds of targets deployed on high walls that are largely inaccessible. The other class of ATR total station, an "active" unit, in which the target unit emits a signal that the instrument locks onto, would require expensive targets with batteries needing replacement, making its implementation financially and logistically infeasible.

One Leica Geosystems TCA 2003 and four TCA 1800 total stations featuring ATR technology have fulfilled the demanding needs of the automated monitoring program at Highland Valley Copper. Using approximate pointing information stored in the project database, the units quickly and automatically seek each target and measure horizontal direction, zenith angle and distance. Search windows can be implemented to ensure that the TCA does not search beyond the expected position of the target and find a neighboring target. The TCA units are interfaced via RS232 ports directly to computers or through wireless radio connections, and are fully controlled by software drivers designed by ACA using commands from the Leica GeoCom command set. Instruments with GeoCom are able to recognize and act on certain sequences of characters (commands) that are sent to it via the serial port. An instrument can be told to drive to a certain location, activate the auto search function, make a measurement and send current register values (measurements) to the RS232 port.

With a large field of view, a single Leica TCA 1800 controlled by ALERT software can monitor multiple extraction areas.

At the heart of the automated monitoring system at Highland Valley Copper is ACA's ALERT software suite. The ALERT suite is composed of a series of modules that automate surveying tasks, handle database management and provide graphical user interfaces. An initial setup was required to catalog the elements of the pit monitoring networks (including survey point names, TCA locations, communication parameters) and to create projects with ALERT. Once projects were defined, the Highland Valley Copper slope stability team was able to create an observation schedule for each area of the pit and wait for displacement results. Processed data is automatically made available to the mining engineers in near real-time. By using network connections, the oversight of current data collection activities and modifications to observation schedules could be done remotely without Highland Valley Copper personnel ever having to leave their offices.

From the safety of the shelter, a Leica TCA 1800 automatically surveys hundreds of retroreflector targets installed on the walls and pit benches.

ALERT is completely autonomous and features several self-recovery features that were critical for the automated monitoring projects at Highland Valley Copper. Many scenarios that are not typically an issue with manual operation were identified and automatically handled. For example, the computers that run ALERT have all been configured to automatically reboot if power is lost, allowing a background service to complete any interrupted data collection tasks. ACA also developed a "watchdog" power cable for the total stations. The cable works in conjunction with the data collection module to sense if the communication system gets locked up, in which case it is temporarily switched to allow a clean reboot of the TCA firmware.

The modular design of ALERT provides Highland Valley Copper personnel with many options in designing the computer networking and communication systems for their monitoring program. This flexibility is extremely important in an open pit mining environment where infrastructure such as power supply, wireless networking coverage and radio repeater availability not only differ from location to location, but also change over time. The installation at one of the

A Leica TCA 1800 keeps a 24/7 watchful eye on the open pit mine to maintain a safe working environment.

Highland Valley Copper pits has the ALERT software running on a single office computer that controls two TCA units via wireless serial port radios with all data stored and processed directly on the office computer. The downside of this scenario is that a breakdown in radio communication will directly result in a loss of data being collected. A different scenario is being used at another one of the pits where computers installed at each of the total station sites provide a fully autonomous data collection system, while an office computer is configured to transfer data from the remote sites via wireless networking. In this scenario, if communication is lost, the system will continue to collect data on schedule and all available cycles are automatically transferred when the network link is restored.

Overcoming Obstacles

Open pit mining environments are very dynamic: instruments are often moved, new sections of pit wall require monitoring and current instrument locations may be slated for blasting and excavation. When the slope stability team at Highland Valley Copper needs to monitor a new area, a new project with the updated position of the TCA instrument can be set up with a quick visit to a few of the ALERT user interface modules. The target seeking data is entered either by using existing coordinates or by sighting any new points that are being added. The system is quickly back online and ready for use in its new location.

