

Unmanned Aerial Vehicles: A new tool for landslide risk assessment

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ABSTRACT

The use of Unmanned Aerial Vehicles (UAV), or drones, in landslide risk assessments is 'taking off'. This has been made possible by rapid advances in UAV technology in recent years that have seen the emergence of affordable and sophisticated UAV with payloads capable of carrying high resolution cameras and other remote sensing equipment. UAV provide a quick, safe and potentially superior means of inspecting large scale, remote and difficult to access landforms with significant cost benefits compared to traditional inspection methods. UAV can be mobilised quickly, require minimal human resources and facilitate rapid on-site assessment and hazard identification. Inaccessible and hazardous terrain can be inspected in real-time allowing assessment methodology to be adapted in the field. In addition, data collected by UAV can be used to produce high resolution 3D models in 'client-friendly' visualisation formats as well as accurate ground surface surveys. However, if we embrace the use of UAV, what role is left for geotechnical professionals to play? This paper attempts to answer this question and provides recent case studies to demonstrate the application of UAV technology in landslide risk assessment.

Keywords: unmanned aerial vehicles, drones, landslide risk assessment

1 INTRODUCTION

Rapid advancements in remotely-piloted technology have seen a dramatic increase in the use of unmanned aerial vehicles (UAV) for a wide range of applications. UAV, also known as Remotely Piloted Aircraft (RPA), Unmanned Aerial Systems (UAS), or drones, typically comprise an aircraft system remote-controlled by an operator on the ground or by a pre-programmed autonomous piloting system (Antonio, 2016). UAV come in a variety of forms: multi-rotor systems (Figure 1), unmanned helicopters and fixed wing aircraft.



Figure 1. Quad-rotor mini UAV system carrying a high resolution camera.

Since World War II, UAV were developed for military applications, but owing to their increased accessibility and affordability they are increasingly being used for commercial applications and by amateur enthusiasts. UAV applications are wide-ranging and include: surveying, topographic mapping, condition assessments of buildings and structures (such as bridges and seawalls), monitoring of habitats, vegetation and noxious weeds, firefighting, disaster relief, wildlife surveys, geomorphological studies, geophysical surveys and archaeological site inventories (Nardi, 2009; CASA, 2015; Bell, 2016; Walker 2016). Over the past 5 years, the popularity of multi-rotor UAV

systems has increased due to their widespread commercial availability, relatively low cost, sensor technology, ease of operation, and performance (CASA, 2015; Walker, 2016).

2 OPERATION AND LICENCING

Commercial and recreational use of UAV is currently tightly regulated in most countries; however, legislative changes are being implemented in an attempt to keep up with advances in technology. In Australia, UAV pilots must hold certificates for UAV and radio operation, obtained by passing an examination, and recording at least 5 hours of flight or simulation time in a specified UAV category. In addition, UAV pilots must also be employed by a company holding a UAV Operators Certificate. Operation of UAV is generally limited to visual line of sight. Further restrictions apply for the use of UAV in controlled airspace such as within 3 nautical miles of aerodromes, above 400ft (122m) as well as prohibited or restricted areas (CASA, 2015). Additional flight limitations may also be set by clients and public organisations that may place further restrictions on flight areas and data collection (e.g. UAV may not be operated within a certain distance of active transport corridors such as railways and motorways).

There are currently no international standards for the use of UAV for landslide risk assessment purposes, although attempts have been made to draft standards for the use of micro-UAV for rockfall emergency conditions (Giordan et al., 2015).

3 LANDSLIDE RISK ASSESSMENT APPLICATIONS

Landslide studies typically involve field mapping to characterise the geomorphological conditions and identify hazards. Depending on the scale of the problem, this can take considerable time and rugged terrain can pose access restrictions. Cliffs and steep slopes can be inspected using rope access methods (Hunter et al., 2009), however this also comes at considerable cost and productivity can be slow. Traditionally a number of remote sensing methods have been employed to complement field studies including: photogrammetry (airborne and terrestrial), stereoscopy, and terrestrial and airborne laser scanning (LiDAR). These techniques can be hindered by short timeframes, 'blind spots' / shadowing caused by slope geometry (resulting in unobserved surfaces), surface roughness and reflectivity, and vegetation screening (Neithammer et al., 2012; Lightbody and Wilkinson, 2015). In addition, captured images typically require editing using sophisticated processing software to correct for optical distortion, such as that caused by variations in relief (Niethammer et al., 2011).

