Introduction

This study aims to develop the application of photogrammetry for geological mapping in an open pit mine (Lindsays Pit located in Coolgardie, Western Australia). Several photographic surveys of the same pit were captured under different light conditions using different focal length lenses. Photogrammetry was applied to the photographs to match pixels, construct point clouds using a powerful bundle adjustment algorithm, then converts these point cloud into wireframe and textured three dimensional models. The three dimensional models are georeferenced using a method where UTM coordinates were accurately determined for ground control points, spread across the entire pit, using survey grade GPS.

Digital elevation models and orthorectified images were generated from the photogrammetric models to digitally map the pit. Field work was also carried out to complete pit mapping by conventional methods. The field maps were then compared with the interpretations derived from digital mapping. The digital interpretations were able to identify significantly more structures, especially quartz veins (about 500 as compared with 100 through field mapping), and they were able to obtain data from inaccessible exposures. However, field mapping did detect some important structures not necessarily evident in the digital dataset and field observations were essential in order to be able to identify rock types and verify structural interpretations. It is concluded that this technique is a powerful enhancement to geological mapping in open pit mines, especially because of safety, accessibility and time pressures, however it is best complimented with field observations. Photogrammetry also offers an unprecedented ability to archive and share fundamental geological data.

Methodology

This study aims to test and develop a workflow for photogrammetry-based mapping. There are several criteria affecting the quality of a photogrammetric survey, including the duration to complete the survey due to changing light conditions. This study conducted various experiments to derive the optimal conditions to obtain high quality results. The results were then used to derive digital geological maps before comparing them against and integrating them with field data collected by traditional mapping methods. The series of steps involved from photogrammetric survey to processing are discussed below:

1. Image capturing
2. 3D Modelling
   - 2.1. Point cloud
   - 2.2. Geometric construction
   - 2.3. Texture building
3. Georeferencing
4. Field and digital mapping

The first and most important step to start with is the proper image capturing technique which can cover all areas of the target object. These images are then stitched together and rendered to produce a three dimensional model in three to four steps using Agisoft Photoscan™. This 3D model was georeferenced very accurately to produce orthorectified images and digital elevation models (DEM) in ArcGIS. Field mapping was done alongside to compare it with later digital calculations for measuring accuracy. DEM and orthorectified images were then used for producing digital maps described in results section.

Figure 1 shows three methods for photographing the whole pit. These techniques were able to cover all areas of the pit for construction into a successful model. Several experiments were carried out including light conditions, time of the day, focal length, total time of survey and image rendering settings to finally get a successful 3D model. Figure 2 shows a tilted view of the successful textured and georeferenced 3D model which was later used for further processing. Figure 3 shows field map of all units and accessible structures exposed in Lindsays gold mine.

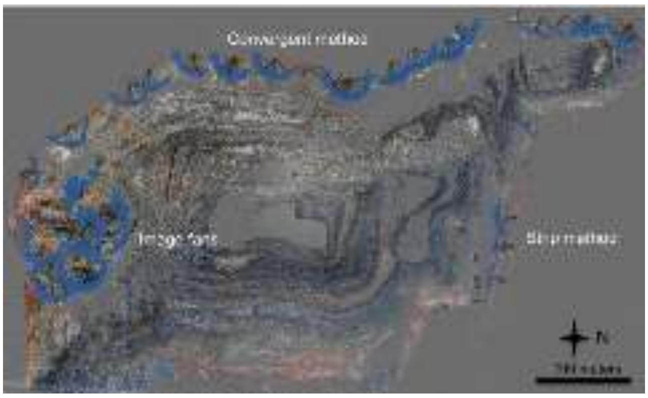

Figure 1. Showing various techniques for image capturing.

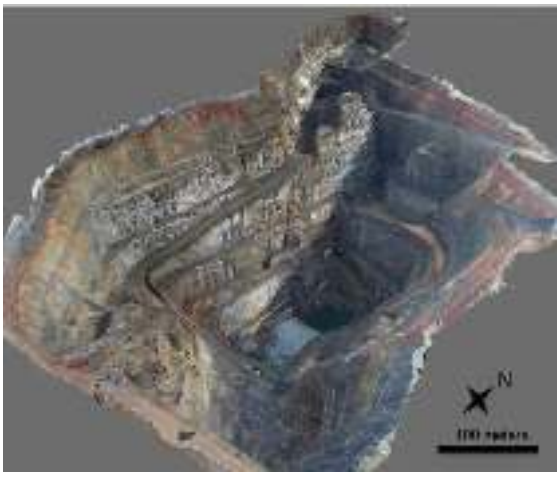

Figure 2. Side view of first successfulmodel facing north east.

Results

After comparison of digital maps with field generated maps, a relatively straight-forward result is that the data acquired by means of digital mapping is far more extensive than that collected by the traditional mapping methods. A great deal of the data marked on the digital maps is from locations of the pit which were inaccessible during field mapping and could not be observed. Nonetheless, certain faults were missed in the digital interpretation due to photographic distortions (e.g. southern end of the pit). Thus a comprehensive interpretation of photogrammetric digital data requires some level of field observation to provide a satisfactory result. There is a great deal of information present to study on digital maps especially from inaccessible parts of the pit due to safety precautions.

Figure 3 (Top). Geological map produced by traditional field mapping techniques.

Figure 4 (Left). Showing the level of detail attained when focused on a certain part of 3D model. Wall captured using 105 mm focal length lens.

An example of the level of detail visible in a 3D model of a shear zone location in pit is shown by figure 4. Digital map of complete map produced in ArcGIS, showing trace of lithologies and structures mapped on georeferenced Orthorectified image of Lindsays pit is presented in figure 5.

