Drone Surveys vs. Traditional Manned Aircraft Surveys

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ABSTRACT

Manned aircraft have been capturing aerial imagery for photogrammetry since World War 1, and drones or Remotely Piloted Aircraft (RPA) have been taking aerial images since the mid-2000s. Using different photogrammetric techniques, these aerial images can be processed into spatial data products such as ortho-photography mosaics, Digital Surface Models (DSMs), Digital Terrain Models (DTMs) and vector Computer-Aided Design (CAD) plans. This paper compares drones and manned aircraft for image capture capabilities, discusses the different methodologies to prepare the data and assesses the different data products created from each method. An example quarry site was flown using both a drone and a manned aircraft. Data products such as stockpile volumes, vector mapping and ortho-photo mosaics were prepared and compared. It was found that stockpile volumes are similar in quality from both manned aircraft and drone, but for this site manned aircraft had advantages for the whole site ortho-photo mosaic and vector mapping. Drones and manned aircraft, like all surveying instruments, are just tools to generate the required data. Like all tools, one is not necessarily better than the other for all projects, but the user should determine the most appropriate technology for each project.

KEYWORDS: *Photogrammetry, aerial photography, aerial survey, drones.*

1 INTRODUCTION

Aerial photography from manned aircraft and drones is especially useful in surveying larger areas quicker than possible by land surveying as well as surveying areas that are dangerous to land based surveyors (Wolf, 1974; Aber et al., 2010). Both drone and manned aircraft imagery may produce orthorectified photography and may generate point clouds to allow for the preparation of Digital Surface Models (DSMs, i.e. models of the tops of all features including buildings, plants and trees) and Digital Terrain Models (DTMs, i.e. bare earth models). Stereo vector mapping is only possible from images captured by a manned aircraft.

This paper discusses the image capture capabilities for drones and manned aircraft such as sensor characteristics, geographical and legal limitations, and capture spatial extents. Data preparation for stereo mapping and point clouds is then reviewed. Further, ortho-photography mosaics, elevation models and vector Computer-Aided Design (CAD) models generated from both drones and manned aircraft are analysed.

2 IMAGE CAPTURE CAPABILITIES

2.1 Sensor Characteristics

Manned aircraft generally carry a medium or large format specialised aerial camera system. Often the system is made up of:

- Camera that captures RGB imagery and often near-infrared imagery as well. Examples of medium format cameras are the Leica RCD30 (80 megapixels) and the Phase One iXM-100 (100 megapixels). Examples of large format cameras are the Leica DMC 111 (375 megapixels) and Vexcel UltraCam Condor Mark 1 (190 megapixels).
- Inertial Measurement Unit (IMU) and survey-grade Global Navigation Satellite System (GNSS) receiver that together provide continuous 3D positioning, velocity and attitude determination.
- Gyro-stabilised sensor mount that provides full compensation for perfectly vertical photography.
- Forward-motion compensation for outstanding image quality.

The specialised aerial cameras used in manned aircraft are usually metric cameras that have been factory calibrated. This means that the characteristics of the camera, such as exact lens focal length, radial lens distortion and the position of the principal point in the image coordinate system, are known precisely.

Ground Sample Distance (GSD) is a measure of resolution of the captured images. The GSD is the size of each pixel or the distance between centre points of each sample taken of the ground. A 5 cm GSD means that each pixel will cover approximately 5 cm x 5 cm of ground. Manned aircraft lead the market for imagery with GSD greater than 5 cm.

Drones, also known as Unmanned Aerial Vehicles (UAVs) or Remotely Piloted Aircraft (RPA), usually carry small format uncalibrated cameras and a consumer-grade GNSS for approximate positioning. Some examples of cameras used are DJI Zenmuse X5S (21 megapixels) and senseFly S.O.D.A. (20 megapixels). Some drone configurations include a gimbal to better attempt vertical photography, or a survey-grade GNSS for more accurate positioning. Manned aircraft sensors capture few, lower-resolution, calibrated images, while drones capture many, higher-resolution, uncalibrated images.

2.2 Geographical and Legal Limitations

There are many locations where drones are either not permitted to fly in Australia or where prior authorisation must be obtained from the Civil Aviation Safety Authority (CASA) or the military.

