Flights of wonder

Goldman Sachs puts the worldwide total addressable market for non-military drones at $38 billion by 2020, with triple-digit CAGR for commercial and civil government use, and 16% CAGR for recreational use[1] – efficiency, cost reduction and safety are principal drivers for their adoption. John Chadwick looks at developments in mining

Preparing an Aibotix UAV for work

Drones or UAVs (or UASs – unmanned aerial systems) have had a significant impact in many areas of professional and personal life but their impact has been perhaps greater in mining than anywhere else. They have made a big difference simplifying work processes and allowing safer information gathering throughout the whole gamut from exploration, through mining to tailings deposition. Surveying, volumetric assessments, visual inspections – all have benefitted from the use of drones.

In his article on *UAVs for Mining and Aggregate Operations*, Jeremiah Karpowicz (Executive Editor for Commercial UAV News, quotes Iain Allen, Senior Manager, Mining Information Technology at Barrick Gold. "The biggest change that UAVs have enabled is around stockpile volumes," Allen said. "With conventional surveying, it's inherently unsafe to have people on the stockpiles, so we would do the best we could, and it was very time-consuming. With UAVs, we get better data, faster and more safely. We can get 3D models as often as we want."

Nevertheless, mining and exploration companies wishing to use drones must be very aware of local regulations in regard to flying these aerial vehicles. And these vary dramatically from country to country.

Idrone Inspection notes "the importance of safety for all out in the field. By allowing drone surveyors to collect accurate aerial data from above, UAV technology can vastly reduce risk by analysing areas of concern and implementing plans of action out on the field.

"Drone-based data collection can also boost productivity; surveying projects that once took days or weeks using traditional surveying techniques are now possible in just a few hours." Applications include:

- Geotechnical referencing
- Surface stability monitoring
- Joint mapping
- Control for mining in void areas
- Mapping of steep inaccessible inclines
- Resource calculation
- Geophysical & watershed/catchment area modelling
- Supporting photography
- Security.

Robert Simmerling and Peter LeCouffe got together to found **Harrier Aerial Surveys**. Their idea was to marry surveying with GIS to bring a new level of efficiency, cost-effectiveness, and accuracy to surveying clients. As they explain, "traditional surveying methods consist of either terrestrial or using a full-sized aircraft. Neither of these methods is as efficient, cost-effective or accurate as using a UAV can be.

"With traditional surveying techniques, you need lots of people, lots of time, and lots of equipment. And in return, you get fewer data points. Using both fixed-wing and multi-rotor UAVs, the team can collect 15,000,000 data points where traditional methods would have gathered a mere 1,500 points.

"The accuracy of the photogrammetry techniques Harrier uses is within 1% of comparable datasets produced by LiDAR (Light Detection and Ranging), that uses light in the form of a pulsed laser to measure ranges (variable distances) to the Earth."

"Data captured by drones combined with dedicated analytics can easily measure and quantify information that was hard and time consuming to get before," said Emmanuel de Maistre, co-founder and CEO of **Redbird**. "With all these new datasets, people are really changing the way they monitor their site operations. The cloud allows a new collaborative and more efficient approach to the monitoring of the sites. Even if people are not experts with data and data processing, they can interact with one another and effectively collaborate thanks to a user-friendly cloud interface."

In their paper, *Applications of point cloud technology in geomechanical characterization,*

analysis and predictive modelling, John Lyons-Baral of Hexagon Mining and John Kemeny of the University of Arizona, explain: "Point cloud technology is now an indispensable tool in geological and geotechnical data collection, interpretation and analysis. Open pit and underground mines of all sizes are regularly collecting point cloud data as LiDAR and photogrammetry surveying devices have finally become affordable and the workflows fast and efficient. Past challenges of large data processing and manipulation are gone with recent technological advancements in computer hardware and software. These innovations reduce file sizes, ease rendering requirements and allow for the implementation of real-time 3D viewers and surface meshing tools. With its ability to remotely (safely), rapidly and accurately extract large quantities of georeferenced and 3D-oriented data, point cloud technology provides numerous applications to the geomechanical field. The list of uses is continuously growing, so this paper specifically focuses on digital outcrop modelling and digital terrain engineering."

GEM Systems notes that UAVs "have gained rapid acceptance and popularity as they are relatively inexpensive, collect good quality data, and they can be equipped with many kinds of sensors, ranging from simple cameras to infrared cameras, and now, magnetometers.

"Mineral exploration is a natural fit for a UAV for a number of reasons. Manned flights in remote areas are dangerous and cost significant resources to support, including mechanics, fuel dumps and more. UAVs are easier to launch, mobilise, set up and refuel. Moreover, UAVs can fly in most weather and at night – giving significant productivity gains over conventional airborne surveys.

GEM explains that it takes one man day to walk 10-15 line km of magnetic survey. To do a grid of 100 line km, it would take roughly 10 days, plus all the support of food, etc. A drone could collect 100 line km in less than one day. In addition, the safety concerns of a person out in the bush for 10 days are real with respect to personal injury. Use of a drone, mitigates much of the risk associated with a survey like this.

Another advantage that GEM points out – "the drone is flying higher and therefore the signal is slightly reduced, [but] the shear density of the data, both along line and between tightly spaced lines of 10 m, far outweighs the sparse data collected on the ground , that is susceptible to near surface noise, such as boulders and operator shake."

Comparing drones versus airborne surveys, GEM notes that "whereas an airborne survey provides clean quality data, safety restrictions force the plane to fly at a minimum of 300 ft

Part of GEM Systems' success is due to its components – "specially designed for high resolution and noise-free data: Responses of a dipolar target fall off as the inverse cube of distance so the farther from the source – the smaller the signal. This can be compensated for by using an ultra-sensitive magnetometer such as the Potassium optically pumped version. The GEM GSMP 35U Potassium UAV magnetometer is at the core of its UAV offering

(90+ m) in most cases, and line spacing of typically 100 m. With a drone, flight height is less, typically 150 ft (about 45 m), and line spacing can now be effectively flown at 10 m. This creates a level of information not seen in the exploration world before. This kind of detail will ultimately lead to new understandings and discovery.

