Utilising UAV surveys to support closure design and execution

Elis Smedley, Principal Engineer, Mine Earth Pty Ltd
Shannon Mackenzie, Director, Mine Earth Pty Ltd
Ray Gerrard, Director, Gerrard Consulting Pty Ltd

ABSTRACT

Good quality survey data is essential for the development of robust and effective closure designs for mining landforms. The continual improvement of unmanned aerial vehicles and ever-increasing photogrammetry processing options means that high quality terrain surveys and orthophotos can be quickly and cheaply developed. This information, combined with the analytical tools available on cloud-based processing platforms, can provide invaluable information for the development of closure designs and to support execution of closure works.

This paper highlights how unmanned aerial vehicles can be utilised to support mine closure design and execution, including a case study example.

INTRODUCTION

The ongoing development of unmanned aerial vehicles (UAVs) and associated hardware and processing options mean that they now provide an extremely useful tool in supporting the development of closure designs for mining landforms and to provide compliance information during and following closure works. By combining a mosaic of photos obtained using a UAV with known control points, photogrammetry may be utilised to develop cost effective, high resolution terrain surveys and orthophotos.

UAV-based survey has several key advantages relative to traditional approaches, including:

- Quick and accurate.
• Cost effective.
• High survey point density.
• Reduced safety risk, especially when operating on closed sites where access and ground conditions can be challenging.
• Limits disturbance resulting from foot traffic.
• Can be undertaken independent of site-based survey resources.

The aim of this paper is to present some examples of contemporary UAV survey equipment and processing options; demonstrate how UAV surveys can support closure design using a recent case study from the St Ives Gold Mine; and provide examples of how UAV surveys can support quality control during closure execution works.

EQUIPMENT AND PROCESSING

A UAV survey requires a UAV and ground control to undertake the survey, control points and processing software.

UAV

UAV surveys can be conducted using readily available off-the-shelf UAVs. The DJI Phantom 4 or equivalent is well suited to this purpose (Plate 1). The Phantom 4 offers the advantages of being simple to operate, reliable, cost effective, lightweight (<2 kg), portable, durable and having a reasonable battery life (>25 minutes). These units can be transported during air travel as carry-on luggage and fall below the 2 kg threshold that requires operators to be licenced with the Civil Aviation Safety Authority.
The UAV is operated via a hand controller equipped with a tablet (the Phantom 4 operates well using an iPad Mini) or smart phone. Free DJI applications enable UAV flights to be planned and undertaken.

The flight plan for a UAV survey can be prepared using the DJI Groundstation Pro (GS Pro) application or similar (Plate 2). Within GS Pro, the survey area can be drawn onto Google Map images. The user then enters the flight and camera properties, and GS Pro will generate an efficient flight path and present information including the estimated pixel size, flight time and battery requirements. By modifying parameters including flight height and overlap percentage, the user can quickly customise the outputs to achieve the desired survey resolution whilst minimising flight time and battery requirements.

Once the survey plan is finalised, the flight plan and associated information is uploaded to the UAV. Once deployed, the UAV commences the flight plan. Once the battery reaches a pre-determined level of charge, it will return to the take-off location for battery replacement before continuing with the flight plan.
The UAV will return to the take-off location once the flight plan has been completed.

Plate 2   GS Pro interface

**Ground Control**

Ground control is required to correct the survey. A typical survey should utilise at least six ground control points (GCPs) however a greater number of GCPs will increase the accuracy of the survey. GCPs should be located across extents of the survey area, with points located on the higher and lower locations within the survey area.
Traditionally, GCPs were established using manually surveyed points. This process is time consuming and requires a qualified surveyor and specialist equipment such as a Rover. A practical alternative to using surveyed ground control points is to utilise smart GCPs such as AeroPoints (Plate 1). AeroPoints incorporate an internal GPS, battery, solar panel and a WiFi transmitter. One AeroPoint should be placed on a known surveyed location, within 10 km of the survey area, to provide global accuracy. Once positioned and activated, the AeroPoints record GPS data at 10 second intervals to refine their location. Following the completion of the survey, the AeroPoints are recovered and automatically upload the location data when connected to WiFi. By utilising AeroPoints as GCPs, it is possible to achieve survey accuracy of <20 mm (Propeller Aerobotics, 2017).

