Seeking Historical Ground Deformations from Archival Aerial Photography

Robert PAQUET and Harvey MITCHELL, Australia

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SUMMARY

Attempts to monitor ground subsidence caused by mining can mean that past records of the ground surface are wanted, but of course they are not always available. Historical aerial photographs present themselves as a source of ground surface data waiting to be processed. The effect of longwall mining on surface subsidence is essential in the prediction of this effect for future longwalls. This assessment is primarily empirical as it is difficult to account for the unknown geological variables and their effect on the ground surface. The aim of the prediction of ground subsidence due to mining is to protect the integrity of natural features and man-made infrastructure on the surface. Traditionally subsidence is measured and monitored by surveyors on foot. The surveys are of high accuracy, observing subsidence along the centre-line and cross-lines of the longwalls, and along lines of local interest (roads, etc). It is felt that 3D data observed remotely could bring further light on the shape of the subsidence trough, although the same level of accuracy as that observed by surveyors on foot would not be attained. Archival photography could be used to assess the subsidence trough where subsidence data does not exist. Aerial photographs taken at three epochs over two decades over a coal mine south of Newcastle have been examined to see whether any useful ground change information can be gleaned from them. The photography, having not been taken for this purpose, is not ideal, and various detective tasks have been undertaken in an effort to detect change in landform in the face of the various difficulties: the scale of the photography is not as large as desirable; coverage of individual images is inconsistent from one epoch to another; camera calibration information has not been available; and control points have been hard to place when the cultural and natural features have changed. Moreover, control points can be influenced by the deformation being studied. Comparing surfaces without using control is a novel approach. It can be affected by inappropriate surface models across areas of water and wide areas of ever-changing vegetation. Experiences in the matching of surface models without control points and the lessons learnt from it will be reported.

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1. BACKGROUND

The investigation concerns the detection of ground subsidence due to the longwall method of underground coal mining. Longwall coal mining is widely used in Australia. Coal mining is a significant industry for the economy of the state of New South Wales in which the study is located. Indeed, coal mining is so extensive in the valley of the Hunter River as well as further afield in the hinterland, that Newcastle, at the mouth of the Hunter River, is currently the largest coal exporting port in the world. In the latter half of last century, the coal mining industry turned towards longwall mining methods (where appropriate), whose characteristic is a full extraction of the coal within a panel. The panels can measure in excess of three kilometres in length by up to more than 400m in width (typically 200-350m). The longwall panels are separated by large pillars which support the roof above access and ventilation roadways. A consequence of the method is that the overburden above the longwall mine collapses almost immediately behind the extraction face. Evidence of subsidence is likely to be found at the surface as the overburden fills up the mining void. The extent of the subsidence effects is function of the extraction thickness, the overburden nature and thickness, and the mine geometry. This obviously can have important consequences for the surface infrastructure, notably buildings, roads, railway lines, subterranean cables and pipelines. This study was initiated by the subsidence group of Industry and Investment NSW, in collaboration with the surveying section of the University of Newcastle, NSW. The aim of the project was educational, providing tertiary students with a final year project subject. It also serves the purpose of examining the feasibility of using archival photogrammetric data to revisit past land deformation events due to mining.

2. OPTIONS FOR DEFORMATION DETECTION

Subsidence is easily measured and monitored by surveyors on foot. Those surveys are typically of high accuracy, with emphasis on the observing of subsidence along the centre-line and cross-lines of the longwalls, and along lines of local interest, such as roads. It is felt that 3D data observed remotely could bring further light on the shape of the subsidence trough, although the same level of accuracy as that observed by surveyors on foot would not be attained. Archival photography could be used to assess the subsidence trough where subsidence data does not exist. However, the determination of landform subsidence from historical aerial photography has a number of characteristics that make it problematical. Because the photography is historical, permanent visible ground markers which might be monitored are not available. Although ordinary ground points may reveal any subsidence, it is felt that 3D data observed remotely could bring further light on the broader shape of the subsidence trough, even though the same level of accuracy as that observed by surveyors on foot would not be attained. Archival photography could be used to assess the subsidence trough in those cases where subsidence data does not exist. To this end, DEMs can be created from aerial photography to enable change in surface shape to be detected by a simple comparison of topographies.