Brodie McCrory, a prospector based in Canada's Yukon Territory, comments on "the tremendous value of improved mapping resolution. Any additional geoscientific surveys must, in my opinion, be overlaid on the most accurate surface and/or elevation model available. It is - at best - misused resources and - at worst - can be misleading. Missing a diamond drill target by a few metres due to an inaccurate surface model would produce a (incorrect) negative result that would be very difficult to identify in the future.

"Outside of the positioning and mapping uses, there's continued interest in geophysical surveys that could be performed by a UAV. Some have some potential to replace current helicopter or fixed-wing aircraft surveys, such as magnetometrics.

"However, there are the physical limitations from this platform that are the same as any aerial survey. Despite the novelty and excitement around UAVs, there is no practical benefit from having a ground penetrating radar unit in flight. This applies to many physical properties - the closer to the ground, the better. I don't foresee UAVs dominating groundtruthing or surface data collection for many years yet.

"There's research being done into SAR and safety applications underground but without GPS, autonomous navigation is difficult. But, with the driving goal being to improve safety, I believe this will be one of the earlier lateral developments for UAVs; a modern-day 'canary in a coal mine'. This would be more relevant to larger development and production mines with the infrastructure in place to support it.

"Lastly, there are already many automated and unmanned vehicles in use in mining - such as remote controlled underground equipment. I foresee more submarine mineral exploration using unmanned vehicles.

"Logistics is most likely the primary concern of any mine project. I have heard of helicopter flights carrying AA of batteries for a critical task. If supplies could be delivered in an automated fashion, it would eliminate a huge amount of the overhead associated with remote mine sites.

"The one product that I think has a good chance of (relatively) fast uptake is a GPS guided cargo parachute. It has similar costs as a fixed-wing while able to deliver its payload to a helipad-sized target."

Flying aeromagnetics

In July, **Alta Vista Ventures** signed a Binding Letter of Intent to purchase a 100% interest in the unmanned aerial vehicle (UAV) division of **Pioneer Exploration Consultants**. The UAV division of Pioneer specialises in providing UAV solutions to the mining and exploration industry and has successfully completed aerial surveys throughout Canada, the US and internationally for both major and junior mining and exploration companies. It is a leader in mining and exploration related UAV-based survey technology.

In late 2014, Pioneer developed the world's first commercially available UAV based magnetometer survey called UAV-MAG™. This proprietary survey uses ultra-sensitive magnetic equipment to aid in the discovery of ore deposits.

Alta Vista says: "There are many competitive advantages to UAV based magnetometer surveys, of which the key is not having to rely on helicopters – a significant cost saving to the client. Surveys can be flown at much lower elevations and at much closer line spacing than conventional surveys, enabling the delivery of much higher quality exploration data. Further, a UAV flies at a much slower speed than a helicopter and it is believed that that adds to much more detailed data. Additional cost savings that get passed on the client stem from the system's portability; the entire system can be transported anywhere in the world at a fraction of the cost of a conventional airborne magnetic survey system. This allows for surveys in very remote settings and in extreme conditions."

Another area of specialisation includes UAV based LiDAR surveying. LiDAR says Alta Vista "is becoming a more popular tool for mining and exploration companies as it gives a very accurate representation of topography, even in heavily forested areas. Many junior exploration companies attracted to LiDAR surveys do not undertake surveys due to the cost of helicopter

based surveys. Alta Vista believes that cost effective UAV based LiDAR surveys using Pioneer's proprietary UAV mounted system will become much more popular with junior exploration companies."

Other services provided by the UAV division of Pioneer include 3-D site modelling and volume calculations, high resolution orthophotos, pit and pile surveying, environmental monitoring, tailings dam survey control and remote site inspections.

Michael Burns, President & CEO of Pioneer Exploration Consultants commented, "The management of Alta Vista Ventures forward thinking business plan is the perfect fit for our fast growing UAV business."

Alta Vista Ventures' goal is to enter the UAV industry by purchasing a varied group of companies that will complement each other and, in turn, create a consortium of businesses that will cover all aspects of the UAV industry.

Burns explained to ***IM*** how Pioneer, starting in 2014, designed and built in-house a multicopter UAV-MAG™ survey system, and flew the first ever 590 line km multicopter-based survey.

GEM Systems offers complete turnkey systems for helicopter bird or fixed-wing systems; magnetometer, up to four sensors; gradiometer with radar altimeter, GPS 20Hz and data acquisition system. The company states that, "the optically pumped GSMP-35A is the most sensitive magnetometer for airborne applications:

- Smaller and lighter sensor: 112 mm x 64 mm (cylinder type) - 0.9 kg and electronics box: 229 mm x 56 mm x 39 mm - 0.63 kg
- Highest sensitivity in a commercial airborne magnetometer for detection of even the most subtle targets
- Highest absolute accuracy, cleanest data with no need of filtering
- Secured internal memory to store up to 3,000,000 readings
- RS-232 & Larmor frequency output

So, explains Burns, "we combined a proven UAV platform with a potassium vapour GSMP-35A magnetometer, resulting in a system with excellent performance specifications and survey capabilities. The UAV is a rotary wing UAV platform, chosen based on its payload capacity and flight time of about 30 min." He went on to explain that GEM Systems GSMP-35A potassium vapour sensor package is a proven airborne magnetometer with 0.0001 nT resolution, 0.3 pT sensitivity and 10 Hz sampling [for maximum survey density]. The sensor package includes an ultra-light weight laser altimeter, GPS, and an IMU (inertial measurement unit) to record the sensor's velocity, orientation and XYZ movement.

"The result," he explains, "was our UAV-MAG system which can fly up to 150 line km per day at an all in cost to the client of less than $100 per line km. Mobilisation costs are the same as getting a person on site with 100 pounds (45 kg) of gear, due to the light weight and compact size of the UAV-MAG, so rather than being a major cost addition to the survey, it's becomes an insignificant expense.

