RFC Ambrian

New Technology & Innovation

Report 4 – Ground Monitoring, Drones, and Mine Safety

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Front picture: GroundProbe SSR-FX

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Executive Summary

In this fourth report by RFC Ambrian on innovation and new technology we focus on Ground Monitoring, Drones, and Mine Safety. These have a common thread relating to the monitoring and measurement of mine operations and infrastructure efficiently, potentially autonomously, and safely.

Ground Monitoring Now an Exact Science

The use of radar technology for active slope monitoring and detecting slope failures has been around for some time but the technology has been improved and updated and is now the leading technology in use. Using radar technologies, equipment, and software, mining companies are now able to monitor and detect wall movement in open-pit and underground mines, understand when it becomes a problem, and predict when a collapse is likely to occur.

Underground ground penetrating radar on hand held equipment is now able to give instant feedback on rock structures. This helps identify rock structures, including blast induced fracturing, and helps identify dangerous areas where a fall of ground is a risk.

Drones continue to Penetrate the Industry

Drones have become common place and an integral part of the mining industry, and only look set to increase their presence further. In fact, mines are believed to be using drones more frequently and across a wider range of applications than many other industries. Interestingly the technology is still at an early stage of development and still has significant potential, and not just in open pit mines but also in underground operations.

Drones can be used in almost every aspect of the mining value chain, from discovery through to production, ore processing, transport, services and rehabilitation. The ability to collect visual information from the air speeds up data collection and provides a level of safety by removing personnel from around operations. Drones are currently being used mainly for regional exploration, terrain surveying and mapping, conducting stockpile volumetric audits, drilling and blasting design, equipment and mine site inspection including security, and geotechnical monitoring and modelling.

Mine Safety Has Been Digitalised

One of the important drivers and outcomes of implementing innovation and new technology is the improvement in safety. The development of autonomous mining equipment is probably one of the biggest steps forward for improved mine safety. Autonomous systems effectively remove most staff from operations and exposure to risks. These risks include dust, noise, vibration and physical injury. Komatsu recently reported zero serious injuries after 10 years of autonomous vehicle operation.

In additional to the removal of staff from hazardous mining areas, new technology is being introduced to protect those workers still operating in the mining environment with developments in wearable technology. Meanwhile, virtual reality is being used as an industrial tool to train and educate workers in the workplace, but in a simulated safe environment.

Ground Monitoring

Slope monitoring systems play an important role in the management of open pit mines and have evolved significantly since the use of piezometers, extensometers and photogrammetry. The three main tools for ground monitoring in open pit and underground mines today are GPS, radar, and LiDAR. The use of radar technology for active slope monitoring and detecting slope failures has been around for some time but the technology has been improved and updated and is now the leading technology in use.

The beam of radar emitted from the antenna mounted on a fixed or movable platform scans the slope faces in both vertical and horizontal directions. The movements along the slope are monitored rapidly and also continuously. Inherent to radar technology are many features that make it an ideal monitoring tool. In a dusty and smoke-filled mining environment, radar is able to penetrate through dust, rain and other weather conditions that other technology solutions are not. It is able scan from extended ranges of many kilometres, and does not lose measurement accuracy as range increases, with its sub-millimetre deformation measurement accuracy remaining constant at any distance. This is obtained without the need to install artificial reflectors on the slope.

Figure 1: Aerial View of Landslide at Bingham Canyon Mine in 2013

Source: Rio Tinto

On 10 April 2013, Rio Tinto Kennecott in Salt Lake City, Utah, experienced the largest landslide in mining history. As a result of Kennecott's strong safety culture, preparation, and sophisticated monitoring systems, no one was hurt during the slide.

The outcome was less fortunate in the Brumadinho tailings dam disaster in January 2019 and the Mariana dam disaster in 2015. Both tailings dam failures were in Brazil and both mines were owned by Vale. These accidents have prompted increased scrutiny and monitoring of tailings dams around the world and is likely to result in an increased use of ground monitoring equipment in these situations. The World Mine Tailings Failures (WMTF) organisation forecasts that without major changes to law and

regulation, and to industry practices, and without new technology that substantially reduces risk and increases loss control, there will be a further 19 very serious tailings dam failures over the next nine years.