Very broadly, a drone cannot be operated:

- Higher than 120 m (400 ft) above ground level.
- Closer than 30 m to other people or above people at any time or height.
- Closer than 5.5 km to a controlled aerodrome or airfield (usually those with a control tower).
- Anywhere it could harm people or property if the drone should fail and fall.
- In prohibited or restricted airspace.

One method of determining a prohibited or restricted airspace is by using a CASA-verified drone safety app or web application. OpenSky by Wing Aviation LLC (Wing, 2021) is an example of a web application (Figure 1). The orange colour indicates that flying is allowed with conditions at this site. In this case, the drone would be operating within 5.5 km of a non-controlled aerodrome or helicopter landing.

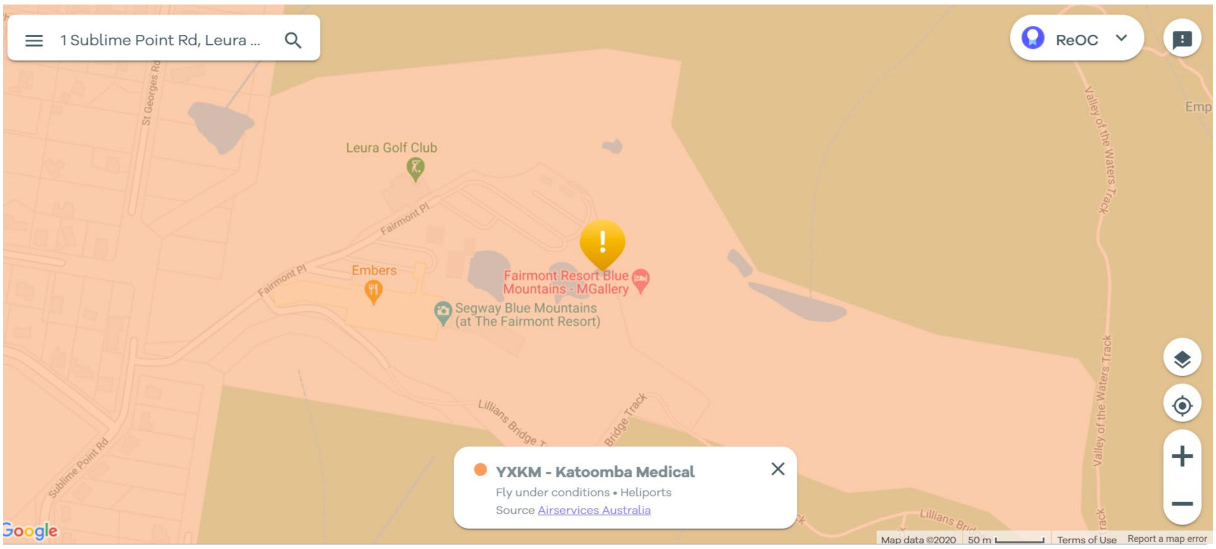

Figure 1: Screenshot from OpenSky (Wing, 2021) for Leura.

There are many areas throughout Australia where prior authorisation is needed. For example, in Sydney OpenSky shows some areas in red where authorisation prior to flying a drone is required (Figure 2).