"To our knowledge, our survey costs are extremely competitive with both conventional airborne and ground based mag surveys. This becomes a significant advantage for our clients, letting them put more resources into ground, and that's huge for them.

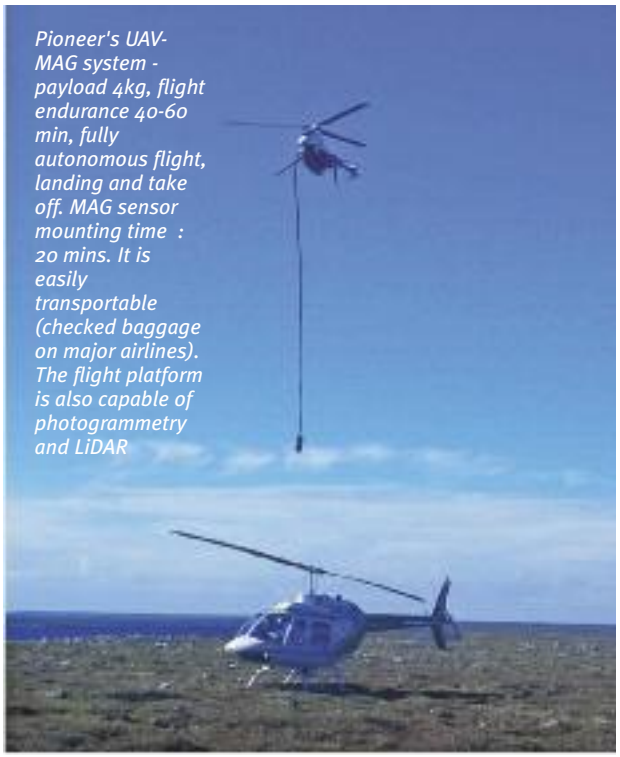
There were three main goals for the initial design:

1. To reduce magnetic interference of the flight platform in order to collect high quality magnetic data
2. Create a system that is both reliable and flexible enough to fly a mag survey and collect aerial photos for ortho-imagery and digital elevation models in the same day
3. Create a highly portable system with the ability to fly a survey safely and simply in any terrain and under challenging weather conditions.

"We achieved the first goal by employing a 'towed bird' sensor configuration," Burns explains. The sensor is slung below the craft by a specially designed lightweight mount system. This allows sufficient separation between craft and sensor, and achieves low drag and no noticeable reduction in flight time.

"The remaining requirements pushed us away from fixed wing platforms and into multicopters for a number of reasons. With the UAV-MAG system, we can launch from the middle of a survey grid in heavily forested, steep terrain and not worry about take off and landing. Once in the air, the UAV-MAG takes care of the rest by flying the survey autonomously and returning home for landing. We found this invaluable for remote surveys. The small size of the platform, compared to a fixed wing system allows fast flight launching and easy transport. We can carry our fully flight-ready system by hand, ATV [all terrain vehicle] or vehicle, and launch within minutes. No complicated launching platforms, or landing fields required. What we have created is a truly versatile survey platform for multiple sensor packages, essentially a Swiss Army knife UAV, and our clients so far have been extremely pleased with the results and reduced survey costs."

Essentially, Burns explains, the Pioneer system means two people can do in a day what would need six people on the ground and take a week. Furthermore, there is no aerial competition for such surveys – drone use is equally as good (and much cheaper) than doing it by helicopter. When considering large regional surveys, however, the helicopter- or fixed wing-mounted survey is still the best.



Pioneer's UAV-MAG system - payload 4kg, flight endurance 40-60 min, fully autonomous flight, landing and take off. MAG sensor mounting time : 20 mins. It is easily transportable (checked baggage on major airlines). The flight platform is also capable of photogrammetry and LiDAR

Burns considers there to be great potential for the future, with exploration spending coming back to higher levels in many parts of the world. Large mining companies, he explains tend to either do their own work – like BHP Billiton – or contract the work out, like other major mining companies, for which Pioneer has worked. And as the juniors start finding money again for exploration, he anticipates a lot of contract work from them.

For surveys carried out in rugged topography and requiring the best possible terrain correction solution, **MWH Geo-Surveys** uses a **senseFly** eBee professional mapping system to collect low level photogrammetry and terrain data. The company has developed an enhanced processing system to leverage the high precision GNSS gravity positioning and the ultra-detailed digital terrain model/orthophoto "to create an unparalleled terrain correction solution. This digital imagery also provides valuable photo data which has a multitude of exploration and project planning uses.

"Terrain corrections can now be calculated to an unprecedented degree of accuracy using this new technology along with our processing solutions."

An eBee was also used when the Al Ram chromite mine in Oman in 2015 contracted MWH Geo-Surveys International to run a micro-gravity

exploration survey of the mine. The goal of the survey was to map sub-surface chromite veins.

This would in turn allow a targeted drill program to identify the location and depth of chromite veins for future mining operations.

A critical element in high-resolution gravity surveys is the ability to accurately calculate and correct for local topography. Such accuracy is particularly important in areas of difficult, complex terrain such as the Al Ram site.

"Our gravity surveys require precise RTK GNSS surveying at each gravity measurement point," says Kevin MacNabb, a founding partner and owner of MWH Geo-Surveys.

In order to produce a micro-gravity survey in an area of difficult topography like Al Ram, which has deep, sheer pit walls and is surrounded by rugged mountains, a high-quality, high resolution DEM (digital elevation model) is essential.

So, MacNabb turned to MWH's senseFly eBee drone, which was purchased for exactly this type of data collection. "The drone allows us to create cost-effective, high-resolution DEMs and orthophotos, in support of geophysical surveys like that at Al Ram, solving a technical problem very effectively," he explains.

eMotion was important to this project, as it is to all such projects. It is senseFly's intuitive ground station software, supplied with every senseFly drone. It is used to plan, simulate, monitor and control mapping flights.

