Robert Pell looks at how UAVs are growing in use in the mining industry, and which companies are leading innovations in this high-tech space

Scanning from the sky

There is a wave of excitement around Unmanned Aerial Vehicles (UAVs) encouraging a range of industries to explore the potential of this futuristic technology. UAVs can be used for intelligence, surveillance and reconnaissance, and offer unique opportunities for improving productivity in the mining sector. The advancements in UAVs, and their ability to carry different payloads, is turning the mining sector into an emerging frontier for new technology. In recent years, these miniature flying machines have helped the industry find cheaper and safer ways to map minesites as well as explore for minerals via remote control.

UAVs are powered aerial vehicles with no human operator on board and can fly autonomously or be piloted remotely. UAVs are smaller and lighter than manned aircraft and can carry sensors and communication equipment. They are now offering a unique, cost effective way of carrying out a range of tasks central to many mining operations.

The fact that UAVs can carry different payloads means that they can be used in a range of mining applications such as;

- **Reconciliation**: Using photogrammetry techniques for monitoring stock pile volumes and design comparisons for excavation and dumping equipment (where a fast turnaround of data is essential so that mining operations can take action while the machinery is still in the area)
- **Rehabilitation and environmental**: Using infrared and multi/hyperspectral payloads for vegetation mapping and topsoil monitoring
- **Geology and geometric applications**: Unmanned AIrcraft Systems (UAS) can cover a large area that could previously only be mapped with manned aircraft
- **Gas monitoring and spontaneous combustion**: Fly aircraft into the area to monitor sulphuric gas levels. Without UAS the monitoring is 'hit and miss', as it involves setting out monitoring devices based on wind direction in the hope something is collected
- **Imagery**: Multispectral 3-band imagery for use in presentations, data analysis, and QA of GIS layers
- **LiDAR**: Use for volumes, excavations and dumping, reconciliation, dig versus design, ramp grades & width compliance
- **Geotechnical monitoring**: Detect movement in the spoil piles by comparing UAS data to scan data
- **Real time fleet management**: Tracking the efficiency and locations of mine equipment.

The first UAVs designed for mine surveying and mapping first appeared around 2008, but were hindered by the lack of processing power. In the last few years there have been great improvements in this area, which has once again encouraged UAV market development.

There are two main types of UAV available that are commonly used for surveying work in the mining sector. The first is a fixed wing model which tends to be compact and lightweight. They are built for one-man survey operation, and are ideal for aerial mapping and terrain modelling of larger areas, including minesites and stockpiles, and undertaking topographic surveys.

The second style of UAV is a rotary blade, or propeller-based system. Unlike the fixed wing models, these mini-copters are able to fly in every direction, horizontally and vertically, as well as hover in a fixed position. This makes them the perfect instrument for detailed inspection work or surveying hard-to-reach areas such as pipelines, bridges, power lines and rail tracks.

Drone manufacturers

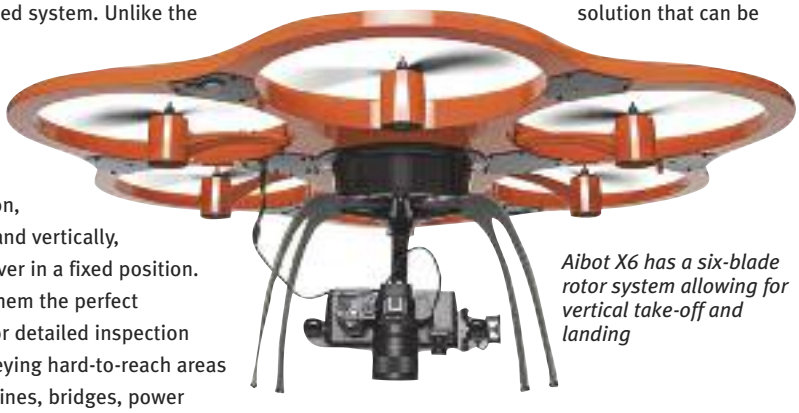
Hexagon announced its intent to be a major player in the UAV and drone market by acquiring the German drone manufacturer, Aibotix, in 2014. They manufacture the advanced Aibot X6, which has a six-blade rotor system or 'hexacopter', allowing for vertical take-off and landing.

DroneMetrex created an aerial photogrammetric mapping solution called the TopoDrone

"The Aibotix acquisition is an important addition to Hexagon's photogrammetric and mapping technologies portfolio," said Hexagon President and CEO Ola Rollén. "The growing number of applications for UAV-based solutions offers huge growth potential, especially in areas that require frequent and local updates such as smart city applications, dynamic GIS, and emergency response."

