Comparison of photogrammetry and survey laser scanning output data for use in mapping joints in open cut highwalls

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COMPARISON OF PHOTOGRAMMETRY AND SURVEY LASER SCANNING OUTPUT DATA FOR USE IN MAPPING JOINTS IN OPEN CUT HIGHWALLS

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ABSTRACT: The Anglo American open-cut coal mines in Australia routinely obtain structural data from exposed highwalls to determine the potential for instability caused by joint orientation, joint dip, and joint persistence. Three methods are currently available to obtain this data: direct in-pit measurements with a geological compass, photogrammetry, and laser scanning. Direct measurements are often very time-consuming and can lack the precision of other methods due to the inability to perform proper line surveys where mandatory safety stand-off distances are enforced at the toe of each highwall. For this reason, photogrammetry has been the method of choice for many years, where stereo pairs are used to create a 3D image of the highwall. In recent years however, laser scanners now appear to be the preferred method of data acquisition due to their faster capturing and processing time, as well as their user-friendly CAD processing functionality. Concerns however have been raised over the accuracy of laser scanner data as examples to date have lacked the point cloud density necessary for picking representative joint planes. To resolve this issue, both methods were applied on the same highwall and the outputs compared. From this comparison, it was concluded that accuracy is not compromised with laser scanner acquisition methods as long as the correct intensity is selected prior to capturing the scan. Discrepancies were however identified between the joint orientation outputs of Sirovision and I-site mapping technologies. These discrepancies are attributed to the different algorithms each program uses, as well as the survey control and density of data points produced and required by each method.

INTRODUCTION

The identification and mapping of structural features such as joints, fractures, and faults is an important responsibility of the geologist/geotechnical engineer in any open-cut coal mine, where the persistence and orientation of these features can have a significant influence on the stability of an exposed hard wall (i.e. highwall or endwall). The failure to identify adverse structures ahead of mining can lead to injury to personnel, and damage to equipment, as well as significant delays and/or coal losses to mining operations in extreme conditions. Regular highwall mapping is therefore integral to assessing the geotechnical stability of future strips so coal can be uncovered as efficiently and safely as possible.

At Anglo American Metallurgical Coal (Met Coal), CSIRO/CAE’s Sirovision has been the preferred software package for photogrammetry, and Maptek’s I-site scanner is the most popular laser scanner utilised throughout Met Coal’s five open-cut operations in Australia. Both methods produce similar results in the form of a spatially orientated 3D model of the wall under analysis, onto which the direction of joints, fractures, and faults can be traced. The methods of obtaining these results, however, vary significantly in terms of workload and user friendliness for essentially the same data.

With the advent of this technology, in-pit line surveys are now seldom used to collect mass volumes of data due to the increased exposure of personnel to “no-go” or “drop-zones” at the toe of a hardwall. Nonetheless, line surveys are still important to ‘ground-truth’ joint planes mapped by photogrammetry and laser scan technology.

The impetus for this paper is to present a direct comparison of laser scanner (using Maptek’s I-Site 8800 laser scanner version 3.86x, Maptek, 2012) and photogrammetry (CAE’s Sirovision version 4.2, CAE, 2012) data, obtained from the same highwall, to show the similarities and differences in output data of these two methods, so a comprehensive understanding of their capabilities for highwall mapping can be obtained. This comparison will ensure the most appropriate method is selected so subsequent slope stability analyses can be undertaken as efficiently, accurately, and safely as possible to suit the end user’s needs.

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OVERVIEW OF METHODS

The following section provides a brief overview of the acquisition and data processing requirements of both Sirovision and the I-site scanner. A more comprehensive description of each method is available on each of the company’s websites. Both methods require both a field acquisition and an office processing component.

Sirovision

Field process

Personnel (generally site geologist/geotech) identify the area/extent of the hard wall requiring analysis and based on this area select the number of sections to be photographed. A minimum of three surveyed control points (generally in the form of high visibility marker cones) are then placed at the crest/toe of the hard wall as well as from the positions where the first set of stereo pair images are taken so that the images can be georeferenced back in the office. This process of photographing stereo pairs (i.e. near-identical photos of the same area taken at pre-determined distances apart) is continued along the desired length of the wall in a horizontally progressing fashion, ensuring adequate overlap is incorporated into adjacent images at each location so that a mosaic of sequential 3D images can be stitched during office processing.