RIEGL developed a remotely piloted airborne carrying platform, the RiCOPTER, a high-performance X8 array octocopter. The VUX-UAV LiDAR sensor, the IMU/GNSS unit, a control unit and up to two high-resolution cameras are assembled to build the VUX-SYS, a fully integrated system solution, ready to be mounted on the RiCOPTER. Equipped with the VUX-SYS, the RiCOPTER enables high-performance unmanned surveying missions offering a flight endurance of up to 30 minutes at a maximum take off weight of slightly less than 25 kg

LiDAR specialist

The **RIEGL** VUX-1 series was introduced to the market as a series of small and light weight survey-grade LiDAR sensors. The instruments can be employed for a great variety of surveying applications ranging from mobile laser scanning to UAS/UAV/RPAS-borne laser scanning and airborne laser scanning from manned platforms like helicopters, gyrocopter and ultra-light aircraft.

All these solutions are based on the RIEGL VUX-SYS which is a completely integrated laser scanning system of low weight and compact size for flexible use in kinematic applications. The

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system comprises a RIEGL VUX-1 Series LiDAR Sensor, an IMU/GNSS system and a dedicated control unit. REIGL says "the excellent measurement performance of the VUX-1 in combination with the precise inertial measurement unit and the associated GPS/GLONASS receiver results in survey-grade measurement accuracy over its full range of applications.

The VUX-SYS also forms the core of the RIEGL VMQ-1HA which is a compact, economically priced high-speed single scanner mapping system mobile mapping applications operated from a car, train or boat.

In their paper *UAV-based Laser Scanning to meet special challenges in LiDAR Surveying*, Philipp Amon, Ursula Riegl, Peter Rieger and Martin Pfennigbauer of RIEGL Laser Measurement Systems "highlight some of the advantages of LiDAR technology - such as multiple target capability or independence of environmental light conditions – proving that laser scanning is perfectly suited for demanding surveying applications."

They assess the potential of unmanned aircraft based laser scanning by means of several practical examples. "Capable for VLL (very low level) flight, the new class of small UAVs offers yet unknown possibilities and perspectives to close the gap between high-altitude airborne and ground-based laser scanning."

They differentiate and analyse typical applications for which ULS is proposed and assess the respective challenges.

"The VUX-1UAV is the first laser scanner of survey-grade measurement quality specifically developed for unmanned airborne laser scanning.

"Specific software solutions for mining applications allow automated surface extraction and feature modelling as well as breakline extraction out of the scan data, thus providing the standard results to mining customer requirements."

Barrick Gold experience

UAVs are "great for surveyors because it means they can spend less time collecting data and more time using it," says Barrick's Allen. "This technology also allows us to survey areas that were previously too dangerous to send anyone."

An orthophoto of the different ore stockpiles at Pueblo Viejo generated by the eBee helps the mine site team determine which ore to send to the mill and when

At the Barrick-operated Pueblo Viejo gold mine in the Dominican Republic, a small fixed-wing UAV, the senseFly eBee, can survey a mine area of 450 ha in four hours. The UAV collects survey data from pre-marked ground control points using GPS technology. The resulting orthophotos provide rich detail of all exposed surfaces in pits, quarries and stockpiles. They also help track the stability, construction and volume of materials within tailings storage facilities. They even account for the curvature of the Earth's surface and correct distortion for digital maps to reflect distances more accurately. These activities strengthen already robust on-site monitoring activities and provide greater detail than traditional tracking methods.

With further processing, the orthophotos will 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.

Pueblo Viejo processes up to nine different types of ore, but lacks the space to stockpile them separately. Hence, different ores are stacked on top of each other. While that may seem like grounds for a mix-up, the 3D 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 has an EPP foam body and wings, 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 power 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.

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

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stockpile. A LiDAR scanner costs $180,000 and the scanning process introduces a greater possibility for human error. One eBee costs around $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. When you factor 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 explained in 2014. "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."

The operational advantages of UAVs accumulate quickly. 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," Jefferys says. "The UAV data has enabled clearer communication of daily mining plans at all levels. It is an established production tool."

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 obviates the need for ground control points, saving considerably on time while capturing the elevation in the hilly terrain around Pueblo Viejo to within 30 mm.

A DJI UAV in flight

Jefferys says the existing UAV technology has greatly enhanced efficiencies and the quality of survey data at Pueblo Viejo. "It's technology that's really under-utilised in the mining industry," he says.

Powerful partnerships

DJI, a world leading aerial-imaging company, has partnered with leading UAV software company **Propeller Aero**, to launch an integrated solution to reduce costs, improve safety and drive operational efficiency for mining users.

The partnership integrates DJI's market-leading commercial-grade aerial platform, the Matrice 100 with Propeller's cloud-based software specifically designed for surveying and inspection. This easy-to-use, fully-integrated solution will provide enterprises and commercial UAV operators a simplified, quick and efficient way to automate operations and access data. The solution will enable businesses to accurately perform on-site measurements, volumetrics and share data seamlessly with just a few clicks.

"It's great to see innovation around DJI's aerial technologies and how these ideas are turning into actual business opportunities and practical use cases," said Michael Perry, DJI's Director of Strategic Partnerships. "Deploying UAVs for surveying and inspection can significantly reduce costs, minimise workplace hazards and realize fundamental operational improvements. Being from Australia, Propeller Aero has had the considerable advantage of developing alongside the industries that have been using commercial UAVs since 2002; the platform is already integrating drone data into the existing work flows and processes that businesses are using."

The Matrice 100 platform has all of DJI's easy-to-fly technology built in, including the flight controller, propulsion system, GPS, DJI Lightbridge, a dedicated remote controller, and a rechargeable battery. This system automatically manages the most complex tasks required for flight, so businesses and companies can focus on getting the job done. Propeller Aero's online platform offers industry-leading capabilities for geospatial data processing, analytics and collaboration, including instant volumetric calculations and the ability to track changes over time. It has seen rapid adoption by commercial drone operators and enterprise clients in over 60 countries.

