DISPLACEMENT MONITORING AND VISUALISATION USING TERRESTRIAL PHOTOGRAMMETRY

K.P Soole,
CSIRO Exploration and Mining
G. Poropat
CSIRO Exploration and Mining
K.W. Mills
Strata Control Technology
B. Radloff
Baal Bone Colliery

SUMMARY

Digital photogrammetry has been shown to be an effective and efficient method for visualising and measuring subsidence behaviour of sandstone cliff formations. The system described in this paper provides the capability to measure subsidence movement over areas that are inaccessible to conventional subsidence monitoring techniques. Preliminary comparisons with a more traditional survey technique (total station survey to prisms) has shown mean variations, between the techniques, in vectors of movement of 17 millimetres.

The system described provides visualisation of the sandstone cliff formations through the generation of 3D images which can be rotated to be viewed from any angle. Visualisation provides a powerful tool for measuring, interpreting and understanding the shape, structure and geology. 3D images provide an advantage in tracking vectors of movement of natural features over a large area of inaccessible escarpment.

This paper provides a description of the technique and results obtained to date. The photogrammetry techniques used are based on photogrammetry techniques developed for mine highwall mapping. The results obtained in mapping subsidence exceed expectations for the camera system used. Further development will be undertaken to develop this technique for commercial applications in landform stability monitoring.

Through the generation of a large number of vector movements and visualisation a more complete knowledge and understanding of subsidence behaviour of sandstone cliff formations is derived.

1. INTRODUCTION

Environmental and safety concerns associated with longwall mining under sandstone escarpments at Baal Bone Colliery has provided the incentive to investigate photogrammetry techniques for the measurement of subsidence and to compare the results with total station surveys for a number of control points (Radloff & Mills 2001).

Baal Bone Colliery is located in the Western Coalfield of N.S.W. approximately 30 km north of Lithgow, and 150 km west of Sydney. It is located under sandstone cliffs characteristic of the area.

Baal Bone Colliery has undertaken an ongoing program of subsidence monitoring to better understand the impact of mining subsidence on the stability of sandstone cliff formations. This work is aimed to maximise coal recovery while minimising the impact on these surface features.

Photogrammetry as a measurement tool has the advantage of providing remote measurement over a large area of visible and inaccessible escarpment. The stereo images provide the ability to:

- Locate points of interest on the sandstone formations. Such points of interest include geological horizons, natural joints and mining induced fractures.
- Track the vector movement of individual points identifiable within the images.

A previous attempt to use traditional photogrammetry over Longwall 12 did not provide a sufficient level of interpretive capability (SCT Unpublished Report). The photogrammetry techniques used in this study demonstrate mapping capabilities that are both efficient and effective. These techniques have been developed by CSIRO Exploration and Mining specifically for the mining industry. Successful trials have demonstrated the techniques can be used by non specialist photogrammetry personnel for applications to:

- highwall mapping (geology and geotechnical);
- mapping of soil erosion of spoil and minesite rehabilitation
- volume measurement for in pit surveys.

The application of these techniques to mine subsidence will be further developed as a consequence of the successful mapping trials at Baal Bone.

2. PHOTOGRAMMETRY

Over the last 10 years digital photogrammetry has developed to become a practical tool for general use by non specialised photogrammetrists. The development of digital technologies such as professional digital cameras and powerful personal computers has allowed a major shift in photogrammetry methods. Traditional techniques have relied on manual interpretation of stereo imagery. This required that stereo images be acquired in a form suitable for human stereo vision. They also required dedicated specialised hardware in the form of stereo plotters.

The techniques developed by CSIRO Exploration and Mining require no human capacity for stereo 3D vision. The matching of conjugate points between the left and right images of a stereo pair is performed within software. The matching successfully occurs with low geometrical constraints (compared to traditional requirements). Images can be at different scales, can be converging or diverging with up to 90% overlap between the left and right images. The software is able to successfully match images with relatively large differences in perspective distortion. Manual interpretation functionality is provided for areas of interest where perspective distortion is too great for the software to provide a reasonable solution.

Extraction of 3D data using photogrammetry requires a knowledge of camera location, orientation, lens focal length and image size. In addition the system needs to be calibrated to remove or minimise system errors such as lens distortion.