Control points are normally used in DEM creation, of course, to place surface models on a common datum, but placing control for historical photographs can be difficult when the ground features in terms of both vegetation and visible infrastructure have changed. More importantly, ground control is expensive, and the resources required for placing precise control may be hard to justify when the likelihood of detecting any ground subsidence is low. If the aerial photography technique is to be used to monitor a large number of mines, the cost may be unjustifiable. Only in the event of possible expensive consequences of subsidence will the cost of control be worth bearing.

For these reasons, a different approach, which is somewhat novel and which is the real subject of this investigation, has been adopted here: the digital elevation models from the same areas are placed only approximately in the same datum, but then compared by a surface matching technique. The surface matching technique rotates and re-positions one surface relative to another, until the position of closest fit is obtained where surface separations are minimised. It uses a least squares technique based on conformal coordinate transformations.

The residual differences between the two aligned models can be examined to see whether any ground subsidence is apparent. In practice, the appropriate stereo-pairs of photographs may be firstly controlled inexactly by minimal and/or approximate, low cost (e.g. kinetic GPS) ground survey. Further details of the theory are given by various writers on the topic, but the writers' approach is described by Pâquet (2004) and by Mitchell and Chadwick (1999).

The analysis of the residuals requires that we recognise that there are three distinct causes of differences between the surface models:

- The noise in the DEMs, due to the non-systematic errors, primarily the errors occurring in image matching at the DEM creation stage.

- Changes other than subsidence, in vegetation and cultural features, which is especially likely for roads and buildings due to mining work in sites where subsidence is being studied. In this category we can also include errors which can occur matching over water.

- The subsidence under investigation, which may be small, even of a magnitude which is similar to the noise level, especially on historical photography which is not purposely taken for subsidence detection and which is of lower historical quality. It must be emphasised that the subsidence is presumably regional rather than randomly distributed.

The approach being followed here to cope with noise is firstly to provide a quantified estimate of the level of noise by matching two elevation models created from different stereo-pairs from the same era. A poorer level of precision for the DEM matching from different epochs will be taken as a sign of significant differences between the DEMs, perhaps due to subsidence, but also perhaps due to the vegetation and cultural changes.

To cope with changes due to vegetation, building and the existence of water bodies, sources of the apparent change which may actually be due to the vegetation and cultural features may be studied by examining them in conjunction with features which are visible on the aerial photography.

3. CASE STUDY

3.1 Background

The coal mine which has been used as an example for this work is located at Wyee about 80 km south of Newcastle. The mine could be divided into two separate underground longwall workings, shown as quadrilaterals on Figure 1.

Figure 1: The two long-wall coal mines being studied in his investigation, in the vicinity of Wyee. Diagram prepared by Thomas Noirot.

Aerial photography for 1981, 1990 and 1996 exists for the area of the mine. Details of the available photography are shown in Table I. Figure 2 shows the coverage provided by stereo-pairs from 1990. The photography, having not been taken for this purpose, is not ideal: the scale of the photography is not large; coverage of individual images is inconsistent from one epoch to another; camera calibration information has not been available; and control points have been hard to place when the cultural and natural features have changed.

Table 1: Archival aerial photography coverage of the Wyee coal mine.

Epoch	**1981**	**1990**	**1996**
Run Orientation	North – South	East – West, West - East	East - West, West - East
Photo Scale	1/25000	1/16000	1/16000
Focal Length (mm)	151.44	304.49	152.74
Camera	Wild RC10	Wild RC10	Wild RC30
Negative Film Size	-	230mm × 230mm	220mm × 220mm

Figure 2: Stereo-pair coverage from 1990 for the mine area.