**Processing**

The aerial photos and GCPs are processed using photogrammetry to form the survey and orthophoto. Several different software suites can be utilised to undertake processing including Pix4D and Agisoft PhotoScan. These programs can process the UAV photos (with the GPS location of the photo) and ground control information to develop a 3D model of the terrain.

Alternatively, an integrated cloud-based processing option may be utilised, such as the Propeller platform (Propeller) (Figure 1). The GCPs and UAV photos are uploaded into Propeller and are processed to develop terrain data and orthophotos. The advantages of utilising Propeller or a similar platform include:

- The survey data is stored on the cloud and may be shared with multiple users including the broader project team and external stakeholders.
- The data is presented in an adaptable and high-quality display.
- A range of data (including orthophotos, point cloud data, 3D models, contour data and triangular mesh as well as processing reports) can be downloaded from the platform for use in different software.
• The platform provides a host of powerful analytic tools including volume estimation, cut and fill volumes, elevation heat maps, slope heat maps and cross-section tools.

• Surveys are retained to assess changes over time. Design files can also be imported. Heat maps and cut and fill volumetric assessments can be utilised to assess changes over time and compliance with design surfaces.

Figure 1  Sample Propeller display

CLOSURE DESIGN

Combining UAV survey data with Propeller provides a powerful tool to support the development of closure designs for mining landforms including waste rock dumps (WRDs), tailings storage facilities and open pits.

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A UAV survey was undertaken of the West Idough WRD at the St Ives Gold Mine (the Project) to support the development of conceptual and detailed closure designs for the WRD. This case study is described below.

**Study Area**

The Project is located in the Goldfields region of Western Australia. The West Idough WRD (the WRD) was constructed in two lifts, with a nominal bottom lift height of 10 m and a top lift height of 3 m. A large proportion of the WRD was constructed from oxide material that is prone to erosion. Two sources of durable rock were available from the WRD: a continuous tip located on the northern end of the WRD; and paddock dumped rock at the northern end of the top lift (Figure 2). Additional durable rock resources were available from discrete panels on the WRD however these appeared to be have been placed to address erosion issues on the WRD and were unlikely to constitute appreciable volumes. Previous waste rock characterisation completed at the Project indicated that waste rock was not acid forming.
Figure 2    West Idough WRD

A UAV survey was undertaken of the WRD. The survey was undertaken to develop a terrain survey from which to scrutinise all aspects of the WRD, to define volumes of soil and rock armour resources, to define different areas and to provide a surface for the development of the closure design and a bill of quantities for scope of work development and cost estimation.

The volume calculation tool was utilised to estimate the quantity of durable rock available from the WRD (Figure 3) and the quantity of topsoil stockpiled along the toe of the WRD (Figure 4). Based upon the assessment, there was an estimated 155,300 m$^3$ of rock armour and 68,500 m$^3$ of soil available. Of this, 10,000 m$^3$ of the rock armour was required for the additional bunding at the West Idough open pit (Figure 5).
Figure 3  Rock armour volumes at the WRD
Figure 4 Stockpiled soil volumes at the WRD

Projected bund including a 10 m buffer

Projected zone of instability

Figure 5 Projected abandonment bund alignment

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The orthophoto, elevation heat map, contour data and cross section tools within Propeller were utilised to assess the as-dumped WRD to identify areas that would require consideration during the closure design. The primary areas of interest were associated with the top surface of the WRD, and the heat map and contour intervals were calibrated to focus on the top surface. Two main issues were identified using this approach (Figure 6): there were localised depressions on the eastern side of the WRD top surface; and drainage from the top surface was directed over the WRD batters in several locations.

Additional investigation of the depression areas on the WRD top surface was undertaken within Propeller. A cross-section through one of the depressions (Figure 7) identified it had a depth of 2 m. The orthophoto indicated radial cracking around the depressions (Figure 8) which indicated that they were formed following dumping. These zones required management during closure and were likely formed from concentrated surface water runoff combined with material prone to tunnelling or consolidation.