In recent years, Global Positioning System (GPS) has provided an alternative method for monitoring the geometrical displacement of surface movements. The availability of Differential GPS (DGPS) provides real time information on the stability status of the slope and also the deformation rate both day and night. The method has great advantage when it comes to surface mines with the installation of a series of receivers along monitoring regions. However, the use of GPS is limited by the environmental characteristics, such as the vegetation and mountains and in rapid deformation scenarios. GPS equipment has been used in combination with photogrammetry, total stations network and remote sensing images as the control points for monitoring the slope stability of the mines. Monitoring with ground-based radar and integrating with satellite can provide a multi-source monitoring solution.

LiDAR (Light Detection and Ranging) utilises a beam of laser lights, targeted towards the area of monitoring which returns the pictorial or digital representation of the critical area of the slope and their relative movements using the travel time of the reflected radiations. They provide virtual copies of the slope in minutes, like photographic images highlighting critical areas. Laser scanners are active self-contained measurement technology that generates its own light for measurement process.

The application of laser scanners is well proven in monitoring landslides, but the method is less used in monitoring open pit slopes. The latest LiDAR scanners can be mounted in both the static and mobile surveying platforms which can provide digital elevation models (DEM) in rapid time and the survey of a mine slope can be achieved up to 15 times faster than a conventional survey. The application of LiDAR on mine surveying is simple and saves time and thus provides successful slope monitoring but is restricted to weather conditions and terrain humidity[1] .

Slope Stability Radar

GroundProbe is a leading producer of ground monitoring solutions for both open pit and underground mines globally. Through its technologies, equipment, and software, mining companies are able to monitor and detect wall movement in open-pit and underground mines, understand when it becomes a problem, and predict when a collapse is likely to occur.

GroundProbe commercialised its patented Slope Stability Radar (SSR) in 2001 but has continued to develop its range and has a range of products for different situations. Through the processing of the data the software can show what has moved, when, and predict the time of failure.

The SSR-Omni is one of the most advanced pieces of equipment for full-coverage, high-resolution, real-time monitoring. Merging the best of radar technology with superior-resolution imaging, GNSS and a weather station, the SSR-Omni is a premium, fit-for-purpose monitoring solution and currently GroundProbe's most sophisticated

system[2]. The equipment is designed to detect hotspots of movement in an ultra-fast, all-encompassing scan, covering the broadest of areas with the highest resolution.

The GMS is GroundProbe's second laser-based solution and monitors vast mine areas for long periods of time of many months to many years. It specialises in background monitoring in open cut pits and highly vegetated slopes, and detecting and measuring deformation on tailings dams, dumps and cuttings.

In 2017, GroundProbe launched the GML-Underground, an underground monitoring solution developed specifically for geotechnical convergence monitoring using LiDAR. It is capable of detecting rock and ground support movement with sub-millimetre accuracy.

Figure 2: IDS GeoRadar IBIS-Rover

Source: IDS GeoRadar

IDS GeoRadar based in Italy markets interferometric radar for slope monitoring for mining and civil engineering applications. The company provides a number of products including the IBIS-FM. The system accurately monitors multiple scales of displacements in real time, from early detection of slow movements to fast accelerations associated with slope collapse. The equipment has an operative range of up to 4,500m, allowing it to be safely deployed in accessible areas, without exposing people and equipment to hazardous zones. Thanks to advanced automatic algorithms, IBIS-FM delivers reliable and accurate data in all weather.

IDS GeoRadar also markets HYDRA-U[3] a remote sensing monitoring system for underground. It is designed to trigger early-warning alerts in case of impending collapses to evacuate people and machinery at risk. The system can fit narrow spaces typical of underground operations and is designed for quick and easy transport and deployment in critical areas by a single person. With a scan range of 200m, even non-accessible areas of underground openings can be safely monitored.

HYDRA-U exploits the IDS GeoRadar *Arc*SAR technology, providing a spatial resolution of centimetres with updated displacement information every 30 seconds, corrected automatically for changes in environmental conditions (such as temperature and humidity). Radar heat-maps are overlaid on the 3D model created by the system by means of an integrated laser sensor. An optical and infrared camera improves data interpretation by providing real-time visual inspection of monitored areas.