Data processing

Several different programs and processes are required to create a 3D image suitable for joint/structure delineation once the field data is acquired. Photographs taken in the field are in the form of .RAW files that need to be converted to .TIFF files for further processing using software such as Canon’s Digital Photo Professional or similar. Sirovision’s Siro3D is then used to convert the original 2D images to spatially referenced 3D images so joint data can then be picked in 3D space. Within Siro3D images need to be corrected for lens distortion, spatially referenced to surveyed control points, then aligned and matched to their stereo pair using task set-ups to create a 3D image. 3D images are then imported into a third program, Sirovision’s SiroJoint, where structural features such as joints, fractures, and faults can be automatically or manually mapped, digitised, and projected onto stereonets and rosette plots. Digitised planes and traces can further be exported into additional highwall analysis programs such as Rocscience’s DIPS (DIPS 2012) so further analyses on the likelihood of failure may be assessed.

I-site scanner

Field process

Personnel (generally site surveyors) assess the size and features of the pit and decide on the location of the scan. An ideal location should avoid data ‘shadows’ and ensure the scanner is set up close enough to low reflectivity materials such as coal (to receive an adequate return signal) as well as close enough to the wall to ensure adequate resolution is acquired during the scan. For geotechnical scans, the scanner must be tripod mounted, rather than vehicle mounted. This is to avoid a reduction in accuracy which results from vehicle vibrations if it is left running when the scan is being acquired. A GPS/XYZ receiver is placed atop the scanner and the XYZ co-ordinates are recorded and confirmed with a backsight GPS system generally mounted to the surveyors light vehicle. The scanner then captures a 360° image of the area. The operator selects from this image the area to be scanned and the required resolution. For geotechnical scans, based on site trials, the minimum resolution setting the 8800 should be set at an 8-bit intensity. The laser scan is then acquired. On completion of the scan the data may be examined in the field for any errors. If errors are evident, a second scan can be performed with the necessary adjustments, before the scanner and tripod are relocated to complete another scan of the wall in a horizontally progressing fashion.

Data processing

Upon returning from the field, the scanner hardware is simply plugged into a PC and Maptek’s I-site Studio software converts the point data into a spatially-referenced 3D depiction of the physical landscape. A digital image captured by the built-in 70 megapixel camera can be overlain onto this point data to produce a spatially-referenced 3D image of the scanned area. Planes and traces may then be inserted along joints, fractures, and faults and projected onto stereonets and rosette plots, similar to those produced in Sirovision’s SiroJoint. However, unlike planes mapped in SiroJoint, planes mapped in
I-site Studio may be directly analysed for planar and toppling failure within I-site Studio software, significantly reducing the processing time to complete a kinematic analysis. Nevertheless, I-site Studio data may similarly be imported into additional highwall analysis programs such as DIPS so further analyses on the likelihood of failure may be analysed.

DIRECT COMPARISON OF METHODS

Sirovision and an I-site laser scan of Anglo American’s Foxleigh WC highwall was undertaken in autumn 2012. This hard wall was selected based on its moderate structural complexity, ease of access, and prolonged exposure for the purpose of this comparison. To ensure the outputs were comparable, the laser scan was acquired approximately one month after the digital images were taken for Sirovision analysis. Ideally a survey scan would have been completed within a week of Sirovision, however due to end of month survey requirements the laser scanner was not available until this time. Wall conditions were not observed to change significantly during this period, as no mining activities had occurred in the study areas ensuring the trial essentially compared “apples with apples”.

RESULTS

Spatially referenced 3D images of the WC highwall were successfully produced using both Sirovision and the 8800 scanner. Joint sets were then successfully mapped from these 3D images using their pertinent parent processing software (i.e. Sirovision’s SiroJoin software for photogrammetry produced 3D images and Maptek’s I-site Studio software for laser scan produced 3D images) - see Figures 1 and 2. In Figure 1, the distortion above the crest of the mainpass highwall is a result of Sirovision’s processing of data ‘black-spots’. This distortion does not have any impact on accuracy as the focus area is in the mainpass highwall. In Figure 2, the black spots that are observed above the crest of the mainpass highwall area a result of data ‘shadows’. Similar to Figure 1, these shadows do not have any impact on mapping accuracy.

Based on the CAD functionality built in to I-site Studio, joint planes were much easier to identify using Maptek’s processing software, when compared to the more cumbersome SiroJoint in which the 3D image...
is not able to be rotated, only zoomed in and out. This rotating feature in I-site Studio was particularly advantageous for mapping joint sets orientated at oblique angles to the highwall face. These joint sets were often not as readily identifiable when viewing the 3D image in a fixed plane view as in SiroJoint - see Figures 3 and 4 noting the significant increase in the number of joints mapped in I-site Studio compared to the number of joints mapped in SiroJoint.