Recent studies have reported on the use of UAV for photogrammetric surveys of rockfall instability, rockfall assessments and coastal risk assessments. UAV have also been used for remote sensing and object-oriented mapping of slow-moving landslides. For example, UAV-assisted monitoring of the Super-Sauze landslide in Germany detected horizontal displacements between 7m and 55m over a 17-month interval (Neithammer et al., 2012). UAV-mounted high resolution remote sensing equipment can also be used to collect subsurface data such as soil moisture and medial grain size (Neithammer et al., 2011). More recently, UAV were used to identify and monitor an emergency rockfall situation in Torino, Italy, to assist civil protection agencies with road safety assessments, by providing information on discontinuities in the rock mass and assisting with the determination of scale, dimensions and likely timing of the failure (Giordan et al., 2015).

4 3D MODELLING

Simple applications of UAV involve real time or post viewing of footage and still photographs of the study area. However, for some applications, visualisation of the terrain can be enhanced by creating 3D Digital Surface Models (DSM) from high resolution images. The DSM is created by generating a point cloud reconstruction of the captured area using image photogrammetric processing of multiple overlapping images (Figure 2). Among other factors, the accuracy of the model depends on high quality data inputs (large image overlap, no blur, similar exposure, good quality photographs and accurate ground control points) and the Ground Sampling Distance (GSD), or the distance between two consecutive pixel centres measured on the ground. Ground Control Points (GCPs) can be used to provide a higher degree of accuracy by orienting 3D models in space. The generation of 3D models using photogrammetric image processing software is possible across multiple digital platforms – for example, most smartphones can generate 3D models using freely available software.

Further processing of the point cloud can filter out or remove vegetation and artificial features to isolate the underlying terrain, producing a Digital Terrain Model (DTM). DTM can also be produced by LiDAR survey; however, these techniques can be hindered by shadowing caused by slope geometry and vegetation. UAV-assisted photogrammetric and LiDAR surveys are less prone to these effects as imagery is captured from a variety of angles.

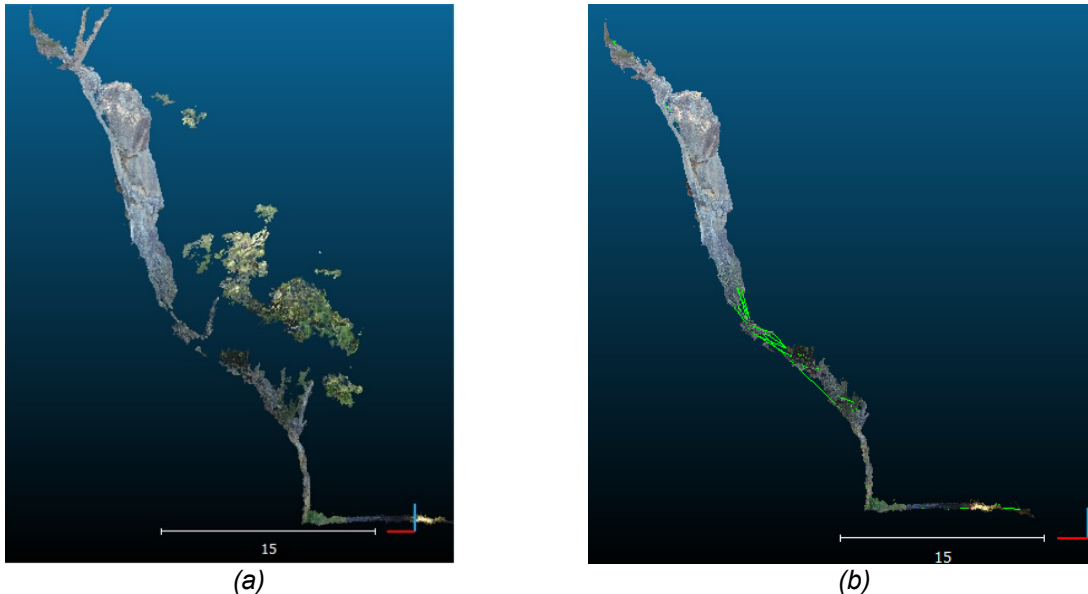


Figure 2. (a) Point cloud produced by UAV photogrammetry (b) Point cloud with vegetation removed.

5 CASE STUDY: RISK ZONING ALONG A RIVERSIDE ESCARPMENT

The authors have used UAV for several landslide risk studies over recent years. These studies primarily involved inspections of large rock cuts, cliffs, and rugged escarpments close to critical infrastructure. We have found UAV offer a rapid and highly flexible means of data acquisition that can be adapted in real time to suit site conditions.

One example involved the use of UAV to investigate a 30km stretch of road constructed along the foot of a sandstone escarpment adjacent to a large river system on the east coast of New South Wales, Australia (Figure 3). The escarpment reaches elevations of up to 140m above road level, comprising sheer cliffs up to 40m high, steep talus slopes and high rock cuts (Figure 4). The road had been subject to rock falls since construction about 100 years ago, with some events resulting in up to 20m³ of debris on the road. The escarpment is heavily forested and largely inaccessible.