Traditional techniques have required the placement of at least 6 ground control points (GCPs) in the stereo coverage. These control points are used to calculate camera position and orientations of tilt, azimuth and elevation.

The system developed by CSIRO Exploration and Mining, relies on the direct measurement of camera position and one GCP in the field of view. The GCP is used to calculate the camera azimuth and elevation. The tilt is constrained to zero by levelling the camera on a tripod.

Professional quality fixed focal length lenses are used (zoom lenses are not recommended as the lens parameters will vary in an uncontrolled manner). The lenses are calibrated for distortion and the original images resampled to remove distortion prior to photogrammetry mapping.

Current research is developing techniques to eliminate the requirement for any control points in the field of view. This capability can currently be achieved by mounting the camera on a theodolite and directly measuring the camera orientation parameters.

Mine subsidence requires the measurement of vectors of movement over a period of time. For this application permanent camera positions should be established and positions surveyed each time the photogrammetry survey is performed. Ideally the camera positions should be placed in areas not subject to subsidence.

3. PHOTOGRAMMETRY TRIALS AT BAAL BONE COLLIERY

Longwall 20 commenced mining under an area of sandstone cliff formations up to 60 m high. A convenient vantage point on cliff formations on the other side of a valley and remote from mining provided a good location for establishing permanent camera locations. The distance from the camera stations to the escarpment varied from 200 metres to 300 metres. Camera stations were established approximately 40 metres apart.

A conventional survey using a combination of GPS and theodolite survey methods was used to survey the camera stations and 6 GCPs on the escarpment to be monitored. The GCPs were comprised of small reflective prisms cemented to the sandstone escarpment. The prisms were centred on 300 mm diameter white circles painted on the escarpment. The white circles provided easy identification of the prisms within the photographs. The GCPs were located generally in accessible positions near the top of the cliff (Figure 1).

A Nikon D1 digital camera with a 60 mm lens was used for the photography. This camera contains a 2000 by 1312 array of sensors 11.8 microns in size. The ground resolution of each pixel for this system at 200 m is 40 mm x 40 mm and at 300 m is 60 mm x 60 mm.

The camera was mounted on a theodolite and the azimuth and elevation angles measured for each image exposure. This allowed replication of the orientation parameters each time a monitoring exercise was performed. Replication of orientation and position also replicated systematic errors within the system thereby nullifying these errors when calculating the vectors of movement.

3.1 Results

Photogrammetry and theodolite surveys were acquired before mining started and after subsidence was essentially complete. The terrain model generated provides the ability to determine the location of geological horizons, natural joints and mining induced fractures as well as the cliff formation itself. The positional accuracy achieved is better than 0.5 m in easting and northing and 0.1 m in height. Substantial improvements to positional accuracy are expected with the use of a longer focal length lens and higher resolution digital cameras.

Calculations were made of vector movement of subsidence on the ground control points. Comparisons between the photogrammetry survey and the theodolite survey (Table 1) show variations of vector lengths between –33 mm and +11 mm (mean –17 mm). This represents a variation of less than 1 pixel difference, where the resolution of 1 pixel is between 40 mm and 60 mm. Figure 1 shows the location of the 6 control points used in the comparison.