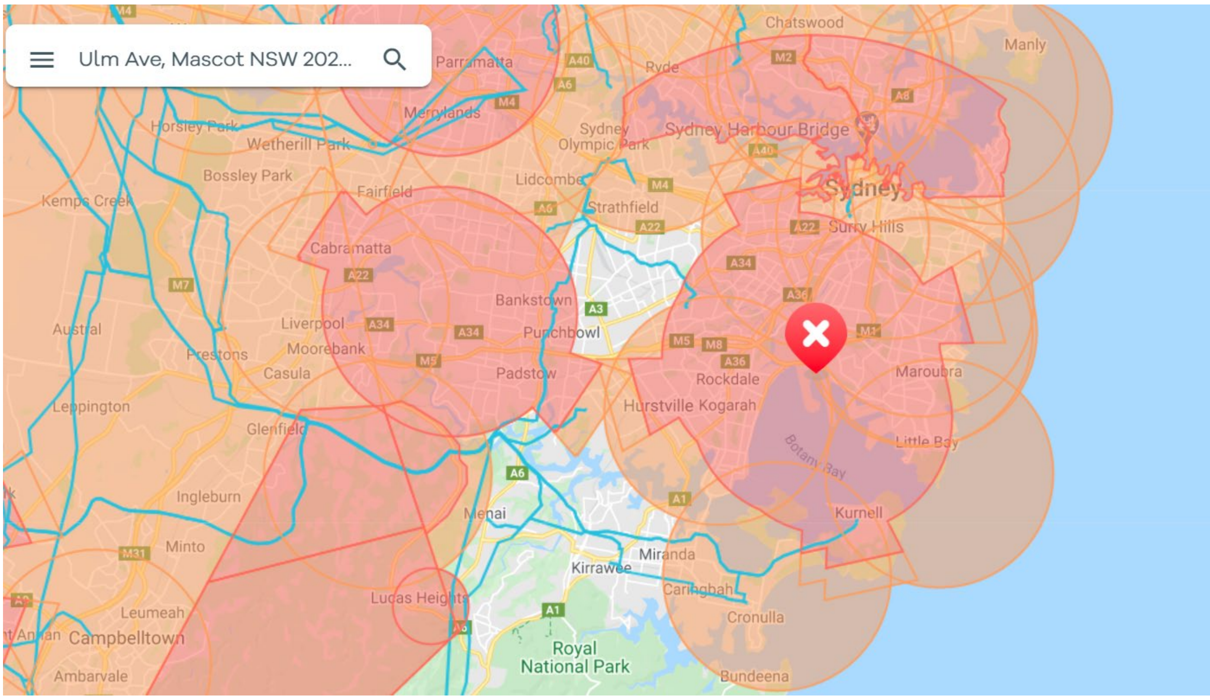

Figure 2: Screenshot from OpenSky (Wing, 2021) for the Sydney area.

Manned aircraft have significantly less restrictions on where they can fly because pilots are in constant communication with air traffic control. However, air traffic control does impose restrictions on when flying can take place in restricted areas.

2.3 Spatial Extents of Capture

The size of the area that can be captured depends to a large extent on the Ground Sample Distance (GSD) required. A higher GSD means that the flying height of the drone or manned aircraft must be lower. A lower flying height means more runs need to be completed to cover the required area of interest.

The amount of image overlap also affects the size of the area able to be captured. Drones use uncalibrated cameras, are not able to guarantee truly vertical photography, and need large image overlaps because of the photogrammetric image processing techniques required for drones (see section 3.2). Commonly a drone survey requires an 85% forward overlap and a 75% side overlap, whereas manned aircraft typically may use a 60% forward overlap and a 30% side overlap when doing stereo mapping.

The sensor footprint is also important in calculating imagery coverage. Table 1 shows some typical image footprint coverages at 5 cm GSD. It should be noted that while 5 cm has been used in this comparison, drones are not permitted to fly higher than 120 m above ground level.

Table 1: Image footprint comparisons (* indicates flying height not permitted with drones).

	Zenmuse X5S (small format)	**Leica RCD30 (medium format)**	**Leica DMC111 (large format)**
Lens focal length	15.4 mm	53 mm	92 mm
Image width	5,280 pixels	10,320 pixels	25,728 pixels
Image height	3,956 pixels	7,752 pixels	14,592 pixels
Flying height	235 m *	510 m	1,179 m
Image footprint width (cross track)	264 m	516 m	1,286 m
Image footprint height (along track)	198 m	387 m	729 m

The speed of travel of the drone or aircraft impact the coverage area, as does the number of batteries available for a drone. For a typical multi-rotor drone project, each battery lasts around 15 minutes, and with each battery typical coverage is around 25 ha. Therefore, in one hour perhaps around 75 ha (0.75 km^2) can be covered.

A fixed-wing drone has longer endurance and flies quicker. The Wingtra fixed wing drone advertises 110 ha (1.1 km^2) coverage in a 1-hour flight (Wingtra, 2021). Medium format cameras may capture around 70 km^2 per hour with a 5 cm GSD, while larger format cameras may cover more than 200 km^2 per hour with a 5 cm GSD.