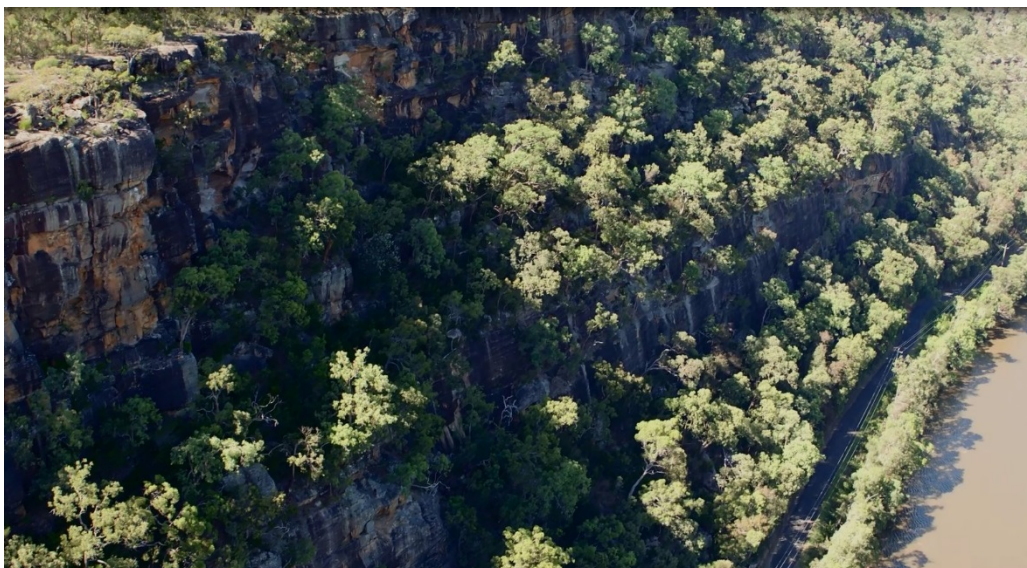


Figure 3. Riverside escarpment captured by UAV.



Figure 4. UAV photo showing cliffs and loose talus 40m above road (road lower right).

Due to the extent of the escarpment, a high-level risk zoning study was required to rank areas of highest risk and allow risk management works to be prioritised. An initial risk assessment was performed to identify high risk sites using traditional methods such as orthophotos, topographic maps and a walkover from road level. Following this preliminary assessment, a detailed risk assessment was complemented by UAV flyover to characterise hazards otherwise not observable from road level. UAV flyovers were performed at several of the high risk sites over one day with a total flying time of about 3.5 hours during which time approximately 4km of escarpment was inspected. The largest site comprised an 800m long, 160m high escarpment captured by a flying time of about 35 minutes. By manoeuvring the UAV to different positions, visual obstructions such as trees and topographic features could readily be overcome. A number of 3D DSM of the high risk sites were created from still photographs taken during the flights (Figure 5). These were provided to the client using on-line viewing applications and were very well received due to the ease of viewing and navigation and enhanced the decision making process.



Figure 5. 3D model of cliffs captured by UAV photogrammetry

As the hazards in this study typically comprised detached boulders (talus) and rock falls associated with cliffs, traditional methods of assessment would have lacked the required resolution or been prohibitively expensive (e.g. helicopters). Even helicopters are unable to fly as close to the landform as the UAV, which was able to fly within about 1m of cliff faces and trees.

6 CASE STUDY: DISCONTINUITY MAPPING TRIAL

6.1 Background

A discontinuity mapping trial was conducted at a former quarry site in a porphyritic, columnar basalt (Figure 6). The purpose of the trial was to investigate the reliability of discontinuity orientations acquired remotely using an UAV, for use in kinematic analyses. The orientation of 20 discontinuities, all of which were joints, were measured using a geological compass. The joints were labelled in the field. Images were captured using a 'DJI Inspire 1' Mini-UAV fitted with a 'DJI X5' digital camera with 16MP resolution capability. Six GCPs were surveyed with a differential GPS to georeference the images.