A review of the areas where drainage from the WRD top surface reported to the batters (Figure 6), determined that these zones were typically associated with erosion on the batters. Outside of these zones, no major erosion impacts were observed on the WRD batters.

Evidence from the assessment of the WRD top surface indicated that effective management of surface water was a key factor in the development of the WRD closure design.
Figure 6  Heat map of the top surface of the WRD
A closure design was developed for the WRD. The closure design consisted of a conceptual design, detailed design, cost estimate and scope of works. The objective of the closure design was achieve a safe, stable and non-polluting final landform that was able to support revegetation.
A conceptual design was developed within a workshop setting and documented for discussion with key internal stakeholders. The workshop was attended by experienced closure practitioners with backgrounds in engineering, geology, earthworks and rehabilitation expertise to ensure that it was constructible, practical and that the basis of design was adequately addressed. Key design factors developed for the WRD conceptual closure design included:

- Outer batters were to be reprofiled to an angle of 15° and treated with rock armour where appropriate. On the eastern and southern batters, where the top lift was located close to the crest of the bottom lift, the batter would be shaped such that it was a single slope. For the remainder of the WRD, a berm would be retained between the two lifts.

- The conceptual design was predicated on the storage of incidental rainfall on the WRD top surface. The WRD top surface and berm were sized to contain the 2,000 year average recurrence interval rainfall event with adequate freeboard.

- The WRD top surface was designed to be level. The depression areas should be backfilled continuous 250 mm thick layers and traffic compacted using material with a reasonable fines content to form a layer 500 mm proud of the remainder of the top surface, such that they are free-draining.

A detailed design was developed for the WRD. The terrain survey of the existing WRD was exported from Propeller as a point cloud and a combination of Surpac and the 3D-DigPlus Natural Re-grade (3D Dig) model were used to develop the detailed bulk earthworks design.

Surpac was utilised to model the removal of coarse rock resources for use as rock armour and for abandonment bund construction, and the removal of the soil stockpile from the WRD reprofile zone. Surpac is widely utilised mine planning software. Surpac generated cut and fill volumes for the closure earthworks and provided a final surface following the completion of the modelled task. Rock armour was initially sourced from the paddock dumped...
rock resource on the top of the WRD and additional armour where required was sourced from the northern tip-head resource.

3D Dig was used to model the reprofiling of the WRD batters and reshaping of the WRD top surface to facilitate reprofiling of the eastern batter. 3D Dig is a mining and earthworks simulator and can be utilised to develop design surfaces and undertake transport analysis. WRD batters were reprofiled to achieve the design angle of 15°. Using 3D Dig, the reprofile volume was calculated for each stage of reprofiling combined with transport analysis (Figure 9) which broke each stage into tranches of volume by reprofile distance. This was utilised as a key input into the scope of works and cost estimate for the WRD.

Figure 9  Transport analysis of WRD eastern batter reprofiling using 3D Dig
The final design surface for the WRD is presented in Figure 10. The design surface met the requirements of the detailed design and modelled cut and fill volumes as well as estimated armour and soil volumes. The total estimated WRD reprofile volume was 62,000 m³, with average push distances ranging by panel from 20 m to 52 m. The estimated WRD rock armour requirements were 42,600 m³ and the modelled soil requirements were 32,500 m³. Both rock armour and soil requirements could easily be met from locally available resources.

Surface water controls were designed for the top surface and berm to enable the retention of incidental rainfall to meet the basis of design requirements. These included backslopes from the crest and berms and crest bunding, as well as the mounding within the depression zones on the WRD top surface.

Using the design outputs and professional judgement, construction documentation was developed for the closure works at the WRD. A scope of works was prepared to inform the execution of closure works. The scope of works presented the tasks, quantities and construction tolerances required for each stage of the closure works. The scope of works reflected the construction sequence developed within the design and included all relevant information required for the earthworks contractor to complete the work. The scope of works also identified what risks may need to be assessed in undertaking the works. A class four cost estimate was developed based upon the earthworks and areas to be treated which incorporated the modelled push and haul distances to inform production rates.
Figure 10  Design surface for the WRD
CLOSURE EXECUTION SUPPORT

UAV surveys can be utilised to: provide quality management support during closure works; to develop as-constructed surveys to provide evidence of compliance; and form a base surface for post-closure monitoring.