IDS GeoRadar also offers HYDRA-G, a compact, remote sensing monitoring system designed for early warning and real-time measurements of sub-millimetric displacements in buildings, dams, tunnels, mining infrastructures, and cut-slopes.

Ground Penetrating Radar

Ground penetrating radar (GPR) is the application of radar to detect objects below the surface. It has evolved and suitable for a wide spectrum of applications, spanning from subsoil deep objects detection to utilities mapping, road and railway assessments, structure investigations etc. One of the largest global providers of GPR products is IDS GeoRadar which offers a range of GPR products aimed across industries.

Reutech Mining markets the Sub-Surface Profiler which is a ground penetrating radar that gives instant feedback on rock structures while scanning. Its light-weight and patented ergonomic design allows for one handed operation by one person in much the same way as a paint roller. The collected data is wirelessly transmitted and processed in real time. This helps identify rock structures, including blast induced fracturing, and helps identify dangerous areas where a fall of ground is a risk[(4)].

Blast Monitoring

At its Red Dog zinc operations in Alaska, USA, Teck is using colourful, softball-sized sensor balls are distributed into drill holes prior to blasting. Nestled inside each ball, protected by the durable outer casing and an inner shock-absorbing liquid, is a sensor that transmits its location. After the blast, handheld scanners are used to identify where the balls have moved, and that data paints a three-dimensional picture of how the ore body has shifted during blasting. The blast monitoring system is supplied by BMT based in Australia[(5)]. Purpose-designed software, BMM Explorer, calculates the 3D movement vector of each blast movement monitor, redefines ore boundaries or digging levels to account for the measured movement, and calculates the value of recovered ore, dilution and misclassification.

This information is used by Teck's geologists to maximise the amount of valuable ore that is recovered and sent to the mill and reduce the amount of waste rock going into the mill. That results in reduced processing costs and improved productivity, as well as improved environmental performance through better energy efficiency. The blast movement monitoring is reported to be saving an estimated C$6.5m annually.

In Australia, Orica is using a GroundProbe system as a data feedback system to check the effectiveness of drill and blast patterns for post-blast wall stability.

Drone Technology & Mining

Drones have become a ubiquitous and integral part of many industries, including the mining industry, and only look set to increase their presence further. In fact, mines are believed to be using drones more frequently and across a wider range of applications than many other industries[6]. The technology has progressed rapidly in recent years as a result of developments in three technologies; the miniaturisation of electric motors, the miniaturisation of camera technology and the development of light weight lithium polymer batteries. Interestingly the technology is still at an early stage of development and still has significant potential, and not just in open pit mines but also in underground mines.

Technology of Drones

Drones are also called unmanned aerial systems (UAS) or unmanned aerial vehicles (UAV) and come in a number of shapes, sizes, and sophistication. They can be a quad- or multi-rotar, a fixed wing unit (delta wing or traditional wing), or a hybrid of the two. The type of drone used depends on its function. Multi-rotors have good control over shorter distances and can more easily survey vertical faces or confined spaces. Fixed wing drones usually have a longer duration battery life and can cover larger areas but require a landing strip. Hybrid drones offer vertical take-off and landing, and the ability to hover as well as the flight endurance and area coverage capability of a fixed wing drone but tend to be more expensive.

Figure 3: DJI Mavic 2 Pro Used by Kespry for Inventory Management

Source: DJI

Drones can be operated manually or in semi-automated or assisted mode, following a predetermined path (which can be overridden by the pilot for safety reasons) which use global navigation satellite systems, inertial measurement unit (IMU) sensors for positioning and attitude determination, and altitude and heading sensors for height and orientation. The motors are electric, and the drone body is usually made of plastic or carbon fibre.

A drone, combined with GPS and a simple camera or a more sophisticated GIS (geographical information system), allows data to be stored for later use or captured in near real-time from areas that would otherwise be inaccessible, or difficult or unsafe to reach. This allows rapid access to many areas and the potential to monitor all mining assets in real time. Other types of sensors such as thermal, multispectural, magnetometers, LiDAR, and hyperspectural are starting to be used, trials with gravity and seismometer exploration are under way and investigations in to the use of ground penetrating radar and electromagnetics are being discussed[7]. Drones are providing pictures and data that have never before been integrated into the day-to-day operations of a mine.