Of the two areas shown in Figure 1, the coverage offered by the stereo-pairs was better for the northern panels than for the southern ones, and it was decided that this case study would cover the former mine area. The longwall mining in the northern area was completed in 1993, so there was the prospect that the aerial photography from 1990 and 1996 would reveal any surface subsidence. Digital elevation models from stereo-pairs covering the northern mine were created for both epochs, 1990 and 1996, using the VirtuoZo digital photogrammetry software package (version 5.X) (Supresoft, 2010). DEM creation requires that an absolute orientation has been undertaken to provide scale location and orientation to the ground coordinate information, so basic control was provided by a number of points which were not placed in ideal positions, but which instead were placed in accessible positions which did not require access to private property. Control was fixed using kinetic GPS to about 1 metre accuracy. Positions are shown on Figure 1. The control was regarded as cheap and adequate for this purpose, even if not acceptable for more conventional photogrammetry at higher accuracy.

4. RESULTS

4.1 Noise estimation

The DEMs of the same area which were used to estimate the noise level are shown in Figures 3 to 5. Figure 3 shows the DEM created from photographs numbered 90 and 91 of 1996, while Figure 4 shows the adjacent DEM from photographs 91 and 92, also of 1996.

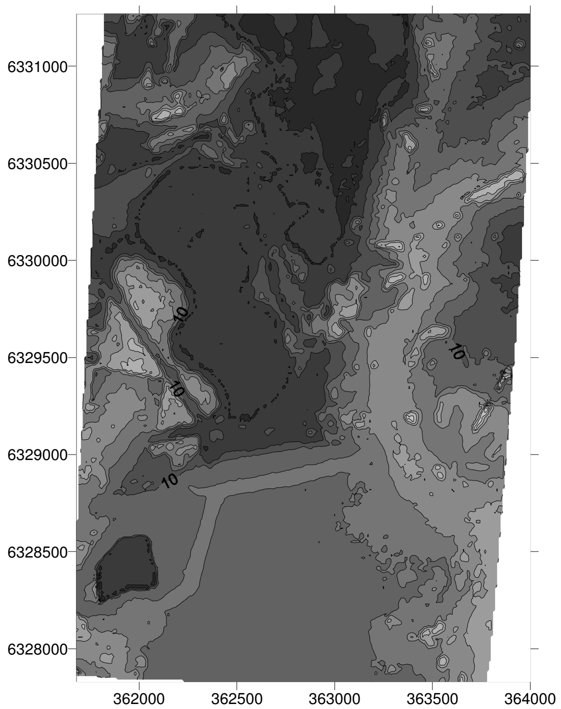


Figure 3: DEM from photographs 90 and 91 of 1996, with 5m contours. The area can be recognised in the north western area shown on the aerial photography in Figure 2.

The surface match, when three shift parameters were sought, gave shifts as follows:

X	-2.66 m
Y	-2.07 m
Z	0.45 m

The r.m.s. of all separations (in the Z direction) was 0.92 m. The mean absolute value of all residuals was 0.50 m. The distribution of surface differences is shown in Figure 5. (When more than the three shift parameters were sought, the surface match was too weak to converge because of the weakness in determining rotation parameters from surface which are essentially plane).

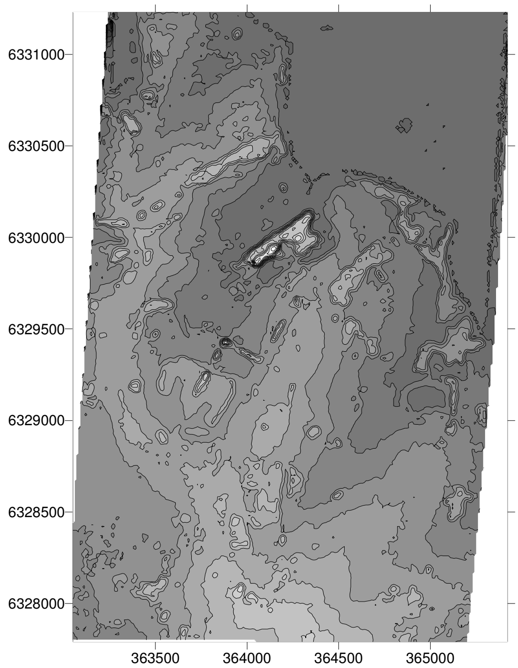


Figure 4: DEM from photographs 91 and 92 of 1996, with 2m contours. The area used in surface matching to estimate noise is shown with contour lines.