Leica Geosystems Mining, also part of Hexagon, has an offering in this sector with the Leica RCD30. This medium format camera and SwissDrones Dragon offer a professional UAV mapping solution that is reliable and certified. It can provide accurate geospatial information and is embedded in a proven workflow environment.

Leica and SwissDrones, a UAV manufacturer, worked together to provide an innovative UAV-based mapping and monitoring solution that can be operated safely in often harsh environmental conditions. The SwissDrones Dragon is a mid-size rotary wing UAV that offers payload performance of up to 50 kg, extreme endurance and a range of safety features.



Aibot X6 has a six-blade rotor system allowing for vertical take-off and landing

It can be operated manually or completely

Leica RCD30, which with the SwissDrones Dragon offers a professional UAV mapping solution

autonomously using proven autopilot technology that is capable of controlling both UAV and payload. The Leica RCD30 for UAV can obtain high accuracy mapping from its UAV-based platforms and is one of the world's first medium format cameras to provide superior multispectral imagery. Its unique photogrammetric design features make the Leica RCD30 an ideal option for standalone or oblique mapping, for integration with a LiDAR sensor, and for operation on board an unmanned aerial vehicle (UAV) such as the SwissDrones Dragon. The unique performance features of the SwissDrones Dragon combined with the qualities of the Leica RCD30 make this an ideal mapping and monitoring solution for local mapping jobs, corridor applications, mining and agriculture.

Maptek joined the airborne surveying revolution by investing in the Australia-based DroneMetrex. DroneMetrex created an aerial photogrammetric mapping solution called the TopoDrone-100. The company claims their UAV is more accurate than competitors on the market, offering real-time kinematic surveying, and achieving elevation accuracy of 25 mm. The Topodrone-100 weighs 2.5 kg, with a total payload of 5 kg, is battery powered with endurance of up to 60 minutes, and has a catapult launching system.

DroneMetrex also developed a new solution for directly georeferenced mapping from UAVs. The difference and, at the same time, the main advantage of the Direct Georeferencing Solution (DGS) is that it encompasses Post Processed Kinematic (PPK) principles.

DroneMetrex Managing Director Tom Tadrowski said: "We went this way because Real Time Kinematics (RTK) has radio-link issues and distance issues. It is limited to the telemetry range and other radio frequency interferences (terrain, vegetation, buildings, and atmospheric conditions). RTK accuracy reduces as distance increases. If loss of radio frequency or telemetry during the flight happens – you have missing data which will compromise the accuracy of the whole flight run."

An important component of PPK DGS offered by DroneMetrex is a high accurate GPS receiver on board the TopoDrone which independently logs the GPS coordinates of the drone for each and every photo position. The accuracy of the photo position is also directly related to the synchronisation of the camera shutter with the GPS logging.

The position of the on-board GPS antenna is also an important consideration in relation to the camera. Unless the antenna is exactly above the camera, and unless the camera is nearly at its nadir and with little or no "crab" then there is always a danger of having geometric errors that will inevitably occur during the flight. The TopoDrone-100 has the GPS antenna mounted directly and accurately above the centre of axis to the Dynamic Stabilised Active Mount and the camera. It ensures minimum "lever-arm" correction for highest accuracy photogrammetry. Differential GPS post-processing is then used to obtain the accurate camera positions.

Silent Falcon UAS Technologies (SFUAS) has secured its first major order with Osprey View, which will use Silent Falcon's solar-powered drones to do mining survey work in Central Africa. Silent Falcon manufactures patent pending small UAVs, components and sensors and is headquartered in Albuquerque, New Mexico. Osprey View, headquartered in Annapolis, is a provider of UAS imagery services.

Osprey View will be deploying these systems to provide aerial mining surveys, aerial mapping surveys and surveillance services to its customers in a variety of countries worldwide, with an initial focus on Africa. Osprey View provides a variety of geospatial, environmental, mining, surveillance and other commercial services using Silent Falcon and other unmanned aircraft.

"We are extremely honoured to have been selected by Osprey View to provide it with the long endurance, long range, multi payload UAS capability it requires to provide a wide range of UAS based services for its customers. Our Silent Falcon system has exactly the capabilities Osprey View requires to fulfil its customers' mission requirements. We believe this initial order will be followed by additional unmanned aircraft systems orders from Osprey View as it expands its business," said John W Brown, President of SFUAS.