Figure 4: Q-200 surveyor Pro Fixed-Wing Drone From Quest UAV

Source: Quest UAV

Drones are becoming an integral tool in the data collection cycle with direct and indirect cost savings. In terms of direct cost savings, some of the most significant savings come in a reduction in the time it takes to complete various tasks such as inspections and surveying. A drone can complete a task in hours that would take human staff days and can do so with a higher degree of precision. The indirect cost savings include the benefits of more frequent and detailed inspections of critical infrastructure like haul roads, pits, plant equipment, and tailings dams.

As with all technology, there are limitations and issues with drones. Their flight times are typically limited to between 30 minutes and one hour depending on the use of a rotorcraft or fixed wing, respectively, although batteries can be quickly changed. They provide a maximum survey coverage of 2.2 km^2 from a single fixed location, assuming a fixed-wing platform designed to operate within the operator's visual line of sight. A license is usually needed to fly a drone for commercial purposes, and when using drones it is necessary to be compliant with local flight rules and regulations, although the remote locations of most mining sites are suited to the application of drones. Also drones need to be seen as digital assets that must be properly managed. Drones provide a tremendous amount of data and require software solutions that ideally integrate in to the mines existing system.

The Use of Drones in Mining

Drones can be used in almost every aspect of the mining value chain, from discovery through to production, ore processing, transport, services and rehabilitation. The ability to collect visual information from the air speeds up data collection and provides a level of safety by removing personnel from around operations. Drones are currently being used mainly for regional exploration, terrain surveying and mapping, conducting stockpile volumetric audits, drilling and blasting design, equipment and mine site inspection including security, and geotechnical monitoring and modelling.

BHP has been using drones since 2014 and has been trialling drones fitted with military-grade cameras to provide real time aerial footage and 3D maps of its mining sites[8]. This has proven to be far cheaper than using planes for survey work. At some of its coal mines in Queensland, drones are used to ensure areas are clear before a blast takes place and to track fumes post-blast. They are also used to improve road safety on sites, by monitoring traffic, road conditions and hazards. At its Olympic Dam mine in South Australia, the maintenance team use them to help inspect overhead cranes, towers and roofs of tall buildings to avoid working at height. The company is now testing specially adapted drones to conduct mineral surveys.

It is reported that Barrick Gold has been using drones since 2012 at several mine sites, for everything from volumetrics, to environmental management, to construction monitoring. KAZ Minerals' surveyors have used a Q-200 Surveyor Pro fixed-wing drone, a DJI Phantom 4 and a Russian built drone called Geoscan, at its opertions in Kazakhstan. The drones greatly improve the efficiency of geodetic work, increases the accuracy of the work, and increases the efficiency of developing the site.

Autonomous systems are currently in their early stages and reliability is being tested. Airobotics has developed an automatic, on-demand solution for collecting aerial data in mining facilities without the logistics involved in drone operations[9]. The Optimus drone operates from a standalone housing called Airbase. The Airbase is a multi-purpose robotic toolbox with a durable external frame to protect the drone when housed as well as critical internal components from the outside environment. The Airbase controls and services the drone without any human intervention. Future operations are forecast to use autonomous drones that will become integrated with other active artificial intelligence systems on the mine site.

Kespry[10] supplies an automated drone and cloud-based software system which is used for stockyard inventory, mine planning, reserve exploration, reserve mapping, and site surveying, enabling customers to easily capture, view, analyse and share data. ABB has a collaboration with Kespry on integrated aerial intelligence solutions for its process industries customers.

There is little available data on the real cost benefits of using a drone. One example was given by solution provider Kespry. It offers a detailed cost savings analysis for measuring stockpiles with their drone system. Whitaker Contracting and Madison Materials used Kespry's automated drone solution and found that combined activities for measuring the Whitaker stockpiles with traditional methods would cost US$37,832 with a six time-per-year frequency. The new annual cost to Whitaker using the Kespry system is US$29,320, a 22% reduction.