![Figure 3 - Equal angle stereonet projection of SiroJoint mapped joints as displayed in Figure 1](image1)

![Figure 4 - Equal angle stereonet projection of I-site mapped joints as displayed in Figure 2](image2)

To directly compare the outputs of both methods, six of the larger and more readily-discernible joint planes were mapped using both SiroJoint and I-site Studio - see Figures 5 and 6. When these planes were plotted on a stereonet, appreciable discrepancies in joint dip were readily identified - see Figures 7 and 8.

![Figure 5 - SiroJoint mapped joints for direct comparison between Sirovision output and I-site Studio output](image3)

![Figure 6 - I-site Studio mapped joints for direct comparison between Sirovision output and I-site Studio output](image4)
To investigate the joint dip orientation discrepancies, the two 3D images were overlain to compare their georeferenced position. From this comparison it was found that the images spatially correlated well to the left (north) of the highwall image, however deviated in spatial orientation to the right (south) of the highwall image - refer to Figure 9. Deviations of nearly one metre were observed when viewing the images in cross-section view - see Figures 10 and 11 (I-site scan is displayed in grey; Sirovision 3D image surface is displayed in pink).

Figure 7 - Equal angle stereonet projection of SiroJoint selected joints

Figure 8 - Equal angle stereonet projection of I-site Studio selected joints

Figure 9 - Overlay of I-site scan (grey) and Sirovision 3D image surface (pink) showing the variation in spatial location of the mapped surfaces

Figure 10 - Spatial variation between I-site scan 3D image/surface and Sirovision 3D image

Figure 11 - Variation in surface resolution between I-site scan 3D image/surface and Sirovision 3D image
Appreciable deviations in joint dip were also observed when comparing SiroJoint manually-selected joint plane orientations with SiroJoint auto-searched joint plane orientations, where two planes were auto-mapped by SiroJoint for the one plane manually identified and traced - see Figure 12.

DISCUSSION

Both Sirovision (photogrammetry) and the I-site (laser) scanner provide the geologist/geotechnical engineer the necessary data to map highwall joints, fractures, and faults, however there are several differences in the acquisition and processing requirements of each method. These are summarised below:

- The acquisition time for Sirovision and an I-site scan data are very similar. However, despite taking approximately the same time to photograph/scan the same area, the acquisition process of taking digital photographs for use in Sirovision is much more physical than that required by the use of a laser scanner;
- Integrity of laser scan data can be reviewed in the field. This is unlike Sirovision data where errors are generally not identified until back in the office during the processing stage;
- Impact on production is reduced when acquiring data by laser scanners, as this method can be completed from the LW bench and generally does not require access into the base of the pit to place (and survey) control points as required by Sirovision. For this reason also, the acquisition of structural data by laser scanners may be argued as safer as there is less potential for interaction with an active pit with this process than with Sirovision;
- Processing of laser scan data is much quicker and less cumbersome than the Sirovision v4.2 process (i.e. requires only one program to process the data unlike the three required for processing Sirovision 4.2 data); and
- Sirovision has the attraction of a significantly lower initial hardware and software set up cost. However, the higher price associated with the versatility of the I-site scanner as a multi-purpose survey tool can often be justified by mine sites as it will not be used solely for highwall mapping.
In terms of output data, several differences can also be identified between the two methods. The most appreciable differences are found in the following areas:

- Mapped joint orientation;
- Spatial Referencing;
- 3D image surface resolution;
- Joint delineation in mapping software;
- 3D image clarity.

**Mapped joint orientation / spatial referencing / 3D image surface resolution**

Prior to this study it was believed that despite the differences in the acquisition and processing requirements between the two methods the output data from both programs was comparable. This study however identified variations of up to $5^\circ$ in joint strike and $15^\circ$ in joint dip between the two methods for the same joint surfaces mapped (refer to Figures 7-8). For kinematic analysis, $\pm 5^\circ$ deviations in joint orientations are considered an acceptable deviation to the true strike direction, however a $\pm 15^\circ$ deviation in dip is considered intolerable for both safety and economic considerations. These variations were discussed in detail with representatives from both CSIRO/CAE and Maptek, with both companies asserting the robustness of the algorithms built into their respective programs to delineate joint strike and joint dip. It is suggested that these variations are attributed to survey control, density of data points produced by each method, as well as the algorithms built in to the software for fitting a plane to an identified joint surface.