"We are very excited to work with Silent Falcon UAS Technologies. Their systems and payloads will enhance the delivery of Osprey View's surveys and services to our customers around the world," said Allen Murray, CEO of Osprey View. "We needed a unique and innovative UAS platform and sensor and payload technology provider and that is exactly what we are getting with Silent Falcon UAS."

Silent Falcon's aircraft are a few feet long, lightweight and solar powered. They can be ordered with a suite of instruments from heat sensors and spectrometers to digital cameras, and can fly for hours. A ground based pilot can be used or it is also possible to pre-program it to fly a certain route. The drones are designed to be flown in areas that are impractical for regular airplanes, such as long or dangerous missions.

Drones and the law

Drones have been around for many years, but have primarily been used by governmental agencies to support law enforcement activities, search and rescue operations, border patrol missions and humanitarian aid efforts. As the

Silent Falcon UAS Technologies has secured its first major order with Osprey View for mining work in Central Africa

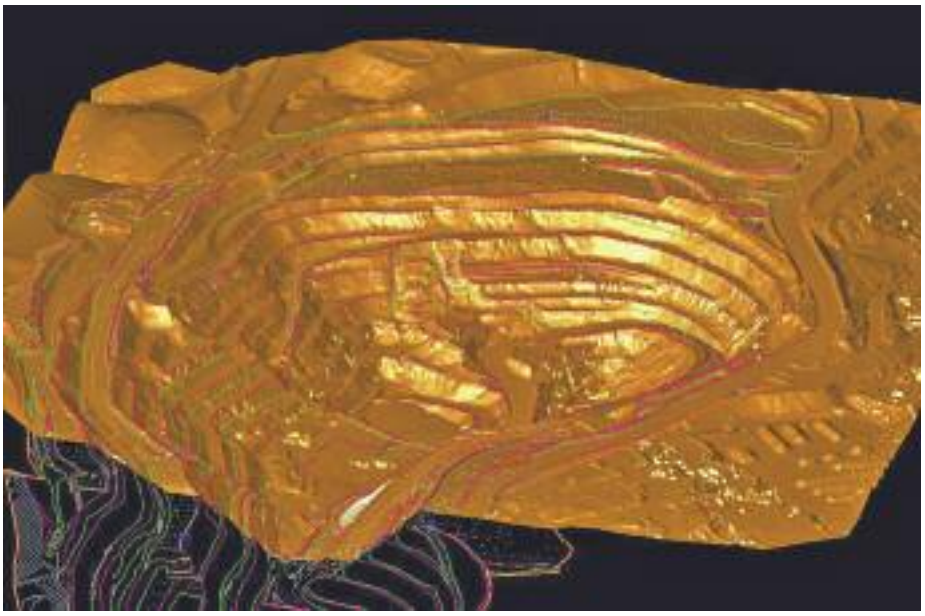
technology has developed and interest has grown for their use in commercial activities and in particular the mining industry, this has also led to the need to strengthen regulations.

The mining industry offers a great commercial opportunity for the companies involved in UAV technology, as it is constantly evolving and innovating to maximise output while also balancing complex safety challenges. UAVs offer the potential to increase productivity while mitigating safety hazards, and mining companies stand to benefit tremendously from integrating UAVs into their operations.

The first consideration for using a drone at a mining operation is whether the country in question has regulations put in place. In the US, only public agencies can fly drones and in Canada, operators must apply for regulatory waivers. In other countries, controllers must keep drones within sight of operations.

Territory Iron was awarded an operating certificate from the Civil Aviation Safety Authority (CASA) to use drones at its Frances Creek operation in Australia. Darryn Dow, Chief Mine Surveyor for Territory Iron said at the time: "We started to look at the potential for UAVs at our mine in late 2012. Given that our team had no previous aviation or RC knowledge, we searched for a turnkey application which included hardware, software and training. This was to help integrate any system we purchased into our current mining operations with minimum disruption to our daily task lists. At that time there were few systems that ticked all the boxes we wanted, especially cost, and we finally decided on the **senseFly** Ebee/Pix4D package being distributed by Haefeli Lysnar Geospatial Solutions in Western Australia. We also approached CASA at about the same time, seeking direction on how to obtain the certification necessary to comply with regulatory guidelines. This lead to enrolling one of our surveyors in the BAK and PPL courses being offered by the Western Australian Aviation College in January and March 2013."