Mineral Exploration

The first stage use of drones in exploration is in surveying and mapping. Drones can then be used to capture geophysical data. Pioneer Aerial Surveys of Canada provides a UAV supported aeromagnetic sensor system[11] and MWH Geo-Surveys[12] of Canada offers high resolution data with its UAV Magenetic System. GEM Systems is another player in the field, with its GEM DRONEmag, a quantum magnetometer developed specifically for drone magnetometer surveys[13]. Radai of Finland[14] also offers geophysical surveys and remote sensing with UAVs, including magnetic surveys.

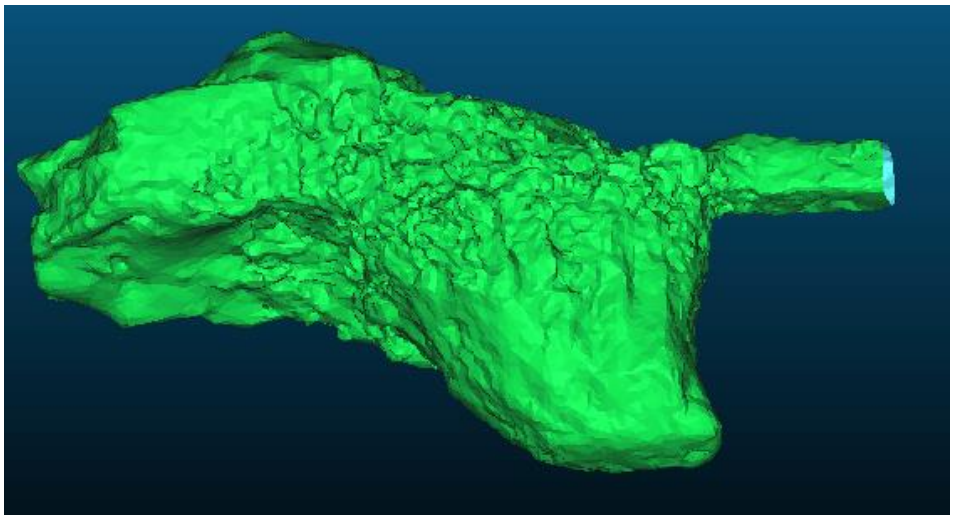
Hyperspectral sensors have become a key tool for a large range of applications in remote sensing and are now widely used in geology, mineral mapping and exploration. During the last few years, lightweight hyperspectral imaging (HSI) sensors have been developed for use on drones.

Another exploration development at an early stage is the use of drones to capture soil samples from site, either using grab samples or reverse circulation drilling.

Surveying and Mapping

Mining operations are increasingly employing drones to perform regular site surveys to document their entire operations. This can be achieved in just hours rather than days with traditional methods. Drones can employ photogrammetry or LiDAR systems. The data can be imported in to an organisation's mine planning software and virtual copies can be used to visualise changes over time. Mining companies are also able to analyse a whole host of soils, vegetation, surface hydrology and groundwater used for monitoring and reclamation.

Figure 5 Screenshot Scan of Underground 3D Laser Map (using SLAM)



Source: Inkonova

Drones usually need GPS assistance to be stabilised during flight, but in certain places this is not always possible; for example, under a bridge, inside of a building or in an underground mine. Terra Drone (a Japanese drone company) uses its SLAM (simultaneous localisation and mapping) system to stabilise the drone's flight when GPS is not available. Swedish company Inkonova[15] (Terra Drone holds a significant

stake in Inkonova) is also developing drones with SLAM technology for mapping. The company was able to map an underground mine in Mali with a volume of roughly 30,000 cubic metres using Inkonova's manually operated drone, TILT Ranger with SLAM. The firm's new autonomous drone can combine its map with additional input from sensors to position and move without GPS.

Meanwhile, Australian-based Emesent is also using SLAM-based 3D LiDAR mapping for its Hovermap[16]. This allows a Hovermap-enabled drone to be deployed in challenging GPS-denied environments to collect 3D and other data. This includes industrial and civil infrastructure, and mining. Specifications include collision avoidance sensors. The company was spun out of CSIRO's Data61 and Hovermap was launched in November 2018.