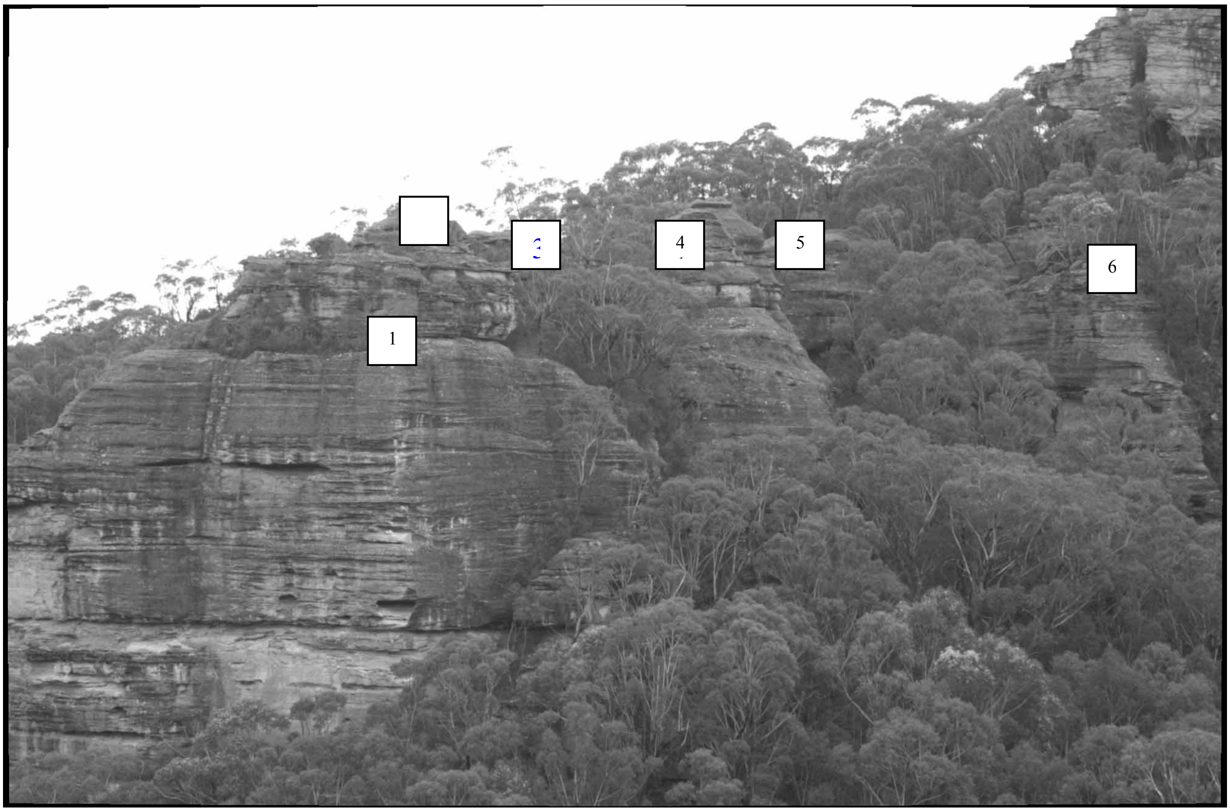

Figure 1: Surveyed control points used to compare results of photogrammetry survey and total station theodolite survey.

Table 1: Comparison of Vector Calculations for 6 GCPs as derived from photogrammetry and theodolite observations.

Photogrammetry Vectors			
GCP	**Azimuth (Degree)**	**Elevation (Degrees)**	**Length (Metres)**
1	**81.1211**	**-54.7022**	**1.704**
2	**82.4692**	**-54.7937**	**1.767**
3	**83.6016**	**-55.1562**	**1.712**
4	**79.3917**	**-55.549**	**1.642**
5	**83.8937**	**-37.1966**	**1.664**
6	**80.3867**	**-22.9476**	**1.288**
Theodolite Survey Vectors			
GCP	**Azimut h**	**Elevation**	**Length**
1	**79.9048**	**-53.7595**	**1.737**
2	**82.1226**	**-53.0002**	**1.758**
3	**82.1660**	**-54.6445**	**1.750**
4	**76.4253**	**-54.134**	**1.664**
5	**82.5284**	**-39.6576**	**1.678**
6	**83.0219**	**-26.1569**	**1.293**

Table 2: Distances from camera to GCPs

	Camera Stations	
GCP	Left (m)	Right (m)
1	217.54	207.43
2	236.47	225.65
3	248.17	235.92
4	252.02	237.99
5	277.86	261.87
6	262.95	243.69

4 VISUALISATION

The 3D images produced from photogrammetry provide a powerful tool for manual interpretation of the geology, geotechnical features, land form and changes. Software developed by CSIRO (Sirojoint) allows the 3D mapping of features directly from 2D images. The images have a cloud of data points (easting, northing and height) typically associated with a visual pixel every 5 pixel x 5 pixels within the image (Figure 2).