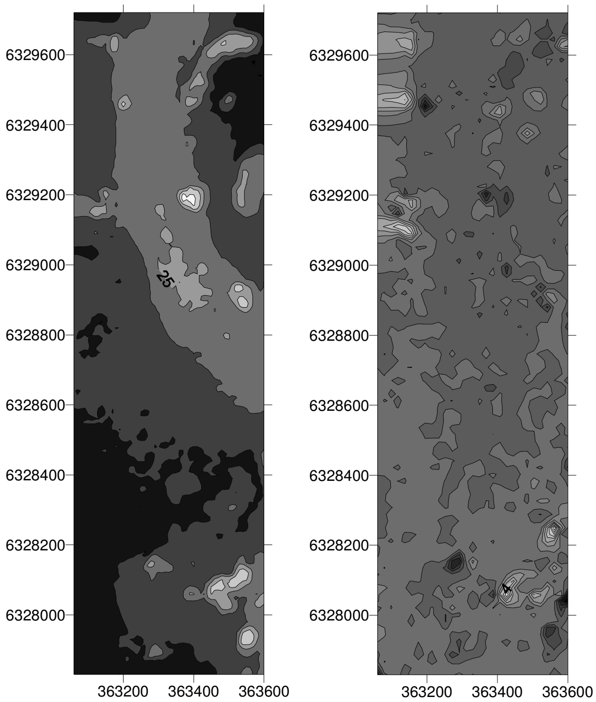


Figure 5: Left: The matched area from the DEM of 1996, as extracted from Figure 3, with 5 m contours. Right: the differences between the two DEMs, with 1 m contours.

4.2 Matching of DEMs from 1990 and 1996

The DEM created from photographs 118-119 of 1990, were matched with the DEM created from photographs 91 and 92 of 1996, which are both shown in Figure 6.

A small section of the overlap area was used in the matching to minimise the use of vegetated areas, which were subject to change, and water areas where contours were unlikely to be valid. Again, the surface match when more than the three shift parameters were sought was too weak to converge. The surface match when three shift parameters were sought gave shifts as follows:

X	5.37 m
Y	3.73 m
Z	-0.23 m

The r.m.s. of all separations (in the Z direction) was 1.81 m. The mean absolute value of all residuals was 1.08 m. The distribution of surface differences is shown in Figure 7, superimposed on a DEM to indicate the location of the match area.