3 DATA PREPARATION

Both manned aircraft and drone imagery can deliver ortho-photo mosaic, DSM and DTM products using the generated 3D point clouds from the imagery. However, only the medium and large format cameras used in manned aircraft provide suitable imagery that may be used for stereo mapping to provide CAD vectors. Surveyed ground control is essential in both drone and manned imagery to provide quality assurance that processing is delivering results within specifications.

3.1 Stereo Mapping

Stereo digital photogrammetric systems allow two overlapping images (a stereopair) to be viewed so that the user's left eye only sees the left image and the user's right eye only sees the right image. This creates a stereo model and allows the user's brain to receive a continuous 3-dimensional view of the landscape. Therefore, the photogrammetrist can directly collect 3D vector data as polygon, line or point features into a CAD or Geographic Information System (GIS) package. The vector data is classified into separate layers such as trees, fences, drainage lines, break lines, buildings, road kerbs etc. at the time of collection. One workflow that may be used for stereo mapping is shown in Table 2.

Table 2: Stereo mapping workflow.

Step	Task
1	Download raw images, GNSS data and IMU data from the sensor.
2	Download RINEX GNSS data from suitable reference stations.
3	Process IMU and GNSS data to get accurate position and attitude of camera.
4	Combine the processed camera positional data with images to obtain accurate principal point coordinates and attitude of each image.
5	Automatic point matching (extraction of tie points between images). This is the first stage in the aerial triangulation process. Aerial triangulation is used to compute the location and orientation of each image in each block of images.
6	Aerial triangulation (with or without ground control points).
7	Export georeferenced TIFF images.
8	Export Exterior Orientation Parameters (EOP) file.
9	Export point cloud (if required).
10	3D stereo mapping (vector mapping).

Some examples of stereo mapping software systems are Trimble Summit Evolution, Hexagon Image Station and SmartTech uSMART. These systems allow for direct vector mapping into AutoCAD, ArcGIS or MicroStation.

3.2 Point Clouds

Point clouds may be generated from both manned aircraft camera systems and drone systems using image matching techniques. Using statistical methods on overlapping images, homologous image points (i.e. points having the same relative position) are identified and correlated. The quality of this correlation may be affected by dark and shadowed regions and by homogenous smooth surfaces.

Once the corresponding points in overlapping images have been ascertained, the 3D coordinates of these points are computed, and a dataset of irregularly spaced points is generated. One workflow for obtaining point clouds from manned aircraft medium and large format cameras has been presented in Table 2 (up to step 9). An example of a workflow to obtain a point cloud from small format cameras from a drone is shown in Table 3.

Some examples of drone processing software systems are Pix4D Mapper, Bentley ContextCapture and Agisoft.

Table 3: Point cloud generation workflow for drones.

Step	Task
1	Download raw images and Exif (Exchangeable image file format) data containing approximate location from the sensor.
2	Import to a software package such as Pix4D.
3	Convert the ellipsoidal heights from the drone GNSS to the Australian Height Datum.
4	Camera calibration.
5	Add ground photo control point information and measure position within image.
6	Create and export point cloud.

4 SPATIAL DATA PRODUCTS

4.1 Ortho-Photography Mosaics

Orthorectification is the process of removing the effects of image distortion induced by the sensor (camera), viewing perspective, and relief (ground surface) to create an image that is planimetrically correct. The resulting orthorectified photograph, or ortho-photo, has a constant scale meaning that features are represented in their true positions in relation to their ground position.

An orthomosaic is a detailed, accurate photo representation of an area, created out of many photos that have been stitched together and orthorectified. Both manned aircraft imagery and drone imagery may be used to create mosaics. The horizontal accuracy of the mosaic depends on the GSD, the accuracy of the elevation model used, the quality of on-board positioning technology and the number of ground control points.

4.2 Elevation Models

A Digital Elevation Model (DEM) is a 3D representation of terrain. A point cloud generated from overlapping images represents visible surfaces that are closest to the camera and are therefore Digital Surface Models (DSMs) rather than bare-earth Digital Terrain Models (DTMs) where above ground features such as vegetation, buildings, people and vehicles are removed from the model (Figure 3). For most engineering projects, a DSM is not as useful as a DTM. Using elevation models derived from image-produced point clouds requires care.