Having the robotic total stations permanently deployed in the Highland Valley Copper pits created additional logistical problems that needed to be overcome. An open pit located in mountainous terrain is a very hostile environment in which to make precise measurements. The weather conditions can vary dramatically hour to hour as well as seasonally, therefore, special shelters with large panes of glass were designed and constructed by Highland Valley Copper engineers. The shelters give the instruments a large measurement range while providing adequate protection from the elements.

The shelters became mini-homes for the TCA units, providing them with a roof over their heads, power, heat for winter, air conditioning for summer, security, and a wireless Ethernet connection to "talk" to the outside world. In addition, the shelters required window shutters to keep the glass safe from "fly rock" during pit blasting operations. Power is supplied to the shelters from the pit power lines, which come from portable substations that have been deployed to power the large shovels used to load trucks. This power is noisy and susceptible to many interruptions of various time spans, which made it necessary to buffer the sensitive equipment from the large spikes and ripples, and to supply additional power to handle outages. The pit engineers created this buffer protection and supplementary power using a large battery/uninterruptible power supply combination.

In the open pit mine, two main systematic errors limit the monitoring system's achievable accuracy. The first is the stability of both the TCA and the control targets used to define the datum; the second is atmospheric refraction.

The spring thaw at Highland Valley Copper causes large changes to occur in the pit structures due to the increase in underground water flows. An eye-opening example occurred near the rim of one of the pits where a TCA unit shifted by more than 45 cm in two months. Using this instrument position as fixed and getting a backsight from a control target, which might be moving similar magnitudes, would create large datum biases that superimpose on the actual displacements determined for the pit wall targets. The resulting biased displacements would be impossible to interpret and become a frustrating issue for the mining engineers. This problem was eliminated by establishing multiple control points and implementing special algorithms in the ALERT processing manager that remove the datum biased portion and report only the actual displacements. An additional benefit of using multiple control points and this algorithm is that TCA units may be positioned in areas that are expected to show movement (i.e., closer to the areas being monitored) without having to worry about instrument movements between observation cycles.

As many surveyors know, atmospheric refraction is the ultimate nemesis—the limiting factor in obtaining accurate results. Although EDM observations can be corrected for variations in the speed of light caused by atmospheric condi-

tions, angular measurements are not so easy to deal with. Temperature gradients crossing the line of sight can play havoc with the apparent direction to the target being observed by bending the light rays. The condition gets worse as lines of sight get closer to obstacles, such as the pit walls at Highland Valley Copper. The open pit mine site was not immune to these effects and large variations in cycle-to-cycle displacements could be seen. When results for cycles observed at the same time each day were extracted on their own and compared with other cycle times (e.g., compare a plot of 10:00 a.m. cycles with a plot of 10:00 p.m. cycles), distinct biases caused by refraction could easily be identified. The pit engineers examine the daily velocity rates, so the slope stability team uses the ALERT averaging module to obtain daily velocities derived from all the cycles that have been observed for that day. This averaging reduces the overall effects of each of the individual refraction biases, providing a much clearer and truer picture of the pit wall behavior.

'Round the Clock Robotics

Four times per day, 365 days per year, these "robotic surveyors" stand guard over their domain and survey all of the hundreds of monitoring targets along the pit benches at the Highland Valley Copper open pit mine. Multiple sets, typically three to five, of direct- and reverse-face horizontal directions, zenith angles and slope distances are observed in each measurement cycle. Least squares adjustment routines handle all set reductions and initial coordinate calculations, while final coordinate values are calculated from special algorithms to ensure that unstable control points don't create false alarms or mask real movements by biasing the coordinate datum.

This high level of automation has improved the work of the surveyor in pit environments. Under the old, manual system, the human surveyor, a slope stability technician, could repeat a section of the pit only once per month, including time for data reductions and analysis. With ACA's ALERT software and Leica TCA total stations completing multiple surveys and reductions per day, the slope stability technician can devote more time to maintaining and optimizing the monitoring network. Special projects and more in-depth analyses of high-risk areas can be performed. With the multitude of data, the human surveyor has transitioned to a planning and analysis role, and is more important than ever.

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