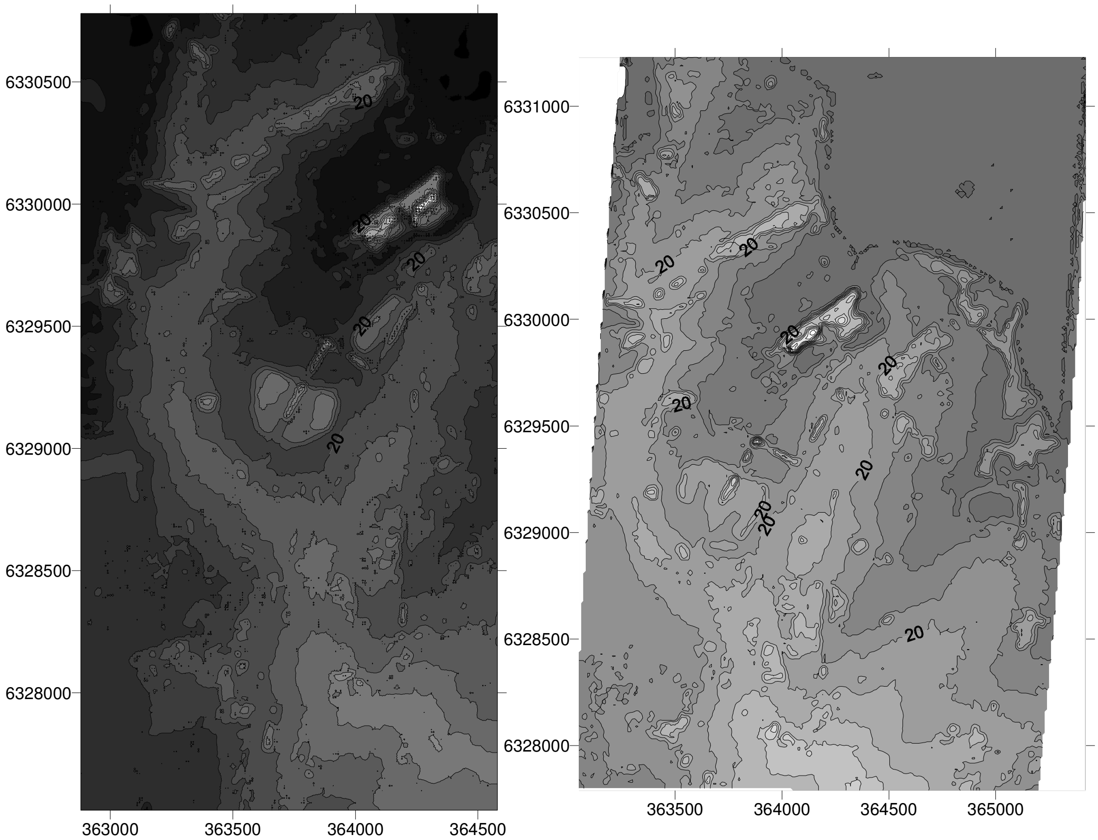


Figure 6: Left: DEM created from photographs 118-119 of 1990; Right: DEM created from photographs 91 and 92 of 1996.

