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Change detection in drill and blast tunnels from point cloud data

Gabriel Walton[a,*], Mark S. Diederichs[b], Klaus Weinhardt[c], Dani Delaloye[d], Matthew J. Lato[e], Allan Punkkinen[f]

[a] Department of Geology & Geological Engineering, Colorado School of Mines, Golden, Colorado, USA
[b] Department of Geological Sciences & Geological Engineering, Queen's University, Kingston, Ontario, Canada
[c] Zublin Inc., Toronto, Ontario, Canada
[d] Mott MacDonald, Vancouver, British Columbia, Canada
[e] BGC Engineering, Ottawa, Ontario, Canada
[f] Vale Ltd., Sudbury, Ontario, Canada

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1. Introduction

During the excavation of underground workings, stress redistribution around the excavation causes the rockmass to deform. The magnitude of this deformation depends on the rockmass conditions, the magnitude, orientation, and anisotropy of the in situ stresses, the excavation method and rate, and the type and location of installed support. Monitoring data which records the deformation of an excavation over time can therefore be used to back analyze information about the rockmass parameters and/or stress state, and can serve as an early warning for more severe failures[1].

With the recent profileration of laser scanning technology (and photogrammetry) in geotechnical engineering applications, it is natural that some researchers have begun to study its potential use as a deformation monitoring tool in excavations. By comparing two time-separated point cloud data sets (or attributes of these data sets), rockmass deformation can be mapped. This deformation can be mapped as either relative or absolute. To obtain absolute deformation measurements, georeferencing must be employed. This typically means that the location of the scanner must be surveyed from a known absolute reference for each instance of data collection using a total station. The advantage of absolute positioning when recording deformations is that translations of individual tunnels due to nearby excavation activities can be recorded; in contrast, only closure measurements can be obtained when using relative positioning[2]. The practical advantage of using relative positioning is that it requires much less time to set up scans, meaning that in an active excavation environment, typical cycle times can be maintained[3].

With the exception of closest point approaches, methods for comparing time-separated point cloud data sets have generally used what we refer to as a "global fitting approach". The global fitting approach for change detection depends on the comparison of 2D or 3D shapes fit to two data sets taken at the same location. Since only a small number of parameters are required to derive the best-fit shape as compared to the large number of data points, anomalous results and random errors can be effectively removed from the analysis. By contrast, algorithms based on closest point distance are significantly influenced by the range error inherent in the instruments used[4].

Delaloye[5] provides a framework for the comparison of point cloud data sets collected in elliptical excavations (see Walton et al.[3] and Delaloye et al.[6] for further developments). When fitting an ellipse to data, the long and short axes of the ellipse correspond to the principal deformation directions within the tunnel. To calculate the amount of normalized tunnel convergence, uniform deformation between measurements must be assumed. The orientation of the ellipse can easily be calculated, and is important to identify because a change in the orientation of the ellipse suggests a change in the deformation pattern.

Whereas previous works have focused on excavations with simple geometries (e.g. Wannanmacher et al.[7], Nuttens et al.[8]), this study uses data from the Creighton Mine in Sudbury, Canada to investigate the

* Corresponding author.
E-mail address: gwalton@mines.edu (G. Walton).

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applicability of various change detection methods for application in an excavation with irregular geometry.

1.1. Light-detection-and-ranging (LiDAR)

Light-Detection-And-Ranging (LiDAR) is a surveying technology which can be used to rapidly acquire three-dimensional (3D) point cloud positional data of surface topologies. Modern scanners can collect 3D points at rates of one million points per second. LiDAR is ideal for underground environments because it produces its own light signal, meaning no external lighting is required to collect high quality data; also, it is robust in environments that are wet and contain particulates in the air[9].

By comparing data from scans at the same location collected at different points in time, changes in the underground environment can be detected. Unlike traditional point based deformation monitoring techniques, LiDAR-data based methods are capable of determining deformation patterns throughout the entire excavation. Also, because of the high volume of data collected, georeferencing and absolute positioning of scan locations is not strictly necessary if only relative changes in size and shape are of interest; which can reduce data collection costs[3].

In a typical 6 m diameter underground mine drift the accuracy of a single point within a LiDAR dataset is in the range of 2–10 mm (this is instrument and survey setup dependent). By averaging large volumes of data, the overall positional accuracy of a surface defined by multiple points can be improved significantly. The optimal averaging technique to be employed depends on the nature of the data being analyzed.