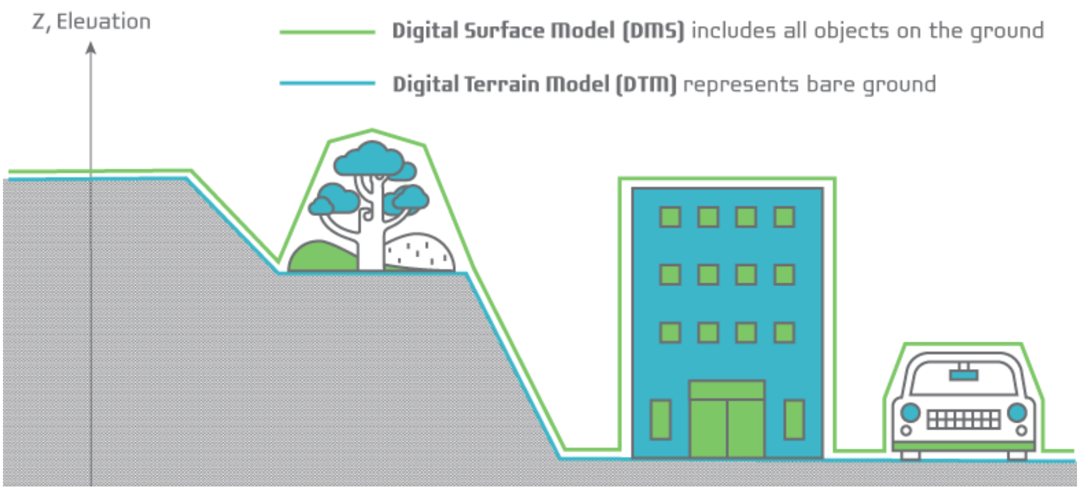

Figure 3: Digital Surface Model (DSM) vs. Digital Terrain Model (DTM).

Smooth homogeneous surfaces may not have enough texture to allow for successful image matching. Road pavements, concrete surfaces and building roofs may generate noisy point clouds. A photogrammetric point cloud gives the appearance that pavements are rutted and wavy due to the noise in the data. Figure 4 shows sections through two building roofs in a quarry, i.e. a roof of a steel building and a curved canopy. Note the large variation in the heights of points defining the surfaces. Figure 5 shows a profile along a suburban road. Due to the homogenous road surface, the noise in the sunny areas is around 0.2 m and in the shadowed areas the noise is around 0.4 m.

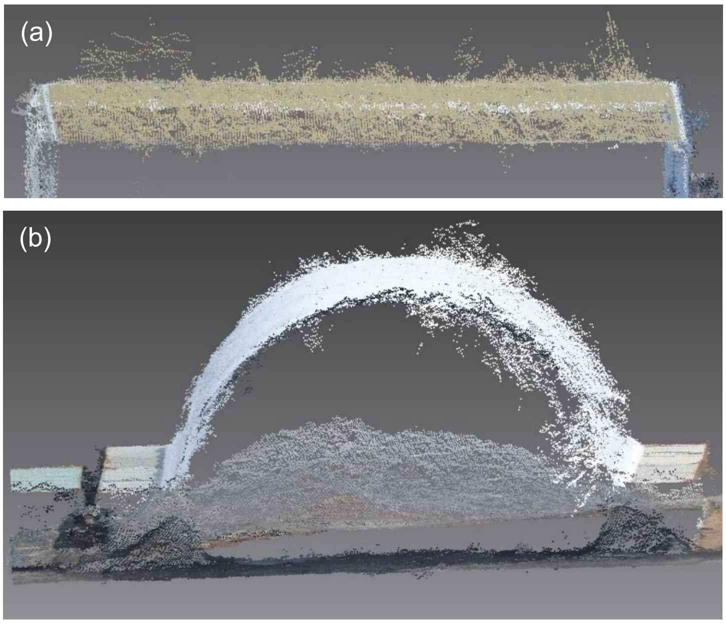

Figure 4: Generated point cloud on homogenous roof surfaces: (a) steel building and (b) curved canopy.