Figure 6: Hovermap Underground Point Cloud Generated from Drone Flight

Source: Emesent

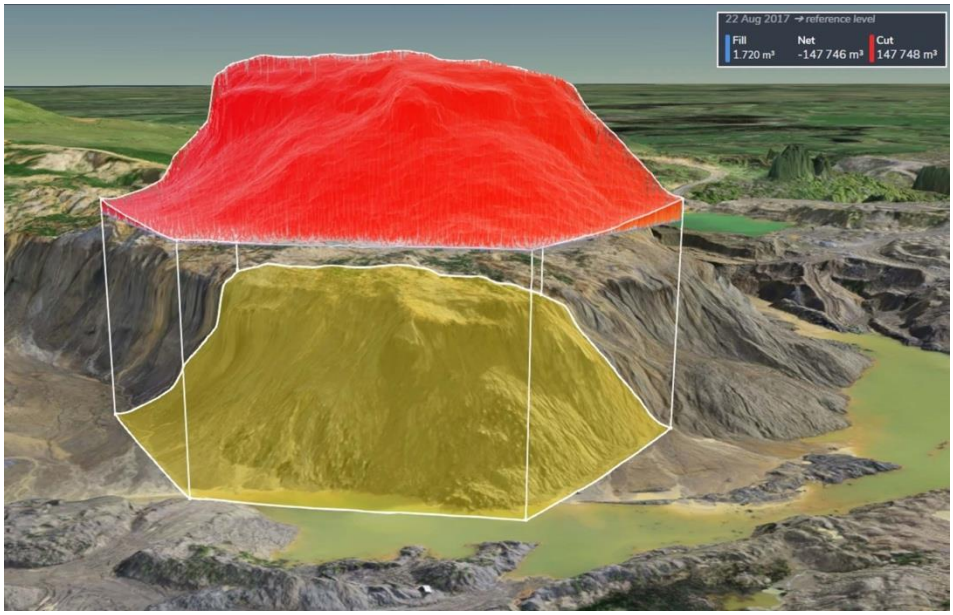
Hovermap enables drones to fly and map challenging and GPS-denied underground environments without the need to send people into potentially hazardous areas. When coupled to a suitable drone it allows the drone to fly autonomously underground to map and explore inaccessible areas. The rotating LiDAR provides an omni-directional field-of-view ensuring 3D data is collected in all directions and obstacles are avoided in all directions. Additional sensors such as RGB colour and thermal cameras, gas sensors, and radiation sensors can be carried to collect a variety of other useful data types. This data can be overlaid on the 3D LiDAR data for visualisation and analysis. The 3D survey data is used to reconcile post-blast stope shapes to the design, monitor drive development progress, and analyse rock structures to determine ground stability. It can also be used to map above ground mining assets.

Geotechnical Monitoring & Modelling

Data collection from open pit mines using drones allows mines to generate orthophotos, 3D models and high-density point clouds with great accuracy. From a geological and a geotechnical perspective, there are numerous opportunities to extract mineralogical and lithological data, as well as structural and geomorphological data. This data can then be used for mine planning, slope monitoring, and grade control.

As explained above, drones are also being implemented in underground mines to capture geotechnical data in inaccessible areas[17]. Models can be constructed, and structural features mapped on those models to predict potential rock failures through the analysis of rock mechanics and/or geological discontinuities.

Figure 7: Stockpile Inventory Management



Source: Beca

Stockpile Management

Many companies are now optimising their inventory management by calculating stockpile volumes, regularly and more accurately using drones. Highly detailed topographic mapping techniques are used to generate a 3D model of the stockpile to high levels of accuracy, and that model generates a volume for the stockpile. In addition to the efficiency benefits it increases safety by eliminating staff from potentially dangerous areas.

Anglo American has been using a fleet of 10 drones to monitor the progress of work and stockpiles in its Kumba iron ore mines in South Africa.

Inspection and Monitoring

Using drones to capture video and images, allows regular inspections to be carried out safely and cheaply. Whole mining sites and specific pieces of equipment can be easily inspected routinely, and the area monitored for security. This not only includes mine and plant operations but also tailings dams and other remote areas. Significant cost savings can be achieved with uninterrupted operation of the equipment and safety is improved through no human contact with the asset.