"We're thrilled to provide an end-to-end solution for the industrial sector together with DJI," said Rory San Miguel, Propeller Aero's Co-Founder and Co-CEO. "As the market leader in

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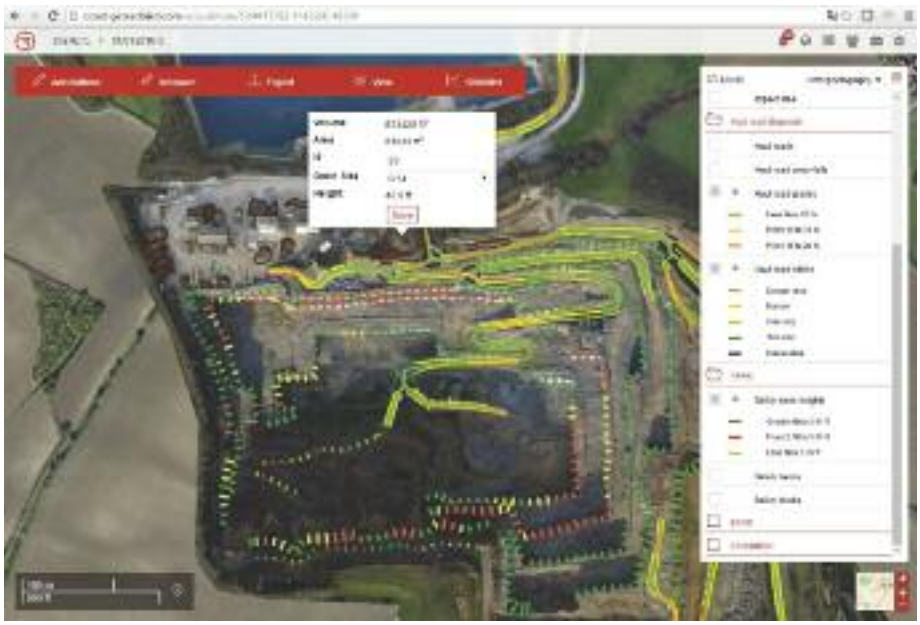

An example of Redbird analysis by drone

UAV hardware, DJI is making its technologies more reliable and easy to use for operators, and at the same time, actively responding to the needs of commercial enterprises. This partnership is a natural step for us, and we're looking forward to bringing this solution to mining."

At the end of last year, Caterpillar announced an exciting new marketing agreement between its Europe, Africa and Middle East region and Redbird. The latter, established in 2013, is a pioneer in the acquisition and analysis of aerial data collected by UAVs. As Caterpillar says, "Redbird's ability to both collect drone data and provide analysis of that data using cloud-based, proprietary algorithms offers significant benefits for customers. Developing relationships with a broad variety of companies like Redbird will accelerate our ability to help our customers become more productive, make better business decisions and optimise their operations."

John Carpenter, Construction Technology and Solutions Manager said "UAV data collection and Redbird's image analytics capability will provide customers with a variety of solutions for their operations, such as material inventory management, haul road optimisation and project progress to name a few."

"Drones are entering a new phase, with data analytics as the heart of this evolution," said de Maistre. "Our solutions have been developed with leading construction companies and quarry operators for the past two years, helping them extract the real value out of drone data."Redbird says it has the "best in-class monitoring tool, trusted by more than 1,000 sites across the world. It turns drone data into actionable intelligence to give mining companies the means to monitor their assets and highlights the "unparalleled production monitoring" potential.

- Access powerful in-browser 3D stockpile computation volumetrics
- Assign each stockpile its material type
- Get enhanced reporting and statistics.

"Get high resolution surveys and compare:

- Automated analysis of orthomosaics
- 2D and 3D views, and many more
- Monitor frequently and detect changes quickly.

"From drone images to powerful analytics:

- Ensure flawless safety
- Monitor high walls, safety blocks and berms
- Optimise haul road design to improve fleet efficiency.

"Plan blasting operations online:

- Automatically upload your blasting information
- Estimate volumes to be extracted
- Visualise instantly.

Blast monitoring

South Africa-based explosives leader **BME** is setting up a High-Tech Services unit dedicated to developing the use of drone technology for clients.

"The aim of this team is to advance our progress in employing modern technology like drones to help us monitor blasts and optimise our clients' fragmentation results," said BME Technical Director Tony Rorke. "Drone-mounted high-resolution cameras, combined with global positioning system (GPS) survey equipment to provide ground reference points, are allowing us to take a quantum leap in more effective blasting practice."

The downstream impact, said Rorke, can be felt in a range of benefits to mining productivity, such as finer fragmentation, higher digging rates and reduced power consumption in mine crusher circuits.

"Better measurement – both before, during and after a blast – is the key to optimising blast results," he said, "and drones advance our measuring ability greatly when combined with BME's other innovative in-house tools like our blast planning software together with our electronic detonation system."

Rorke said while great strides had been made in surveying and drilling blastholes, a mine's survey plan is often not completely accurate or up to date – potentially reducing blast quality.

"Using drones, we can generate high-quality aerial imagery of the blast site after holes have been drilled, capturing the exact GPS coordinates of each hole," he said. "These coordinates are exported into our blast timing design program BlastMap III and into our AXXIS electronic detonator system – allocating precise firing times to each hole as a function of its exact position."

He emphasised the benefits in being able to adjust the timing of a detonation in a blasthole – as well as firing sequences and charge distribution – to take account of any slight divergence of a hole's actual position compared with its place on the survey plan.

BME blast analysis: an aerial view from a camera mounted on a UAV clearly showing the blasting pattern

The versatility of a drone as a vehicle for the camera also extends to valuable monitoring functions during and after the blast.

"Sampling, measuring and quantifying the fragmentation achieved by a blast is much easier when done from an aerial scale image that a drone can deliver, making the analysis much more useful in improving future blasts," he said. "The distribution and volumes of fragment sizes are important to monitor, as these are vital to continuous improvement strategies."