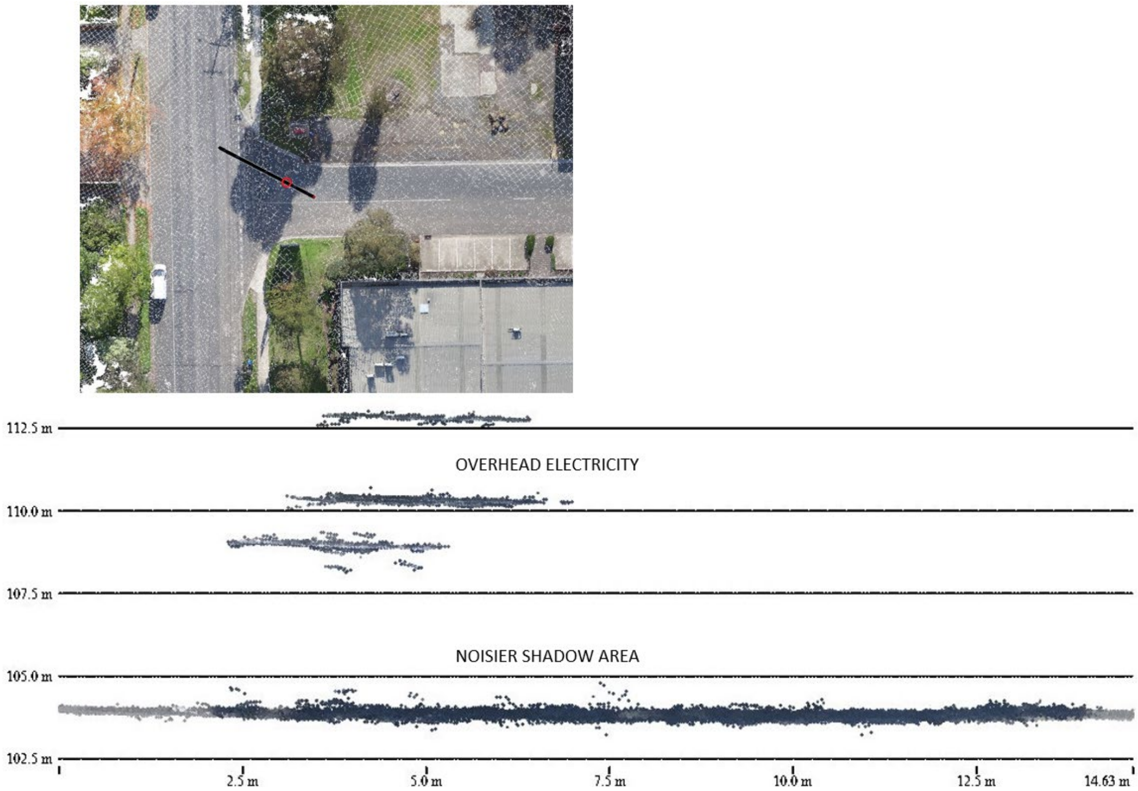

Figure 5: Generated point cloud on homogenous road surface.

In dark and shadowed areas, individual points may have height errors of several metres, and there are often large regions where image pixel matching is not possible, leading to holes in the elevation model. This is especially problematic when defining tops and toes of cliffs and banks. Figure 6 shows a side view of a quarry bank. The grey coloured areas do not have any data due to shadows. Figure 7 shows a side view of a stockpile that was in deep shadow at the time of image capture. The top of the stockpile is approximately 2.5 m lower in the point cloud than the actual top as defined by stereo photogrammetry.