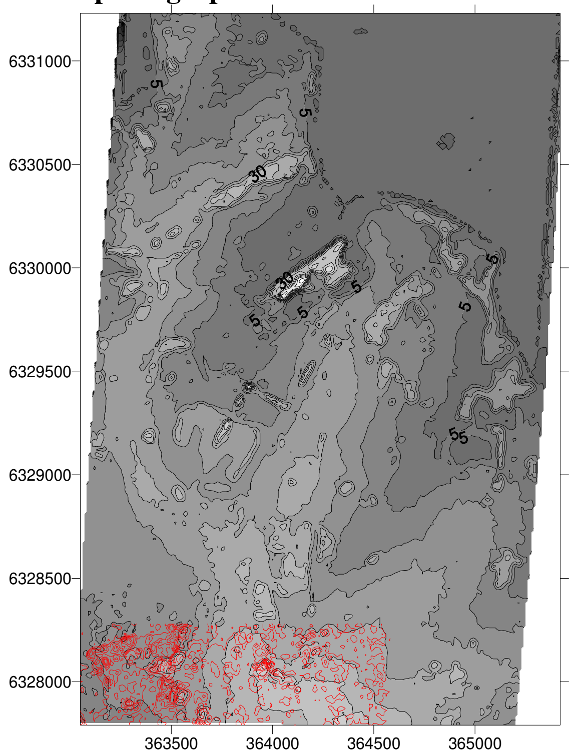


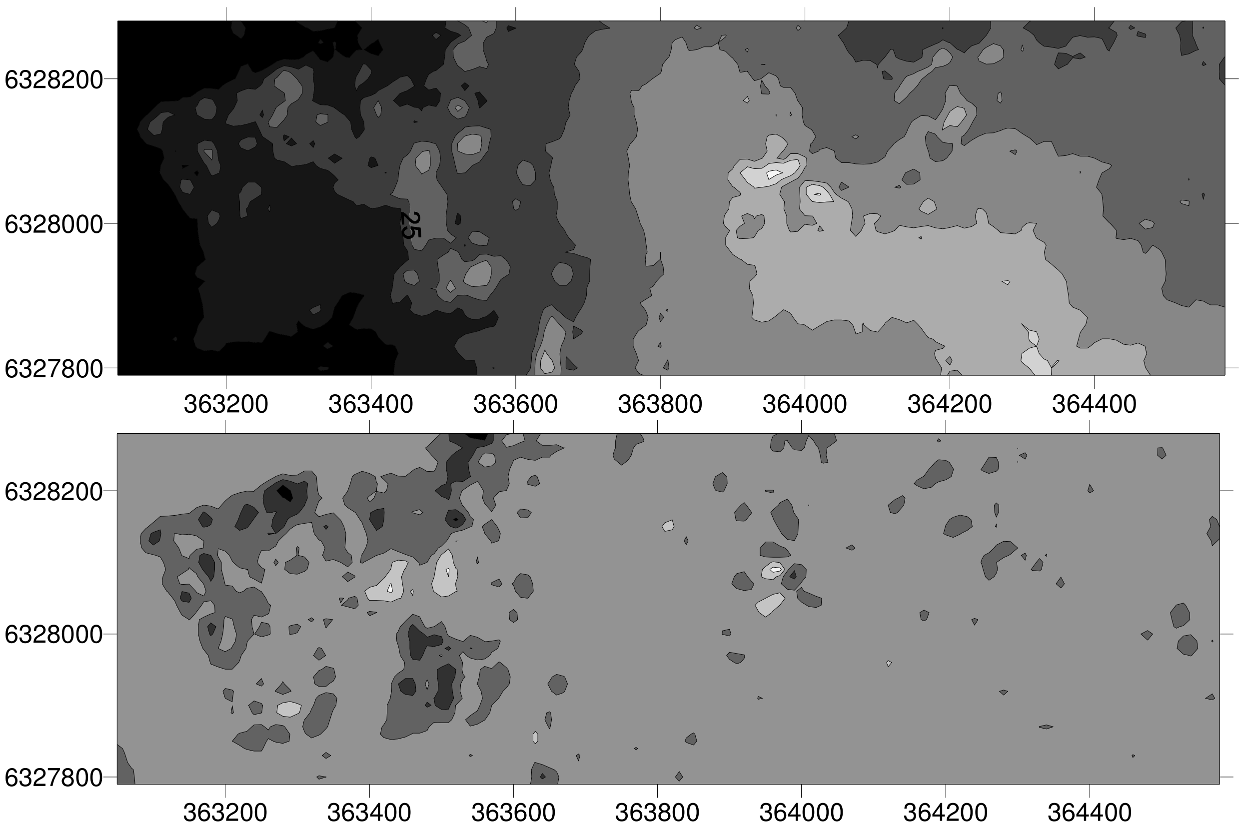
Figure 7: The distribution of surface differences, showing the matched area relative to the full DEM area.

Figure 8 shows more detailed contours which might reveal broader trends. Although there is correlation with topography, there are no apparent regional differences which could be attributed to subsidence.

Superimposing the differences on the original air photographs is a technique which can reveal correlations between the apparent differences and vegetation or buildings which may have changed, which can indicate that the differences are not due to subsidence. No correlation between the contours and the vegetation can be detected in this case, although this has been observed in other cases at the same mines.

5. DISCUSSION

In this case, the contours of surface differences appear to be randomly distributed without apparent correlation with the mines underground. DEMs can be affected by inappropriate surface models across areas of water and wide areas of ever-changing vegetation, but in this case small areas were matched, to obviate this problem. There was also no obvious correlation between the contours and vegetation or buildings, but this has been observed in other cases at the same mines.