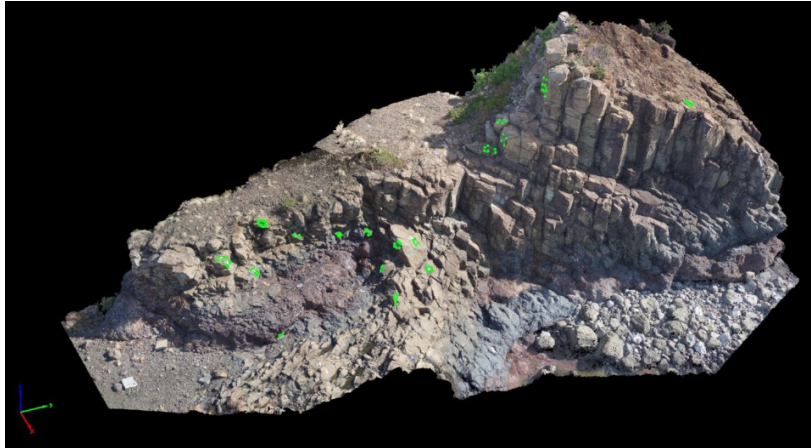


Figure 6. 3D model of case study area captured by UAV

6.2 Discontinuity Mapping

High resolution images captured by the UAV were used to create a point cloud of the study area using photogrammetric processing software. The GSD achieved was approximately 6mm, resulting in a point cloud with a confidence to about 15mm. To account for this variability, a defect surface was drawn by connecting points to form a visual plane of 'best-fit' for each joint plane. The orientation of each plane was then calculated manually using a 3D civil design software package. Field and UAV defect measurements are shown on the stereonets in Figure 7.

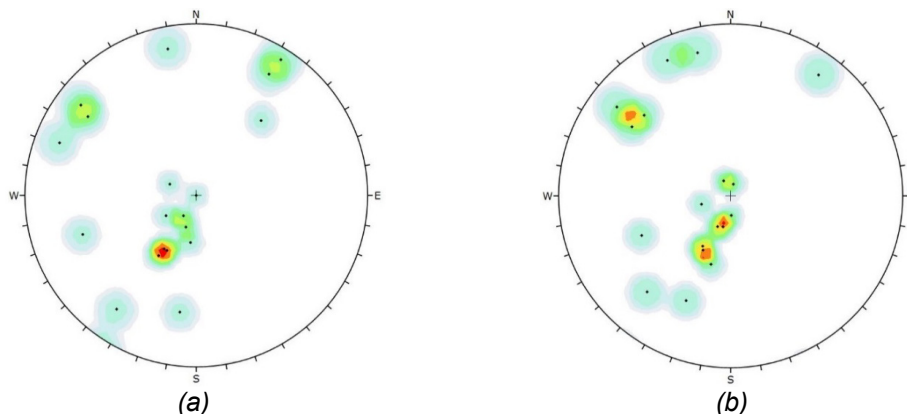


Figure 7. Stereographic projections of defect orientations: (a) poles of direct measurements (b) poles of UAV-measured defect orientations.

UAV measurements were found to vary, on average, by up to 5° in dip and up to 21° in dip direction. Three joints were found to vary by up to 56° in dip direction however this appears to be due to the joints being curved or shallowly dipping. Given that the compass measurements represent the orientation of planes at a point, whereas the 3D model provides a more average representation of the plane, the trial indicates that UAV photogrammetry could be a viable alternative to other methods commonly used to collect defect orientation information such as terrestrial photogrammetry and laser scanning.

7 CONCLUSIONS

The application of UAV to landslide studies reported in the literature has increased significantly over the last 5 years, in response to advances in the technology and increased affordability. One of the greatest benefits of UAV assessments is a significant reduction in field time due to the ability to rapidly survey large areas. UAV imagery allows hazards and features to be viewed from multiple angles in almost any terrain, which is not achievable using any other single method. The flight path can be easily modified in real-time under the guidance of a geotechnical professional, typically without causing disruption to the operation of infrastructure such as roads and railways. The ability to generate accurate 3D photogrammetry models using open source software from photographs taken at multiple angles is a valuable visualisation tool that can be used by geotechnical professionals and clients alike. The discontinuity mapping trial reported in this paper indicates that these models are reasonably accurate and could offer a significantly cheaper alternative to other methods currently used to remotely measure discontinuity orientations on slopes. Due to the high repeatability of this data, such models could be used to detect creep movements in landslides and monitor rock fall history.

We have found that in some circumstances, such as high glare conditions, real time observations of site features can be hampered by reflections on the UAV controller LCD screens. This can result in longer flight times and can place a greater emphasis on review of the data following fieldwork. Advances in virtual reality headsets that allow the user to control the direction of the camera in the field have the potential to overcome this in the near future. UAV use can also be limited by wet weather, strong winds and dense vegetation. We have also experienced significant interference from aggressive birds.

In our experience it is vital that geotechnical professionals direct or control the UAV survey, due to the high possibility of important site features being inadequately captured. However, we anticipate that with time, virtual reality technology may allow an office-based geotechnical professional to observe the flight in real-time and therefore perform their role remotely.

8 ACKNOWLEDGEMENTS

The authors gratefully acknowledge Mr Zack Wasson for his comments on this paper and Diodrone for their UAV operations and photogrammetry processing of the case study data. The authors wish to thank Mr Robert Turner of Coffey Services Australia Pty Ltd and an anonymous reviewer for proof reading this paper and providing valuable comments.

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