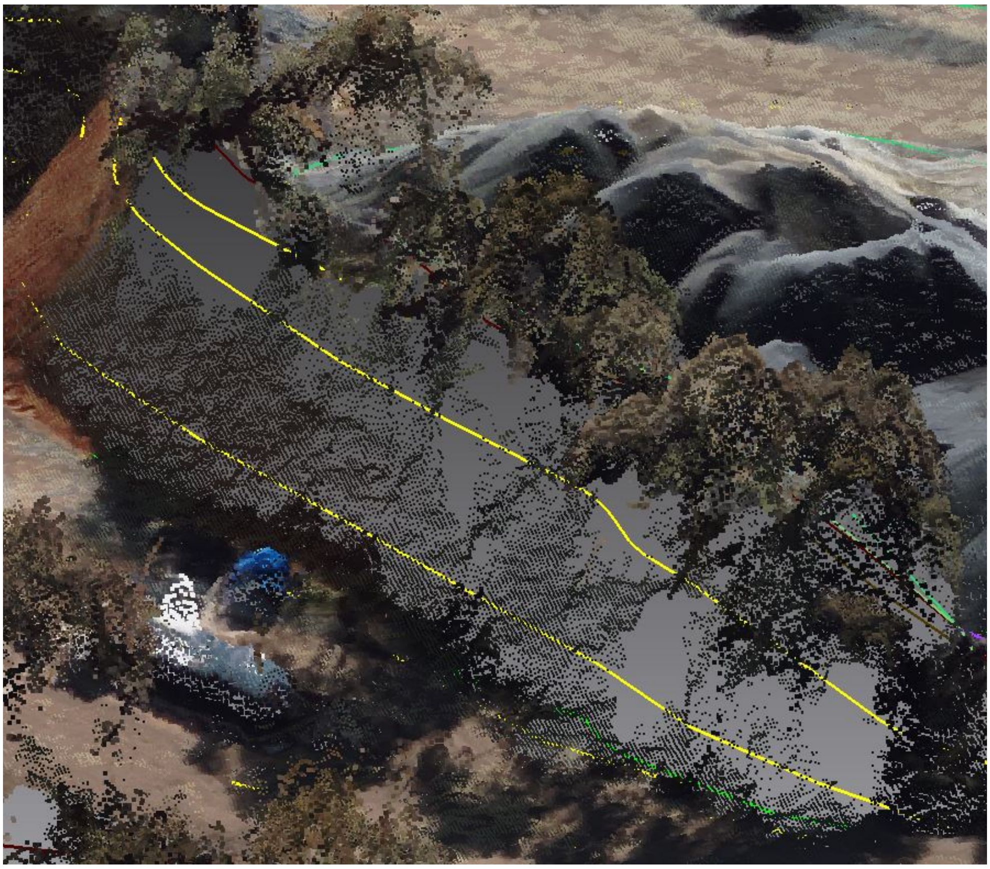

Figure 6: Holes in the point cloud due to shadow (solid grey areas do not contain data, coloured lines represent stereo mapping vector data).

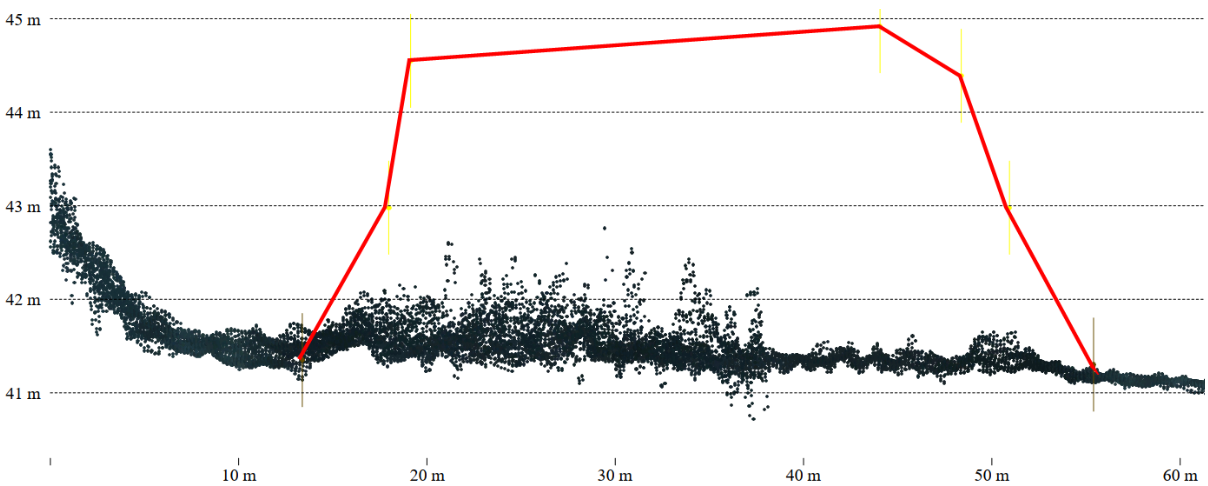

Figure 7: Stockpile in shadow as defined by point clouds (black dots) and as defined by stereo mapping (red line).