2. A global fitting approach for rectangular excavations with rounded corners

2.1. Methodology

Because the design section of the drifts being monitored at the Creighton Mine is square rather than elliptical, an alternative geometric fit, the "rectellipse", was tested. The polar equation for this shape is:

$$\left[\frac{s^2}{4}sin^2(2\phi)\right]r^4-(k_y^2cos^2\phi + k_x^2sin^2\phi)r^2 + k_x^2k_y^2 = 0 \tag{1}$$

where s is a shape parameter, r is the distance from the center of the rectellipse, ϕ is an angular co-ordinate, and k_x and k_y represent the side lengths of the bounding rectangle. The rectellipse can capture excavation cross-sections ranging from rectangular to elliptical depending on the value of s.

2.2. Limitations

Rectellipse fitting was tested for a number of cross-sections of data from Creighton Mine. Unfortunately, the technique was not found to provide an improvement in accuracy for change detection relative to point-point comparisons. This was attributed to two main factors.

Most importantly, the individual rectellipse fit is highly sensitive to the position of the floor. This is problematic, as the shape and position of the floor change significantly from scan to scan due mining activities such as mucking and levelling, which are not of interest for the purposes of change detection. Fitting the rectellipse without the floor simply introduces greater non-uniqueness into the problem and does not lead to improved results (see Fig. 1). This issue could be resolved in future through the use of absolute positioning.

Another factor is that the irregularity of the excavation shape means any rectellipse fit is limited in its ability to capture all of the observed position data. As such, the selection of a "best-fitting" set of rectellipse parameters is more sensitive to minor variations in the data, and is not completely reliable.

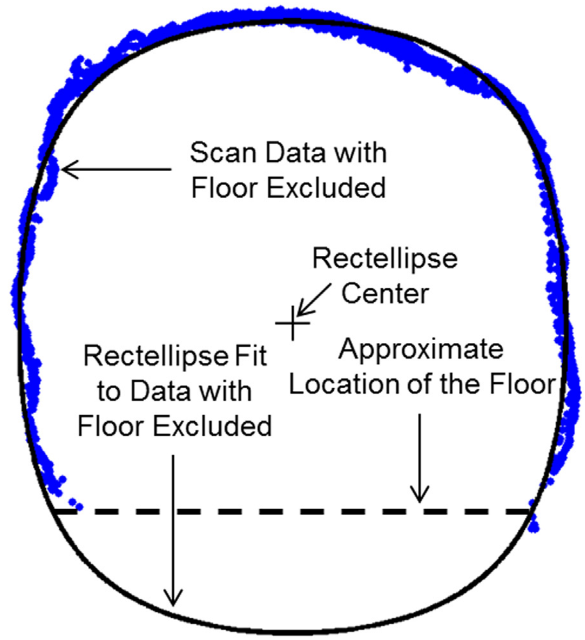

Fig. 1. Example of a rectellipse fit to a cross-section of data from the Creighton mine (note the exclusion of the floor data for fitting purposes).

In addition, the form of Eq. (1) requires that the value of r be solved iteratively for all ϕ, which makes the use of the rectellipse fit computationally intensive.

3. A local averaging approach for excavations with irregular shapes

In contrast to global fitting approaches, local averaging approaches compare various fits or averages to small regions of data between scans. One such example of this using a region-growing algorithm was demonstrated by Lindenberg et al.[10] for application in rectangular tunnels. More recently, Nuttens et al.[8] have proposed an alternative local averaging approach and demonstrated its application in a circular concrete lined tunnel. In this work, a similar methodology to that of Nuttens et al.[8] is employed to test its applicability to mining excavations, which have a much more irregular geometry.

In the approach of Nuttens et al.,[8] several cross-sections of a user-defined out-of-plane thickness, (t_{CS}), are analyzed individually, and then the results can be re-positioned in 3D space. First, the geometric center of the excavation must be identified, and then the data must be translated such that this center point is at the origin. In working with data from the Creighton Mine, the elliptical fitting algorithm used by Walton et al.[3] was found to be relatively robust for this purpose, despite significant occlusion (this is consistent with the synthetic testing of the fitting algorithm performed by Delaloye et al.[6]). It should be noted that the center of the excavation is determined based on the fit to the baseline data set used for the change detection analysis; the same translation is then applied to the second (post-change) data.

For a given angular window, θ_w, the average radial distance of points within the window from the geometric center of the cross-section, r_w, is calculated. This process is then repeated around the full cross-section for a number of window centers spaced at a defined angular increment, $\Delta\theta$, until a set of locally averaged distances have been calculated (see Fig. 2); windows which contain an insufficient number of points are ignored. The distances obtained can then be compared to the same distances for another data set which has been spatially aligned with the baseline data; when comparing data sets, it is critical that the same range of coverage be used for both data sets (filtering can be performed on the aligned data sets simultaneously to ensure that this is

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