The company's first surveyor was CASA certified in June 2013, and by end 2014 Territory had three certified controllers to cover its FIFO rosters. It then set about applying for the operator's certificate for Territory Iron. "Not having completed operating manuals of this kind before, we did struggle to come to grips with the content and structure required. Luckily for us, John Frost – CASA's airworthiness inspector for unmanned aircraft systems – helped us simplify this process by supplying us with a preferred generic operating manual that had been developed to guide new applicants, and we tailored it to reflect our intended use. Risk assessment and drug/alcohol policies already existed within the company so we submitted these to show we were capable of managing our UAV system safely. Following a trip to Canberra to complete the field testing component of the submission, we were awarded our Operators Certificate in December 2013." By April 2014, Territory had flown more than 100 missions and collected data for a wide range of tasks. Monthly reporting of stockpile inventories, pre and post-mining imagery of land disturbance, data capture for exploration and mine planning purposes, photo evidence of environmental and heritage compliance, as well as general presentation imagery used for site communications, accounted for the majority of the routine use of its UAV.



DTM overlaid onto a pit model at Territory Iron's operation in Western Australia

In April 2014, Dow stated: "We recently began to develop geological mapping missions which will eliminate the need for personnel to access areas of the open pit that are hazardous (rock fall potential) or congested (interaction with mobile mining equipment). From a surveyor's perspective, I was initially sceptical that we could produce results that would adhere to the spatial accuracies we achieve with conventional surveying instruments like GPS and laser scanners. This has been enhanced by placing numerous ground control points within the mission area to aid the spatial corrections applied during software processing. Although we allow a slightly larger tolerance in absolute positions achieved with the UAV, the results still fall within industry accepted standards. Now I am confident we regularly achieve a high quality result."

Surveying operations

The most prominent use for drones and UAVs in mining is surveying as they offer about 90% less cost than using a manned helicopter whilst being able to map a variety of terrains by flying close to the ground and gathering more data than workers in helicopters are able to. Additionally, drones are capable of surveying even in cloudy conditions so no time is wasted waiting for particular weather conditions.

Energizer Resources, the well-established graphite producer, purchased two senseFly drones in an attempt to reduce the costs that would traditionally be required with an airborne LiDAR survey. The large MOloo graphite mining project in Madagascar is part of the 1,000 km² Green Giant graphite project in the arid south of the country. The Molo deposit spans 5 km² and is thought to contain between 80 and 120 Mt of high-quality, all-flake graphite which is used in refractories, batteries and consumer electronics.

Energizer Resources contracted mining engineering company, DRA, to perform a full Bankable Feasibility Study to determine whether or not it was viable to bring Molo into production. As part of this study, a full land survey was required. This would be used to create a 3D contour map of the site. The team would then use this to determine the location of the mine's dam as well as the location of its accompanying pipeline, and the positions of plant assets such as buildings and equipment.

Eric Steffler, the Geomatics Manager at Energizer Resources said: "For this survey we looked at various approaches with DRA. We looked at flying a large-scale LiDAR survey for example, using manned aircraft, which would have enabled us to produce a full hydrological model of the region, covering 3,000 km². However this would have been very expensive and involved the importing of aircraft from South Africa".

"DRA discovered that another organisation had already flown some of the area in question

Two senseFly drones were used at Energizer's Molo graphite deposit in Madagascar

and was happy to share its data. With access to this info, Energizer and DRA were able to narrow down the target region to a much more manageable 150 km². We chose to employ drones for two reasons. One was the price. This was very low compared to a LiDAR survey, which would have cost hundreds of thousands of dollars, even with our reduced survey area. The second was that by making a capital investment in two eBee drones, we could then fly these over our other properties in Canada. Since we now have the technology we need to produce digital elevation models and air photos ourselves, we don't have to hire third-party companies to do this for us."

The 150 km² area that was surveyed comprised several parcels. Three large, square areas were flown to ascertain the best location for the site's dam, and an additional corridor covered the route of the favoured dam site's proposed pipeline. There were also three further parcels to the west of the site: the mine site itself; the plant site; and a rectangular parcel, the possible route of a road heading to the nearby town of Fotodrevo. DRA also requested a second set of flights. It required these in order to source baseline data from outside the original survey area and to analyse the condition of an existing road that would connect the proposed plant site with the town of Bekily."

Steffler and his team created a digital terrain model (DTM), in a grid format which could then be used to generate 3D contour maps of the site, featuring half-metre and two-metre contours.

"Air photo interpretation was required to determine the locations of villages, roads, crops, and culturally significant items such as tombs and historic trees," Steffler said. "We also needed to examine the quality of the roads that we would use for transporting material to and from the site, and our RGB shots would also form part of our environmental assessment."