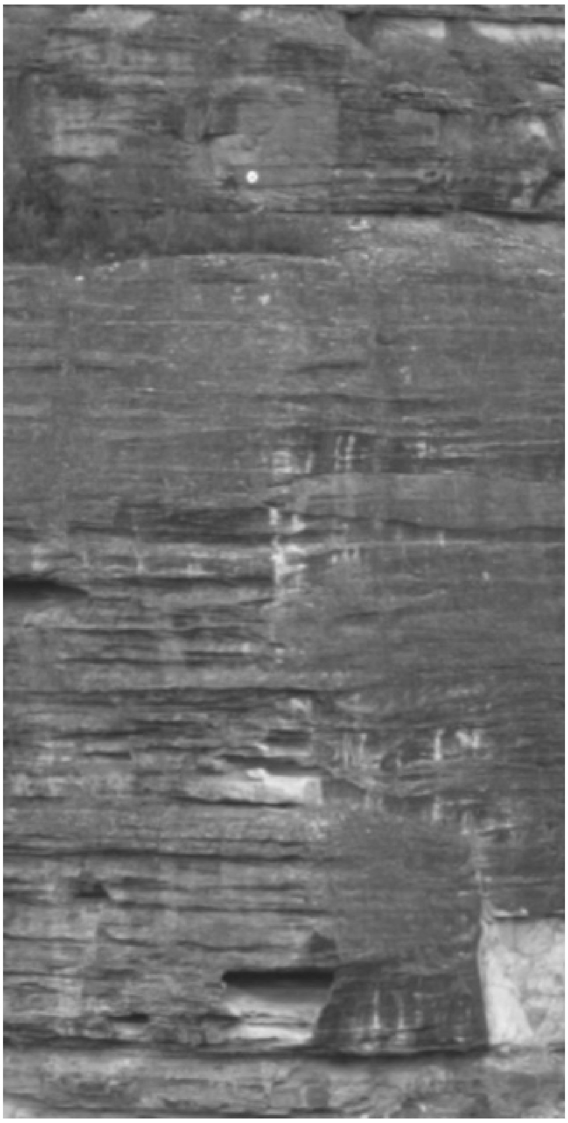

Figure 2: 2D Image Front View

The images can be displayed draped over the cloud of data points. This provides a powerful capability for interpreting shape, structure and geology as shown in Figure 3.

The advantages of using images draped over the 3D cloud of data points becomes very apparent when physical changes occur such as fracturing of the rock (Figure 4). These changes are not apparent if the only data set is the coordinate data in the point cloud. With the photogrammetry derived 3D images it is possible to see the changes and to make measurements of the amount of change.

Visualisation is a powerful communication tool. 3D images present much detail that is not found within numerical and symbolic data or 2D images. The communication of detail over a wide range of the community is much more effective with 3D images. Applications include communication of cliff geometries and subsidence behaviour to technical, management and lay people.

Within the mining industry images are joined to produce large mosaics (Figure 5). These are used for communication within and between different sections of the work force. In particular issues associated with landform stability are effectively and efficiently communicated with images.

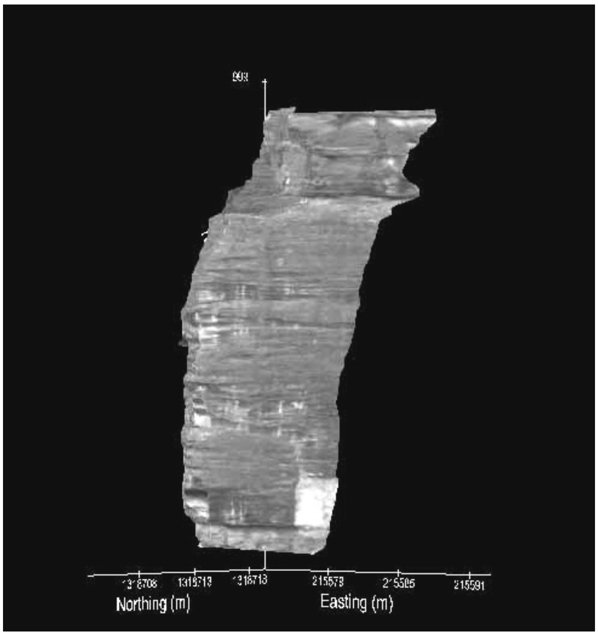

Figure 3. 3D Image side view

Visualisation work undertaken by Guy le Blanc Smith and his associates at CSIRO Exploration and Mining, have taken 3D images and integrated these with other mine data sets to allow visual correlations between data sets, data validation and improved interpretation of mine data (Le Blanc Smith et al 2000).