In Western Australia, drones are being developed to assist with the inspection of autonomous hauling systems. Real or sometimes false obstructions on the haul road can cause an autonomous truck to stop, requiring a manual inspection before it can be restarted causing a delay in the operation. With drone technology the truck can potentially be inspected and restarted far more quickly and remotely.

In Gujarat, India, drones with night vision cameras are being used to ensure tight surveillance of the Sabarmati river bed, where high levels of illegal sand mining are eroding the profits of the mining companies in the region.

With mine tailings dams, drone technology consultant skymineUAV points out that regular monitoring is an important factor which can be achieved with an autonomous drone programmed to fly frequently and when unusual levels of runoff, snowmelt or rainfall can overstress a dam[18]. Since the monitoring and data processing happen automatically, it is much less likely to be skipped or forgotten, addressing both the lack of resources and continuity issues.

It partners with DroneCore, which has an autonomous drone-in-a-box that could be located near the tailings dam. It would be scheduled to fly the entire perimeter of the dam at whatever frequency is necessary, using the duel thermal and HD camera to collect imagery. Once it landed, the imagery would be uploaded to a chosen cloud processing facility and processed to detect the thermal contrasts that would indicate seepage or a leaking pipe. If detected, an alert would be sent to the appropriate people at the mine, along with the imagery. The drone would also be able to collect imagery of the dam that would be used to create a 3D DEM of the dam. This would be stored in the cloud and the data from each flight could be compared to that from previous flights to detect any changes in the size, shape or structure of the dam.

Drilling and Blasting

Data captured from drones allows the bench to be surveyed and photographed prior to the commencement of drilling. Prior to loading explosives, geo-referenced images of the drill pattern allow engineers to confirm that drill holes are in the correct location. Post blast images and video facilitate the analysis of rock fragmentation. Further, a drone derived digital version of an open pit enables engineers and geologists to optimise blast designs, as well as accurately control and document differences in grade across the site.

The Future of Drones

A growing number of drone software vendors are targeting the mining sector with increasingly useful solutions. Also new generations of drones are delivering more and more functionality. Hatch[19] believes the industrial drone industry will only improve its capabilities and list of applications. Soon we will be seeing smaller, more mechanically robust machines with even better data collection. It is expected that fully autonomous drones will routinely fly around the operation, gathering data to provide the mine with an up to date digital image of the operations for analysis making sure everything is in order and only letting management know when there is a problem.

Mine Safety

One of the important drivers and outcomes of implementing innovation and new technology is the improvement in safety. The development of autonomous mining equipment is probably one of the biggest steps forward for improved mine safety in recent years. At the end of 2018, Komatsu reported zero serious injuries after 10 years of autonomous vehicle operation [20]. Autonomous systems effectively remove staff from operations and exposure to risks. These risks include dust, noise, vibration and physical injury.

An autonomous system also has multiple layers of system functionality to detect hazards. For example, with autonomous haulage systems (AHS), only dedicated AHS equipped vehicles operate within a defined autonomous operating zone. All vehicles entering the autonomous zone are equipped with GPS transponders for tracking and staff required to operate in the AHS mining area can be detected through wearable technology. Caterpillar also supplies an 'A' stop: an emergency device activated by an individual that can stop all vehicles within 300m.

The health and safety risks are higher in an underground mine due to the various additional geotechnical and environmental challenges. As with surface mining, the use of autonomy underground aims to increase the productivity of the equipment and improve the safety of the operators. In additional to the removal of staff from hazardous mining areas, new technology is being introduced to protect those workers still operating in the mining environment with developments in wearable technology. Meanwhile, virtual reality is being used as an industrial tool to train and educate workers in the workplace, but in a simulated safe environment.

Wearable Technology

Mining companies are now able to utilise wearable technologies to monitor employee safety and health in the workplace. In recent years, some applications of wearable devices have been reported in the mining industry to support production process control, health and safety management, and environmental quality monitoring. Wearable devices can be classified based on their function, appearance, proximity to the human body, and other parameters, but include smart clothing, smart eyewear, wearable cameras, wearable sensors and medical devices, and smart watches. Various types of sensors are used in wearable devices depending on the intended application. A recent paper gave a good review of wearable device technology[21].