The 150 km² area covered by the drones was most definitely at the larger end of UAV mapping projects, and Steffler calculated that his UAVs completed over 300 flights in total, with an average flight time of 35 minutes, average flight coverage of 2.5 km² , and capturing some 150 RGB images per flight (15,000 photos in total).

"For our flight planning, we set a ground resolution of 9.9 cm per pixel in the drone's eMotion software. We chose this figure to ensure that, after processing the images in Postflight, we could still achieve the 20 cm product accuracy that DRA required. This GSD meant eMotion set a flight altitude of 292 m above the eBee's take-off point. We also used eMotion's multi-drone function to manage flying our two UAVs in the same region at the same time."

Steffler managed the data processing himself, spending up to 12 hours per day on this task — over 120 days in total.

"With 10 to 12 flights flown each day we had 16 to 18 gigabytes of raw data to process every night," he says. "We needed to buy a more powerful computer to deal with this data. Then once the entire survey had been flown, we had to merge the data together. For this we used open-source SAGA GIS software."

The final data products heand his team produced achieved a GSD of 9.75 cm, and accuracy within DRA's requested ±20 cm range.

Steffler is now effusive in his praise of drone technology saying: "The return on our investment has been amazing. We saved ourselves hundreds of thousands of dollars by using the drones in place of airborne LiDAR, plus we have sub-contracted our UAVs and personnel on several other jobs."

Coal in Australia

One of Australia's largest coal mines is using UAVs in their operations. Gary Robertson is a Surveyor and Senior Engineer at a large coal mine in Central Queensland, and began a comprehensive Critical Analysis and Job Step Analysis (JSA) to determine the best survey solution for the company, which has now been sent to corporate so that the findings can be reviewed for other sites and used as a corporate business improvement review article.

Robertson said: "We reviewed every option available on the market, comparing fixed wing UAVs with multi-rotary systems, petrol-run versus battery-operated, large versus small, payloads, targets versus RTK. We looked at systems from America and New Zealand as well as those available locally in Australia."

"We dismissed systems that used a catapult launch because of the energy the catapult stores in line with company HSEC guidelines and also petrol/combustion crafts due to the maintenance side of the regulations & certification. We also needed a solution that had semi-autonomous control so that you could take over either mid-flight or during landing to avoid any potential obstacles. Larger aircraft often needed some sort of catching device or descended by parachute – there was too high a risk of them getting blown off course and landing in the wrong area. RTK systems appeared to reduce turnaround time compared with conventional target placement systems."

In addition to the analysis of the hardware itself, as a CASA approved UAS controller Robertson looked at purchasing and owning the UAV outright, or contracting a service provider that will conduct the flights and post process the data.

"Because of the CASA requirements to become fully certified, we thought the best option was a service provider who was experienced and had all the required qualifications in the short-term, until the business sorts out the CASA UOC, Chief Controller & Maintenance Controller requirements. It can't just be a buy and fly approach as some people think due to the aviation regulations."

Robertson has worked with a local service provider to explore and test a potential mining solution. Matt Ewing, director of UAS service provider company Airmap3D, recently conducted a demonstration flight and data analysis over the mine with his SIRIUS Pro UAV from Topcon Positioning Systems.

"The hardware met all of our safety requirements, as it is launched by hand just above the operator's head and it has semi-autonomous control options to ensure a safe landing," Robertson said.

"The data it supplies is well within our accuracy requirements and the SIRIUS Pro has the unique ability to map accurately without setting out ground control points through GPS

RTK solutions. This has the added safety benefit of removing surveyors from the active mine site environment while also reducing job request turnaround times."

"For me, the appeal in UAV technology is that it gives you the perfect vantage point for conducting surveys. All terrestrial systems face two main challenges on a mine site: covering a large enough area and getting a good vantage point where you can capture the right data. UAV systems are the ideal solution to both of these problems."

"The accuracy, ease of use and reliability of this UAV is astounding. I carry out quality assurance on every job that I do and consistently achieve a mean accuracy of around ±50mm xyz, with a standard deviation of less than 100mm. But I can often get ±20mm mean accuracy, with only a 50mm standard deviation."

Prior to purchasing the SIRIUS Pro, which eliminates the need to set out ground control points, Ewing faced the challenge of getting site access to the mines in order to set out.

"Organising the logistics to get out and set out the ground control points was a long process that would add up to a whole day to each job. But now with the new Pro system, I am able to achieve the same if not better accuracies, without having to go through the ground control setup at all.