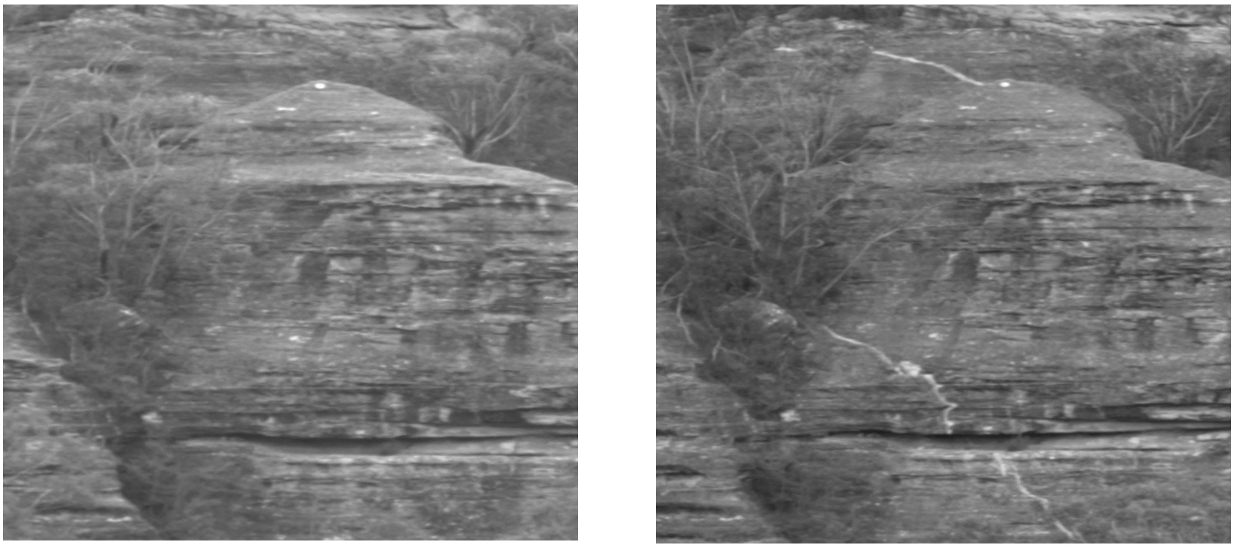

Figure 4. Pre fracture image (left) and post fracture image (right). Note the white scars showing the fractures in the right image. This data is difficult to map other than using photogrammetry.

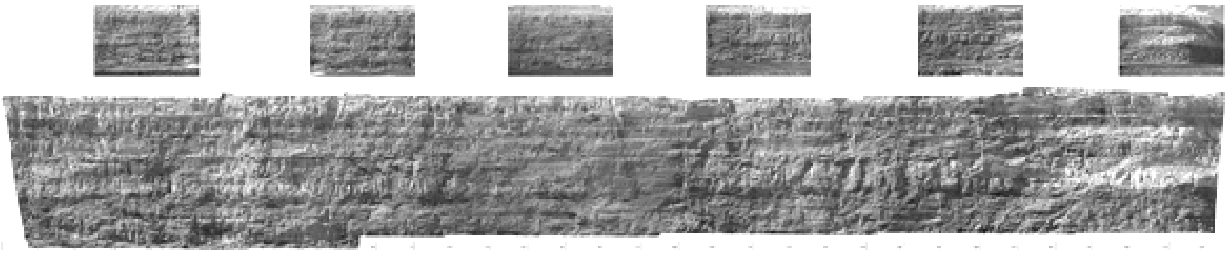

Figure 5: Section of 1.4 km highwall mosaic created from photogrammetry

5. CONCLUSIONS

This project has demonstrated the feasibility of obtaining measurements of movement over large inaccessible areas (in this case a remote sandstone cliff formation). Results achieved, using the photogrammetry system developed by CSIRO Exploration and Mining, show sub pixel measurement with mean variations in the measured vector lengths of 17 mm.

Visualisation of 3D images provides textural information for determining location and comparing movement of points over a wide area. It has the added benefit of allowing the mapping of shape, geology, geotechnical features and provides a visual record of the site before and after subsidence has occurred. In cases where large failure has occurred it is possible to map the extent and shape of failure and derive the mechanism for failure. The 3D images provide a powerful communication tool to the general community, and professionals within the industry.

Further research and development will be performed to expand the technique and develop the tools required to automatically calculate the vectors of movement of a greater number of points over large areas.

6. REFERENCES

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