Software now also allows the creation of a three-dimensional surface of the blast block, by combining the aerial drone imagery and the face profile footage from land-based cameras.

Redbird's latest strategic alliance is with EPC Groupe, a world leader in the manufacturing, the storage and the distribution of explosives as well as the field of drilling and blasting. This will be to the benefit of EPC's customers in more than 30 countries on all five continents. With access from the Redbird cloud platform, they will be able to monitoring, interactively and accurately, the evolution of mine production activities.

EPC and Redbird are combining their expertise to offer a range of innovative services based on the opportunities offered by UAV technology. This premium service provides, for example, an interactive 3D map of the work site constantly updated. "It also enables," they say "the achievement of an unprecedented level of precision for the analysis of mined materials (3D view to measure the spreading, the wave effect; but also the grain size of the superficial layer of the blast), opening the way for a true drive for continuous improvement of the blasts, supported by the methods and tools developed by EPC."

All of the measures and data available in the field, sometimes under-used, are collected, stored and made valuable by making them easily accessible on any medium (computer, digital tablet, smartphone). Customers can thus benefit from an analytical tool, enabling optimisation and the control of work sites, promoting security, respect of environmental constraints and efficient use of resources.

"The use of drones represents in this way a technological leap, bringing more precision and facility of use. It also enables to quickly obtain post-mining information in the form of a 3D model of the demolished pile. In conjunction with the Redbird cloud platform, it opens the path to the analysis and the optimisation of the blast results in order to improve the performance of the whole production chain", declares Ricardo Chavez, EPC Technical Director.

"This strengthens the positioning of Redbird in the mineral industry as a specialist of data processing through drones, and their accessibility via the cloud," says Benjamin Hugonet, Commercial Director of Redbird.

And underground...

Systems are now beginning to break through underground. With ever increasing need to improve safety and maximise operational efficiency, new drone technology is there to replace labour-intensive methods of surveying, inspection and mapping. They can capture 3D spatial data in hard-to-access underground areas in mines with an aim to remove much of the risk and increase safety on site.

Clickmox Solutions, a Canadian based technology company, has developed a 3D mapping system based on SLAM (Simultaneous Localization and Mapping) algorithm, which can be installed on drones or vehicles. This system is capable of building 3D maps in real time without the need for GPS signal for positioning. The company has subsequently released MineFly and TILT Ranger drones as complete 3D laser scanning and mapping solutions specially designed for underground mines and other GPS-deprived areas. TILT Ranger is a joint product of Clickmox and Inkonova, a Swedish high tech company. These solutions overcome most of the challenges underground where physical presence may be laborious, unsafe and expensive. With 30 mm precision up to 20 m, the 3D scanner on MineFly and TILT Ranger can scan any underground mine opening, such as drifts, stopes and ore/waste passes. Possible uses of such a system in underground mines are large-area 3D

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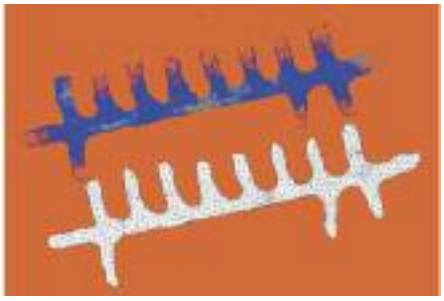
scanning, 3D mapping, convergence monitoring, inspection, surveying, 3D profiling, as-built CAD generation and vehicle positioning.

The TILT Ranger drone is based on tilting rotor technology, which allows it to fly vertically, roll on the ground and climb walls. It is equipped with wheels as well as guards to minimise damage from hitting objects. The laser scanner on the drone is mounted on top by default but can be switched to bottom easily by the operator if needed. In this configuration, it can be used in open pit mines as well.

Underground, point clouds and meshes of drifts and other areas go a long way due to their usefulness in performing geological investigations, ground condition archiving and ground support design. Such meshes are created from the point clouds generated by a laser scanner. Most mines construct these point clouds using stationary laser scanners, which is a time consuming and expensive process. It is impractical to perform repeated scans to update the maps as ground conditions change. A drone-based scanning and surveying system would solve these problems by allowing the operational crew to perform repeated scans quickly and efficiently. A drone-based 3D scanning system can survey underground stopes and drifts empowering personnel to become virtual surveyors from a remote location.

Bundled with ClickMox Solutions' underground scanning hardware, **ThreeDify CloudMesher** is engineered to process large point clouds from 3D scanners or UAVs. Very large point clouds with



A 3D mine drift mesh generated from a point cloud using ThreeDify CloudMesher

points over 100 million can be visualised and edited in an interactive speed on commodity laptops. The point clouds can be further processed to create actionable meshes for downstream mine design and reconciliation to minimise underbreak, overbreak, and percentage of volume variance. CloudMesher is a module within ThreeDify GeoMine workspace, an integrated solution from geological modelling, mine planning, design and scheduling system for both open pit and underground mines. Survey data flows seamlessly among all modules in GeoMine, eliminating the needs for incremental import/export steps, and hence significantly increases users' productivity.

The most compelling feature of CloudMesher is the automatic solid mesh generation from point clouds. With a few mouse clicks, CloudMesher can automatically generate the best fitting solid mesh for any point cloud that represents an underground opening. This is made possible by ThreeDify's powerful meshing pipeline that consists of a globally optimal triangulation algorithm, a manifold-geometry re-meshing algorithm and a mesh shape optimisation algorithm. A mesh produced from this pipeline not only honours the original point cloud, but also is guaranteed to be watertight and manifold with similarly-shaped faces as well as the user-defined vertex count – an ideally-shaped actionable mining object for downstream mine design and reconciliation.

Coming soon, Threedify is also planning to release its cloud based drone mapping software that would allow any individual or mining company to upload drone-created photographs to its 3D drone mapping site to create dense 3D point clouds. Such point clouds can then be further processed with CloudMesher to create actionable mining objects.