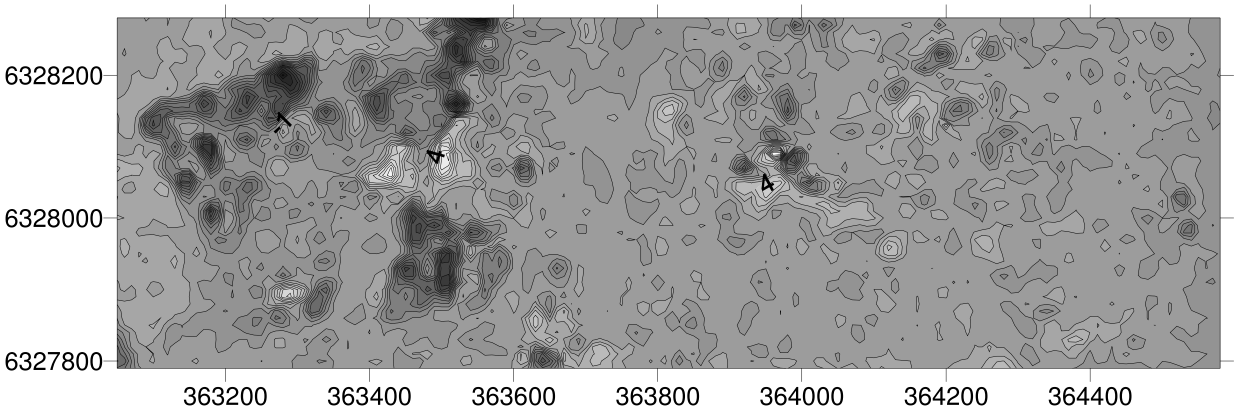


Figure 8: Top: The matched area from the DEMs of 1990 and 1996, with 5 m contours. Middle: The differences between the two DEMs, with 5 m contours. Bottom: The differences between the two DEMs, with 1 m contours.

The surface matching method is not without faults, but it must be recognise that a number of precautions have to be taken with any DEM comparison which is undertaken to detect subsidence, that is, even in those cases where first order control points are available and where markers have not been placed for the specific purpose of monitoring subsidence. The comparison of surface shapes is affected by noise and changes in vegetation and infrastructure in all cases. In this case, therefore, we have to recognise that these changes may additionally affect the surface matching. Overall, the outcomes provide confidence that the technique can be used. The technique will probably now be modified and refined by the investigators.

6. CONCLUSIONS

Comparing surfaces without using control is a novel approach. The surface matching technique has been a cheap and simple means of examining aerial photographs for the detection of subsidence. In the case reported here, subsidence has not been detected, and it justifies the low cost approach. However, it is the technique which is more important than the result and continued improvement is seen as worthwhile.

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BIOGRAPHICAL NOTES

Dr Robert Pâquet has degrees in both civil engineering and surveying, and a doctorate in photogrammetry, and is employed by Industry and Investment NSW. His current work and research includes analysis of subsidence data.

Dr Harvey Mitchell is a Senior Lecturer in Surveying at the University of Newcastle, Australia, with teaching experience in general surveying, geodesy, remote sensing, positional astronomy, and photogrammetry. Current research interests lie primarily in photogrammetry, and notably in medical and dental applications of photogrammetry.

CONTACTS

Dr Robert Pâquet
Mine Safety Operations
Industry and Investment NSW
Mining Subsidence Engineer
PO Box 344
Hunter Region MC 2310 NSW
AUSTRALIA
Tel. +61-2-49316647
Fax +61-2-49316790
Email robert.paquet@industry.nsw.gov.au
Web site:

Dr Harvey Mitchell
School of Engineering
University of Newcastle
University Drive
Callaghan 2308 NSW
AUSTRALIA
Tel. +61-2-49216055
Fax +61-2-49216991
Email harvey.mitchell@newcastle.edu.au
Web site: www.newcastle.edu.au