To obtain a correct terrain model from an image-generated point cloud, errors due to shadows and above-ground features such as vegetation need to be corrected using manual techniques. Figure 8 shows the difference between a point cloud and vector mapping. Note the toes of banks in shadow areas are too high in the point cloud on the shadow side of the stockpiles.

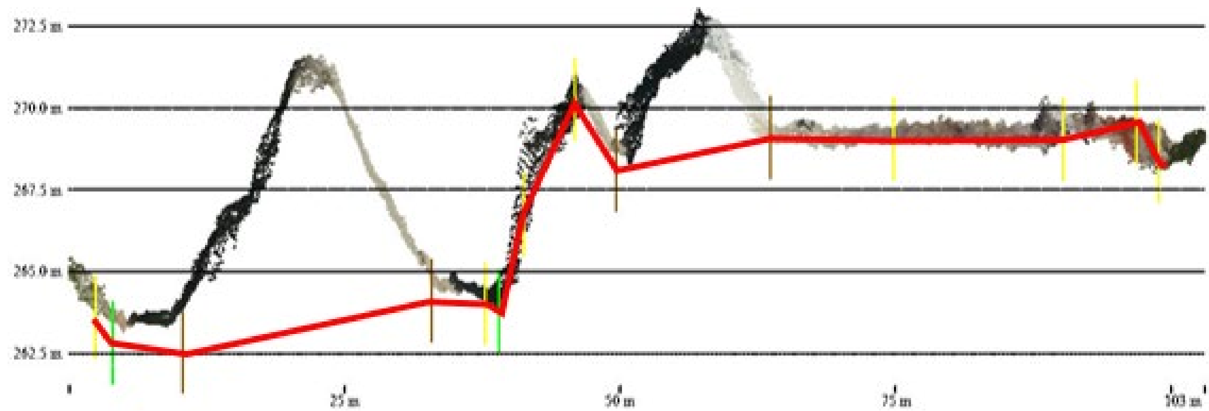

Figure 8: Section through a part of a quarry, showing the difference between the point cloud and vector mapping.

An elevation model generated from stereo mapping is a DTM and similar to a DTM generated from a traditional ground survey. Point-cloud generated elevation models are massive in size, typically many Gigabytes.

4.3 Vector Computer-Aided Design (CAD) Models

Only medium and large format cameras used in manned aircraft provide suitable imagery that may be used for stereo mapping to produce CAD vectors. These vectors are measured directly from the images and do not rely on a point cloud for the height component.

Vectors can be obtained from a point cloud, but the point cloud first needs cleaning and noise removal. After this cleaning, some semi-automatic feature extraction software can be used to attempt extraction of vector strings from a point cloud. Examples of software packages that do this are Topodot and 3D Reshaper. Often the semi-automatic vectors created have many redundant vertices and many false lines that require editing and cleaning up. Vectors may also be manually digitised from the point cloud. Vectors obtained from the point cloud are subject to the same limitations discussed in section 4.2.

5 CONCLUDING REMARKS

This paper has compared drone surveys and manned aircraft surveys in regard to image capture capabilities, data preparation and the data products generated. Manned aircraft sensors capture few, lower-resolution, calibrated images, while drones capture many, higher-resolution, uncalibrated images. Both drone photography and manned aircraft photography can produce orthorectified mosaics and point clouds. Photogrammetrically generated point clouds are limited in vertical accuracy in dark shadows and where homogeneous surfaces are present. Photogrammetrically generated point clouds also require extensive cleaning to generate a bare-earth DTM.

Only the calibrated images obtained from a manned aircraft are suitable for direct stereo vector mapping. Direct stereo vector mapping allows for accurate 3D vectors and for classification of the vectors at the time of mapping.

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