UAV performance

Advantages in the performance of different types of UAVs are illustrated in the following table (courtesy of the Pearcey Institute2) where o = worst, + = average, ++ = best. Capability is rated for range (how far can it fly), endurance (how long can it stay in the air), weather dependence (especially wind and rain), manoeuvrability (in all three dimensions) and payload capacity (weight it can lift).

In a recent article in the AMIRA International Newsletter, The Pearcey Institute also reports "the capability of a UAV also depends on the sensors it carries, and this has also been an area of rapid research and development. The sensors that can be carried are largely dependent on the payload capacity, which has largely become a function of the battery performance/weight ratio. Some of the sensors already deployed in UAVs are illustrated in the following table, which also indicates the main area of application.

Sensor Type	Capability
Digital Camera • Visible light • Still frame • Infrared • Video • Thermal • 3D (stereo)	Mapping Surveillance Obstacle avoidance People/Object identification
Barometric & Ultrasonic	Altitude & Height measurement
Multispectral/hyperspectral scanners	Mineral identification Rock type mapping
Magnetometer & Radiometrics	Mineral identification Rock type mapping Landmine detection
SAR (Synthetic Aperture Radar)	3D Terrain mapping Vertical movement detection
LIDAR (Laser-light detection and radar)	3D mapping using accurate point clouds Obstacle avoidance
Analytical sensors	Gas detection Moisture monitoring

Type	Range	Endurance	Weather dp	Manoeuv.	Payload
Satellite	++	++	++	0	+
Balloon	0	++	0	0	+
Airship	++	++	0	+	++
Glider - Kite	+	0	0	0	0
Glider - Fixed wing	++	+	+	+	+
Prop engine	++	++	+	+	++
Rotor-kite	++	+	0	+	+
Copters:					
Single lift-rotor	+	+	+	++	+
Quadcopters	+	+	+	++	+
Multi-copter	+	+	+	++	++
Coaxial rotors	+	++	+	++	++
Tilt-rotors	++	+	+	++	+

Flight news

Aibotix says it "works with high precision with global customers in mind." A new package it offers includes the industrial UAV Aibot X6 Version 2, delivered ready for take-off. With a dead weight of 3.4 kg and a maximum payload of 2 kg this hexacopter offers a climb rate of up to 8 m/s.

The flight height up to 500 m and up to 3,000 m above sea level allows UAV missions in nearly every environment.

Within a 20 min flight time Aibotix says you can "capture hundreds of pictures and cover areas up to 10 ha. Create point clouds, 3D models and accurate digital terrain models with Leica Geosystems' software or use your existing software solutions."

The Aibot X6 works with GPS, gyroscope, accelerometer, barometer, magnetometer and ultrasonic sensors to make flights as safe as possible. There are various automatic functions such as autonomous flights (thanks to the flight planning software Aibotix AiProFlight which is included in the package), point-of-interest flights, position hold, automatic start and landing procedures, automatic coming-home and in-flight voice support over remote control.

Aibotix AiProFlight allows users to plan and execute autonomous flights

within minutes. Precision is always important for any UAV mission – so Aibotix AiProFlight offers options, GPS and GNSS or RTK flights (however, the additional hardware Aibot HP GNSS 2 is not part of the package).

AiProFlight provides high-quality georeferenced data from the UAV sensors. It can be used for the first step of the post-processing to create the base for different software solutions.

AiProFlight is the communication platform to the Aibot X6 V2. No matter which settings you are going to check or change, no matter which logfile you are going to download - it combines flight planning, black box and communication platform in just one solution.

The Aibot X6 V2 package comes with the battery set in battery case with eight batteries, the Aibotix Ai battery charger set, the Aibotix pilot accessories set (including pilots vest), Aibotix Wi232 (for the wireless communication with your PC, tablet or notebook), USB connection cable, camera screw and the pre-programmed remote control.

The Ai DLVP is the latest development from Aibotix for real-time evaluation of camera data. It has been designed for professional tasks in the field of industrial inspection and monitoring. It allows users to work with Live View to support missions to generate accurate data.

Aibotix notes multi-spectral sensors make the invisible real. "With **Parrot** Sequoia you will get the lightest multi-spectral sensor in the world. Capture RGB and multi-spectral data at one time - geo-referenced and in high quality."

Weighing only 107 g, Sequoia is a powerful sensor in a remarkably small package. This camera features four narrowband filters optimised for analysing data and a 16 MP RGB imager for easy digital scouting. Sequoia's irradiance sensor and integrated GPS make it an accurate and calibrated tool for precision work.

Hexagon Mining's Leica Delta-FW70 is designed to provide professional aerial remote sensing and mapping capabilities in one platform. It features four separate payload bays, capable of holding more than 0.25 m^2 and 2.8 kg of payload. The large airframe can accommodate a variety of sensors and the supplier can integrate sensors and autopilots to meet a variety of needs. This UAV is intended for low cost, reliable, repeatable, day to day commercial operation in harsh environments, poor weather, at night. It has the capability of flight times in excess of two hours and range up to 32 km in poor weather, day or night.

Hexagon Mining says "the key to covering the maximum amount of area in the shortest amount of time is sensor size, not megapixels (MP). Don't be fooled by high MP cameras with small sensors or you will spend up to five times longer gathering imagery. You need to gather the images as quickly as possible."

senseFly launched the albris, a quadcopter UAS for mapping and inspection. The company says it "is a uniquely sensor-rich system. Developed by experts working across numerous fields of robotics, this lightweight quadcopter offers the situational awareness, imaging flexibility and durability [needed] to complete challenging tasks safely, accurately and efficiently.

"albris' low take-off weight of 1.7 kg ensures its users will, in many countries, have less flight authorisation paperwork to deal with than those who use heavier systems."