Quality Management

The efficacy of closure designs is highly sensitive to variance of levels during construction. Employing appropriate quality management controls during closure works is critical in verifying that closure works meet the defined construction tolerance. Quality management controls might include the specification of GPS machine control, adoption of appropriate hold points, regular surveys and construction audits. Closure works at West Idough WRD have not yet been completed, however the controls presented below are planned to be utilised during closure execution works at the WRD.

UAV surveys can form an excellent tool to assist in quality management for rehabilitation works because of: quick turnaround times; the capacity to undertake the survey without interrupting works; and the ability to combine the terrain survey with aerial photos. By utilising a cloud-based platform, multiple users including office-based workers and earthwork contractors can access and interrogate the survey data independently.

By combining regular UAV terrain surveys with GPS machine control (Figure 11), suitable machine selection and diligent supervision; construction tolerances of <200 mm can readily be achieved.

Following initial WRD reprofiling, a UAV survey can be used to compare the reprofiled surface with the design surface to generate cut and fill variance heat maps (Figure 12) and slope heat maps (Figure 13). This can be done in either Propeller (which has a volume comparison analysis tool to determine the variance between design and surveyed reprofiled surfaces) or other three-dimensional modelling programs. By adopting a colour band to highlight where the reprofiled surface does not meet the specification, areas requiring
additional cut or fill can be quickly identified and communicated with field personnel for remedial action.

Figure 11  Machine guidance utilised for WRD closure work

Figure 12  Sample cut and fill heat map for a reprofiled WRD
As-constructed Survey

Following the completion of closure works, an as-constructed survey of the rehabilitated area should be undertaken to provide evidence that closure works have been completed in accordance with the approved closure design. The combination of terrain survey with orthophotos of the survey area means that a UAV survey is ideal for this purpose.

The survey comparison tool and analytic tools (such as the cross-section tool, volume comparison heat map and slope heat map) contained within Propeller can provide powerful evidence to stakeholders that designs have been constructed as intended.

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The as-constructed terrain data can form a baseline for post-closure monitoring, with volume comparison tools able to identify areas of erosion and deposition from future surveys.

**CONCLUSIONS**

UAVs can be deployed to generate high resolution terrain surveys and orthophotos. These surveys can be of immense value in the preparation and execution of closure designs for mining landforms and can be undertaken quickly and cheaply with readily available technology. The use of smart GCPs reduces the reliance on survey personnel and provides a convenient method to obtain survey data on sites that do not have a survey presence. Cloud-based processing platforms, including Propeller, are now available and include a wide range of powerful analytic tools that can assist in deriving relevant information from the terrain surveys and allow a simple comparison between design and surveyed surfaces.

During the planning phase, analytical tools within the Propeller platform can be used for a wide range of activities including: derivation of stockpile and resource volumes; development of cross-sections through areas of interest; assessment of local drainage issues and the development of targeted solutions; and the identification of zones of differential settlement. This information can then be utilised to inform conceptual closure designs, develop resource inventories and assess haulage routes.

Terrain surface data can be extracted from Propeller or other processing tools to provide as an input into earthworks modelling software for the development of detailed designs. Once detailed design surfaces have been developed, they can be imported into Propeller to provide a comparison for survey pickups of the reprofiled surface. Volume comparison heat maps and cross-sections may then be utilised to verify where additional earthworks are required to meet the specified design.

During execution works, regular UAV surveys can be utilised to track the performance of works relative to the design surface. Utilising volume
comparison heat maps to identify areas requiring additional cut or fill, combined with cross-sections through these surfaces, provide an effective visual tool to communicate required remedial actions to field personnel.

Following the completion of closure works, UAV surveys are an effective tool for the preparation of as-constructed surveys. The analytical tools within Propeller can extract key information to verify that construction works meet the closure design and associated requirements. The terrain survey provides a useful basis to support post-closure monitoring, especially with consideration to erosion monitoring where cut and fill comparisons between the as-constructed surface and subsequent terrain survey pickups can readily identify where erosion and deposition has occurred.

BIBLIOGRAPHY