Deloitte, Vandrico Solutions and Cortex Design[22], through a three-way partnership, have developed the Smart Helmet Clip. This new wearable device is lightweight and can be attached to the back or front of a miner's helmet. It contains sensors to detect levels of hazardous gases in the air, a radiation sensor, a temperature and humidity sensor, and other sensors depending on the type of mine. In addition to providing an alert system with yellow to red lights for emergency situations, the helmet facilitates communication between managers and miners. The Smart Helmet Clip comes with onboard GPS, accelerometer and gyro. This allows for the tracking of the movement, or no movement in the event of an accident, of a miner and his location.

Jannatec Technolgies[23] has developed the ENSO Generation 1 Smart Helmet. It provides workers with a number of customisable features to assist with compliance and ensure worker safety. These include GPS, phone, LEDs, camera, and a collision avoidance system.

SmartCap's LifeBand technology[24] gathers the broadest spectrum of fatigue data providing everything from company-wide holistic trends to individual profiling. The technology was developed within Mining3, a Cooperative Research Centre established by the Australian government. Canaria Technologies[25] is developing an earpiece wearable device that monitors your vital signs. Reading an array of different biometrics signals including heart rate, heart rate variability, oxygen, temperature, respiratory rate and head position, the earpiece will gather individuals' medical data.

Hexagon Mining[26] has introduced HxGN Mine Personal Alert, an accident-avoidance device worn by field personnel that ensures 360° visibility around heavy equipment. The collision avoidance system calculates a vehicle's position, heading, and path while Personal Alert's sophisticated measurement technology determines a pedestrian's distance and position. Hexagon is a provider of digital solutions that create autonomous connected ecosystems.

Newmont Mining has a pilot project that includes connected-worker technologies which analyse facial expressions of haul-truck drivers and sound vibrating alarms if the drivers are distracted or drowsy behind the wheel. It also has the Smartband, a wearable device similar to a Fitbit. Worn continuously, it monitors the quality and duration of an employee's sleep and wake periods. Drivers learn about their own particular signs of fatigue or distraction, as well as how lifestyle changes can reduce fatigue and improve their long-term health. The successful trial saw fatigue and distraction events decline by 87% and 68%, respectively.

Virtual Reality

Virtual Reality and Augmented Reality are technologies that are quickly becoming useful tools for the mining industry. One of the main uses has been in safety and training, but virtual reality is also helping companies and stakeholders better understand proposed projects and associated reclamation and mitigation measures. It is helping to enhance mine planning, from productivity to environmental measures, and support reclamation planning.

Teck has partnered with technology company LlamaZOO Interactive to create virtual twins for mine planning and community engagement for its projects [27]. The immersive virtual reality experience brings people to the site without having to travel there and allows them to see aspects of the proposed mine that they could not otherwise see. During a virtual tour, users can fly over the site to view land holdings, geological models, existing and planned facilities, infrastructure that needs to be built, the scale of it, and topography of the mine site and surrounding area. Users can also advance through the different phases of mine development during the virtual tour, including the post-closure and reclamation landscape. The ore body can also be fully viewed in three dimensions.

Figure 8: Virtual Mine using VR Technology

Source: Teck Resources

Barminco has worked with technology specialists to develop a portable Interactive Virtual Reality training system to assist in hazard awareness and 'new-starter' training. Barminco is an international provider of mechanised hard rock underground mining services, from mine development to production. This Interactive VR technology training tool enables the user to realistically experience the underground environment, in addition to providing an introduction to the company's safety process. The technology has the ability to introduce hazards to trainees in a realistic, first person point of view without placing them at risk. It engages the user in all levels of visual, auditory and kinaesthetic learning, making the experience more engaging with the outcome of higher levels of knowledge retention [(28)].

Sentient[(29)] is a Perth-based software development company which provides powerful and immersive 3D visualisation, process control and automation solutions for its clients in the mining and resources industries. This includes; training and simulations, communication and marketing using 3D animations and flythroughs, and real-time data visualisation.

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