"We believe the albris level of application-focused technology is unique in the civilian drone market," said Antoine Beyeler, CTO and co-founder of senseFly. "This platform tightly integrates several one-of-a-kind features, such as TripleView imaging, advanced situational awareness and full flight mode flexibility—to provide inspection and mapping professionals with the functionality they desire from a rotary system."

albris is a future-ready platform with a quad-core computer on board. Like senseFly's fixed-wing drones, it offers users ever-evolving performance through regular software updates, adding the latest drone tech innovations to keep it at the cutting edge for years to come.

The Delta-FW70 Fixed-Wing UAV has many camera and GPS options for a downward facing camera for surveying, mapping, and other mining applications. Aerial imaging is all about the camera, and it can carry a large full frame mirrored DSLR NIR camera which offers the best in imagery and field of view (FOV)

The integrated sensors work together to provide the user with full situational awareness and support obstacle avoidance:

- Five 'navcam' vision sensors allow the operator to see in the direction the drone is moving, automatically via its flight control

senseFly albris in flight

software, without needing to turn the system's TripleView camera head. This technology is unique in such a lightweight UAS, similar to the visual parking sensors in modern cars, but brought into a 3D flight environment

- Five ultrasonic proximity sensors work in harmony with albris navcams to ensure the operator always knows the drone's distance from nearby objects. (The drone's shock-absorbent carbon fibre shrouding is also always on hand to protect its rotors in case of surface contact)
- Numerous other sensors, including inertial measurement units, barometers, magnetometers, GPS and magnetic encoders, maximise the drone's stability and safety.

In another civilian drone first, albris' autopilot-controlled TripleView camera head enables the user to view and record three different types of imagery during a single flight without needing to land to change cameras: HD video, ultra high-resolution stills and thermal still/video.

Since the TripleView head faces forwards, albris can fly up close to target structures such as walls and dams to achieve sub-millimetre data resolutions. Plus, thanks to the head's 270° vertical field of view, users can document objects positioned directly above and below the drone.

albris offers a flight mode to suit every project:

- Autonomous mode — perfect for mapping projects. First, create a flight plan using eMotion X's mission blocks. albris then launches, flies, acquires geo-referenced imagery and lands itself
- Interactive ScreenFly mode — this streaming video mode is perfect for live inspection tasks. Simply use the supplied joypad to navigate and orientate the drone via computer screen. This mode includes flight assistance features such as cruise control and distance lock
- Or stay flexible... create a flight plan, launch in autonomous mode, then 'go live' on demand
- No matter which mode is activated, RC-based manual control always remains available as a backup function and for experienced pilots.

What's flying in?

Kirwan McHarry, Marketing Director, **Mota Group** says "anticipated developments in the near to relatively near future include:

- Increasing flight intelligence
- Steady improvements in battery power
- 3-D printed carbon fibre airframes.

"The steadily increasing capability and smaller sizes for processors, radios, and sensors mean drones large and small will gain more intelligence at lower cost. This will facilitate the automation of routine tasks, helping ensure they are carried out the same way over time. In addition, some commercial and recreational drones will gain the ability to sense and act on conditions in flight. One example is re-prioritising its task list if the drone encounters higher-than-forecast winds that reduce its time in the air."

MOTA says it GIGA-8000 "is a highly versatile platform for airborne missions large and small. Available REMOTE HANDS™ flight management system, only from MOTA, lets you optimise your GIGA-8000 for almost any mission"

We know that one of the exploration booms today is the search for lithium – and other high-tech electronics needs like graphite, cobalt and rare earths.

McHarry notes that "endurance is a significant barrier to UAV flight. Earlier this year Goldman Sachs predicted that automobile lithium-ion battery energy density would increase steadily from an average of more than 150 Watt-hours/kg currently to more than 350 Wh/kg by 2025 with decreasing cost1. This will allow longer flight times assuming this energy density holds for the much smaller batteries found in drones."

Furthermore, "3-D manufacturing can allow for great surface and structural complexity. In drones, 3-D printed carbon fibre could maximise the airframe's strength-to-weight ratio and potentially allow the design of airframes with lower wind resistance. Carbon fibre's benefits may eventually accrue to other components, such as rotors that provide greater lift, and the incorporation of crumple zones to help protect the payload."

Regulatory concerns

Pioneer Exploration's Burns considers that generally it is getting easier as national aviation regulators get to understand and be comfortable with the industrial uses of drones/UAVs. It is the hobbyists that are the potential danger to planes, and people and ground installations. Anyway, much of the mining industry's flying needs are in remoter areas. As long as operators can satisfy basic guidelines, then special permits are not required. However, there can be problems in less developed countries with less developed aviation regulations and little or no experience of industrial drone use.

However, McHarry cautions that "in many nations, despite the easing, there still restrictions. In the US, these include prohibition of flight beyond line of sight and at night, irrespective of whether the flight is over private property. This despite the Federal Aviation Administration having announced it would change the process for commercial drone operation from operators asking for permission (a so-called Section 333 exemption petition) to a new body of regulation, FAR Part 107, which essentially lets many operators take out a license to operate commercially. In addition, there is a new and increasing body of law in the US that regulate drones at the state and municipal levels.

"Mine operators should verify that the drone operators they hire, or their own personnel if they fly drones themselves, are familiar with the regulations as well as knowing how to work with informal practices that may govern in remote areas."

GPS-guided aerial delivery

Earlier in this article, Brodie McCrory noted the importance of logistics. Some remote camp deliveries could use GPS-guided aerial delivery systems, such as **MMIST's** Sherpa™ Precision Aerial Delivery System (PADS). It has been proven and deployed since 2003 and is a cost-effective technology that accurately delivers up to some 4,500 kg of supplies from aircraft under adverse, real-world conditions, servicing exploration teams, etc.

Sherpa systems achieve high accuracy without dangerous low-level aircraft flight, enabling cargo delivery in mountainous terrain and zero visibility.

All Sherpa variants are fully autonomous GPS guided, offering SAASM GPS support and an optional remote manual control, featuring the unique ability to reprogram the target point in-flight with the push of a button.

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