In terms of survey control contributing to differences in joint dip, when the laser scan surface was overlayed against the georeferenced Sirovision 3D image, deviations in spatial orientation were readily identified - see Figure 9. To measure the extent of the variation, the two 3D images were viewed in cross-section where the difference in spatial location was deemed the largest. The two 3D images were measured to be offset from each other by nearly one metre - see Figure 10. If multiple stereo pairs were joined together, a possible explanation for this discrepancy is ‘data wandering’, if only one end of the mosaic was georeferenced using the minimum three control points. However, as only one set of 3D images were captured for this comparison, this explanation has been ruled. Instead, based on the dual survey control and survey acquisition methods involved with the laser scanner, it is considered that the laser scan is the more accurate of the two methods. In addition to dual survey control required by the 8800, this conclusion is also based on a comparison of the two 3D images in cross-section view where ‘good’ spatial correlation between the georeferenced images was observed (i.e. on the left (northern) side of the highwall images). This comparison revealed greater ‘definition’ of the highwall face in the I-site produced 3D image, compared to a ‘smoother’, less-detailed surface produced by the Siro3D 3D image - see Figure 11. This increase in detail is attributed to the spatial resolution (approximately 5 mm point cloud spacing) able to be captured by the 8800 scanner. The observed increase in ‘detail’ in the I-site scan is perceived to reduce spatial deviations to the true joint orientation, whereby the more data points the program has to fit a plane, the less divergence from the true orientation of an *in situ* joint plane to the orientation of a fitted plane is observed, when in-built software ‘averaging’ algorithms are applied.

The hypothesis that the software algorithms may also be the source of joint orientation variance is based on direct comparisons of SiroJoint manually-mapped joints to SiroJoint automatically-searched mapped joints, whereby the orientation of planes fitted by an auto-search of joint planes differed appreciably from those planes that were manually selected - see Figure 12.

**Joint delineation**

The mapping of joint planes oblique to the exposed highwall were more readily discernible using the CAD-processing functionality of I-site Studio, compared to the more restrictive view functions in SiroJoint. Based on this study, it is perceived the cumbersomeness of SiroJoint to prohibit the centre of rotation to vary from the centre of the 3D image may lead to the oversight and/or omission of joint planes oblique to the exposed highwall being accurately mapped in spacing and persistence, as was identified in this study (see Figures 1-4).
3D Image clarity

In terms of 3D image clarity, Sirovision produced a superior quality image compared to the I-site scan (compare Figures 1-2). This difference is attributed to Sirovision’s use of a digital SLR camera to obtain a photographic image, compared the use of a rotating vertical camera by I-site. Although still not as sharp as the Sirovision image, I-site’s ability to overlay the photographic surface onto scanned data points mitigated any shortcoming of a lower-resolution image.

CONCLUSIONS

From in-house, on-site trials, it was concluded that laser scanner (Maptek 8800 I-Site Scanner v3.86x) methods of highwall mapping for delineating joints, fractures, and faults, for use in slope stability analysis is superior in terms of data accuracy when compared to photogrammetry (Sirovision v4.2).

Where the methods differ markedly in acquisition and processing requirements, it was found that the laser scanner had the fastest processing and least physical demands when compared to Sirovision, and was furthermore found to be the more accurate of the methods where deviations of up to 15° in joint dip were observed between the two methods. Joint planes, oblique to the exposed highwall, were also more readily discernible using the CAD-processing functionality of I-site Studio, where the same joint planes were less distinguishable using the more cumbersome SiroJoint interface.

Where there were initial apprehensions about the ability of the I-site scan to capture the necessary point cloud density to accurately map joint planes, these concerns were quickly alleviated be selecting a minimum 8-intensity setting on the scanner. At this setting, the returned point cloud spacing was less than 0.005 m providing a more than sufficient point cloud density for the purpose of mapping joints and faults in the exposed wall. It is therefore recommended that all laser scans acquired for the purpose of highwall mapping be set to a minimum of 8-intensity when the scanner is set-up on the lowwall side (i.e. approximately 50-80 m away from the scanned highwall). Where the scan is to be obtained from a distance greater than 80 m, the scan should be set to 16-intensity to ensure sufficient point cloud density for accurate joint mapping.

Although, the 3D image created by Sirovision was found to be of superior quality and resolution to the 3D photo taken by I-site and overlain on the laser scan, this study has concluded the preference of laser scanners for highwall mapping purposes. Photogrammetry should not however be disregarded as means of structural data acquisition, as there may exist pit conditions where laser scanners are not able to be set up, leaving photogrammetry as the only other acquisition method available for collecting mass joint data quickly and safely.

At all times however, any data acquired by photogrammetry or laser scanner methods should be ‘ground-truthed’ using a compass in order to confirm the accuracy of digitally acquired data.

Future comparisons between the Maptek I-site 8800 laser scanner and photogrammetry (using Sirovision 5) are planned when PC specifications and camera limitations are resolved. Line-survey measurements will also be included in future comparisons to provide the ‘ground-truthing’ discussed above.

REFERENCES