Several models were created comprising different level of accuracy and texture detail. The time required to construct a complete georeferenced model depends upon the level of detail needed, number of photographs and type of lens in use. The processing duration required with respect to quality, number of photographs and polygons and type of lens used to construct several 3D models are listed in Table 1.

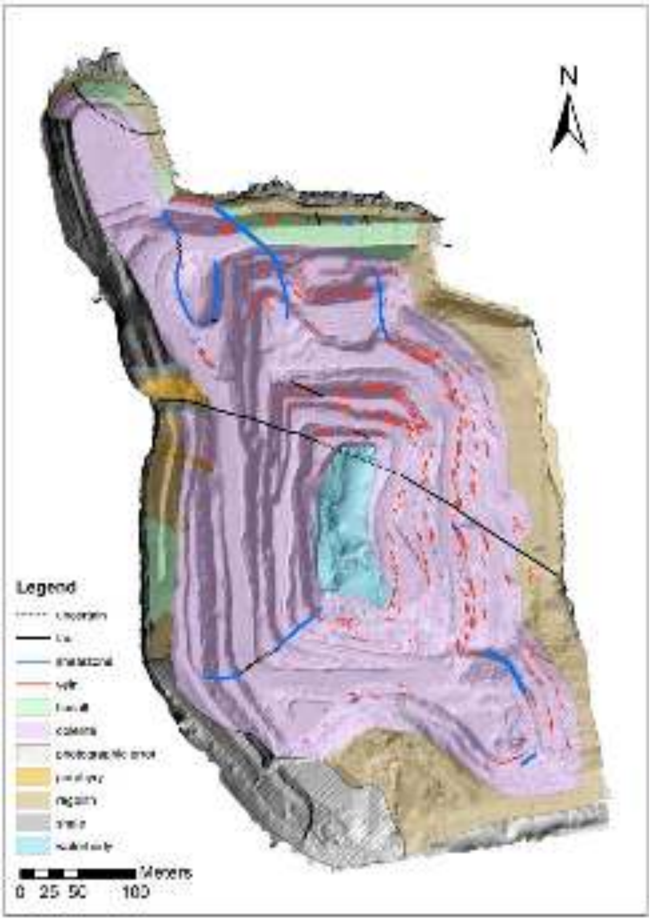

Figure 5. Digitally produced geological map of the pit showing various lithological units and structures.

Table 1. Showing total data processing time required using different parameters.

Focal length (mm)	Number of photographs	Quality of model	Number of Polygons (Approx.)	Total processing time (hours)
28	150-250	High	90000	5-8
		Medium	40000	4-6
50	500-700	High	300000	30-35
		Medium	160000	20-25
		low	50000	10-15
105	600-700	Medium	250000	30-35

Discussion and Conclusions

Digital mapping led to an increase in the number of structures identified and located in Lindsays Pit. For example, approximately 500 quartz veins, shear zones and faults were found digitally as compared with about 100 recorded by conventional field mapping. Similarly, field based mapping was restricted because it is only able to identify structures in limited regions of the pit (e.g. accessible areas along benches and ramps).

The closest digital mapping tool to photogrammetry is laser scanning. However, photogrammetry is a lower cost tool and potentially more useful than laser scanning in many aspects (Koutsoudis, 2013; Westoby, 2012; McQuillan, 2013). Both techniques provide similar results. Favalli (2012) noticed that the comparison of results from both techniques showed less than 1% difference in the models generated by photogrammetry relative to those generated by the widely used LIDaR (laser image detection and ranging) method. Westoby et al. (2012) also compared the results from laser scanning and photogrammetry and showed decimeter-scale vertical accuracy can be achieved using photogrammetry even for sites with complex topography and a range of land-covers.

Thus it can be concluded that photogrammetric digital mapping can be used as a new geological mapping tool, especially for collection of high resolution data not previously available, but field based observations are always important to integrate with the digital data.

Significance and Future work

The models created as a result of photogrammetric processing can be georeferenced to use for digital mapping. They have the potential to track changes in geology as pit walls are mined sequentially. This study has developed an appropriate workflow for digital mapping through photogrammetry, which can be used by the mineral industry for both exploration and mine geology. Large amount of digital data can be stored, shared and archived for future use. Furthermore, it is a low cost tool capable of providing considerable data with little expertise.

One suggestion for future work is to investigate the role of combining UAV and ground based surveys. In our case for open pit mine, terrestrial survey had provided us with good exposure of walls but not the ramps which were parallel to the line of survey. Our main focus was to study pit walls but where it comes to making a perfect 3D model and an error free DEM, it is recommended to use photos from both ground and aerial surveys for 3D construction. Potential survey techniques recommended for more accurate result is shown in Figure 6.

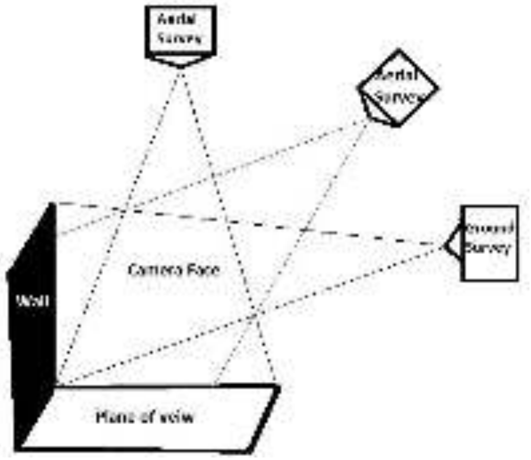

Figure 6. Diagram showing combination of various photographic surveys for better results.

References

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