"That means I can deliver a job to a mine site, from start to finish including data processing, in half a day," he added.

Gold in the Dominican Republic

The Barrick Pueblo Viejo gold mine, located in the Dominican Republic, recently completed a survey using a small fixed-wing UAV. The senseFly eBee surveyed a mine area of 450 hectares in four hours, collecting data from pre-marked ground control points using GPS technology. The resulting survey provided rich detail of all exposed surfaces in pits, quarries and stockpiles as well as tracking the stability, construction and volume of materials within tailings storage facilities at the site. With further processing, the data (orthophotos) can also provide a 3D model of the area surveyed, allowing the surveyors to better calculate ore and other material volumes and track changes in three dimensions.

The minesite is fairly unique as it processes up to nine different types of ore, but lacks the space to stockpile them separately. This means that ores are stacked on top of each other. The three-dimensional models produced by the UAVs can distinguish between the stockpiles, ensuring that the right mix of ore is sent to the mill at the right time.

"The UAVs are an efficient way, both economically and practically, to help us track the stockpiles, optimise space at site and ensure we're sending the right ore to the mill," says Sean Jefferys, Pueblo Viejo's Chief Surveyor.

The eBee UAV has a Styrofoam body, making it very light. It also has a 50-minute flying time under ideal conditions, and has numerous programmed safety features. It will, for instance, return to its launch site if it passes a pre-set low-battery level, ensuring it doesn't run out of juice and crash. Battery error, poor GPS coverage and strong winds are other scenarios that will automatically return the UAV to its launch point where it will make a controlled descent.

Pueblo Viejo has a government permit to fly the UAVs within the mine site at no higher than 500 ft.

Before the introduction of UAVs at Pueblo Viejo, a LiDAR scanner was used to collect survey data. A LiDAR scanner might take as long as five hours to gather data of a complete pit or stockpile. A LiDAR scanner costs $180,000 and the scanning process introduces a greater possibility for human error. One eBee costs just $20,000, meaning it's possible to purchase nine eBees for the cost of one LiDAR scanner.

The average flight of Pueblo Viejo's UAVs takes 15-20 minutes, plus two hours to process the data and generate orthophotos. After factoring in the lower costs of maintaining and operating the site's six UAVs, the time saved gathering and processing data, and the greater accuracy of the data, it's readily apparent which technology is preferred.

"The total cost for procurements, repairs and upgrades of our six UAVs has been $120,000 over two years," Jefferys says. "We get about 300 flights out of a single UAV before something needs to be replaced. We can cover much larger areas with better quality data than we ever could through traditional methods."

Jefferys and his team survey pits and stockpiles every two weeks, which was not previously possible due to the manpower required to traverse Pueblo Viejo's hilly, brush-covered terrain. The UAVs also improve the quality of the data gathered while freeing up personnel to analyse this data.

"The UAVs allow engineers to work with near real-time data. The UAV data has enabled clearer communication of daily mining plans at all levels. It is an established production tool," said Jefferys.

The LiDAR scanner still has its place in surveying, although now it is used more sparingly. The advantage that the LiDAR scanner offers is it can penetrate thick brush cover to generate data, whereas UAVs cannot. The UAV is used only for areas with no ground cover. When surveys of larger areas of the mine are required, something the UAV cannot provide, the survey team uses satellite imagery.

The latest eBee models have Real Time Kinematic (RTK) Differential GPS functionality, meaning each photo is automatically assigned GPS coordinates the moment the photo is taken. This will obviate the need for ground control points, saving considerably on time while capturing the elevation in the hilly terrain around Pueblo Viejo to within three centimetres. Because it is relatively new technology, the current obstacle to acquiring RTK navigation is cost. Nevertheless, Jefferys says the existing UAV technology has greatly enhanced efficiencies and the quality of survey data at Pueblo Viejo.

"Its technology that's really under-utilised in the mining industry," he says.

Manned equipment

The new Riegl VP-1 is a helopod for airborne laser scanning and includes an integrated RIEDLG VUX-SYS fits the small and lightweight RIEGL VP-1 pod, to be mounted on standard hard points and typical camera mounts of manned helicopters. Quick release adapter brackets and a minimum of external cabling (power supply, LAN, GPS antenna) allow quick system installation and removal.

The component weighs around 19 kg and is a robust and reliable airborne scanner carrying platform with a full mechanical and electrical integration of sensor system components into aircraft the fuselage. ***IM***

The new RIEGL VP-1 with an integrated RIEGL VUX-SYS