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Verification of a 3-D LiDAR point cloud viewer for measuring discontinuity orientations

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ABSTRACT: LiDAR (Light Detection and Ranging) scanners are increasingly being used to measure discontinuity orientations on rock cuts to eliminate the bias and hazards of manual measurements which are also time consuming and somewhat subjective. Typically LiDAR data sets (point clouds) are analyzed by sophisticated algorithms that break down when conditions are not ideal, eg. when some of the discontinuities are obscured by vegetation, or when significant portions of the rock face are composed of blast fractures, weathering generated surfaces, or anything that should not be identified as a discontinuity for the purposes of slope stability analysis. This paper presents a simple LIDAR point cloud viewer that allows the user to view the point cloud, identify discontinuities, pick 3 points on the surface (plane) of each discontinuity, and generate discontinuities orientations using the three point method. A test of our 3-D LiDAR viewer for discontinuity orientations on three rock cuts in the Golden Gate Canyon Road area of Colorado is also presented.

1. INTRODUCTION

Joint, fracture, fault, and discontinuity are the four common terms used to describe breaks in a rock mass. Discontinuity is probably the most general among the terms that suggests a break in the continuity of a rock mass, with no implied genetic origin [1]. However, the term discontinuity makes no distinctions concerning the age, geometry or mode of origin of the feature [2]. The term joint is commonly used to describe a discontinuity caused by a natural geological process. The term fracture is a more inclusive term that would include joints, faults, cracks, and breaks induced by blasting [1]. The term fault applies only to natural breaks along which some displacement has occurred. A discontinuity is a significant mechanical break or fracture of negligible tensile strength in a rock, low shear strength and high fluid conductivity compared to the rock itself [2]. Naturally there are breaks or cracks in every rock mass [3].

Discontinuities influence all the engineering properties and behavior of rock [4]. When dealing with discontinuous rock masses, the properties of the discontinuities become a prime importance since that determines to a large extent the mechanical behavior of the rock mass [5]. The presence of discontinuities in a rock mass can affect engineering designs and projects which include the stability of slopes in the rock masses, the stability and behavior of excavations in the rock and the surroundings, the behavior of foundations in the rock (settlement) the type of support, the strength of the rock, and the hydraulic conductivity of the rock which is responsible for the transportation of groundwater and contaminants [6].

Properties of discontinuity can be grouped as geometric and non-geometric. Geometric properties include position, orientation, persistence, aperture, and roughness. Arguably the discontinuity orientation may be the most important property. These properties can be measured directly from the discontinuity if the rock face is readily accessible. Non-geometric properties include wall strength, filling, and water conductivity.

1.1. Rock Slope Failure

Rock slope failure is a common geological hazard in the civil and mining industry. In civil engineering, there is often the need sometimes to cut rocks vertically or near vertical in order to provide roads for the public. Vertical or near vertical cuts are also very common in the mining industry. There is always a possibility for large blocks of rock to fall or slide down from these steep rock cuts. The greater the number discontinuity planes present in the rock mass, the higher the chances of failure since many of the failures result because of release along discontinuity planes. Whether or not failure occurs can depend largely on the orientation of the discontinuities, individually or in combinations (Figure 1). Thus, knowing the orientations of the discontinuities can lead to stability prediction based on well established analytical tools as described by Hoek and Bray [7].

Orientations are typically measured manually in the field using a compass and clinometer. These methods are manual and have disadvantages which include the introduction of erroneous data because of sampling difficulties and human bias, considerable safety risks since measurements are sometimes carried at the base of existing slopes or during quarrying, tunneling or mining operations or along busy highways, difficult or impossible access to some sections of rock faces, and are time consuming and labor intensive which make them costly [8]. Laser scanning and digital images can be less costly, more objective and more precise and accurate in determining discontinuity orientations [9,10].

Figure 1. A rock mass showing a discontinuity along which a rock block slid. The block at the top left corner is also likely to slide with time.

For a given rock mass, measured discontinuity planes can be assigned by using cluster analysis. Cluster analysis techniques are described in detail by Maerz and Zhou [6, 11, 12, 13]. Once having identified discontinuity clusters, graphical or computational techniques can be used to determine the kinematic feasibility of failure (Figure 2) and standard modeling techniques such as limiting equilibrium analysis can be used to determine if failure will indeed take place (Figure 3).

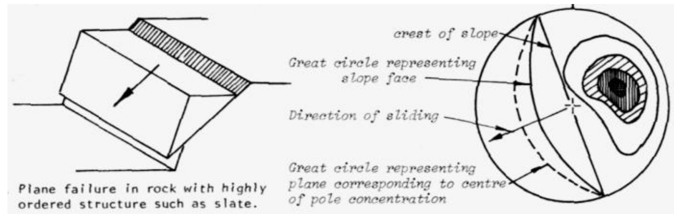


Figure 2: Planar failure geometry (left) and graphical method of determining if slide failure is kinematically possible [7].

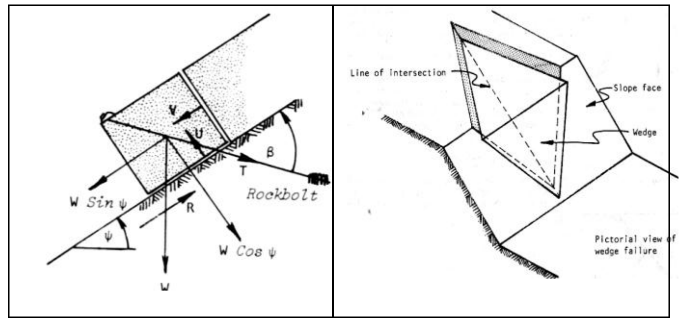


Figure 3: Limiting equilibriums analysis applied to planar features (left) and wedge features (right) [7].

1.2. LiDAR Scanning

A LiDAR (Light Detection and Ranging or Light RADar) scanner uses either a time of flight or phase shift sensors to generate a 3-D image of a surface. It involves the emission of light pulse from a source, which reflects off surface of the object is reflected and returns to the source which then receives and measures it [9]. A high precision counter measures the travel time and intensity of the returned pulse. The pulse source also measures the angle at which the light pulse is emitted and received, these enables the spatial location of a point on a surface to be calculated [9]. The result is a million of points reflected from the surface. The points are represented by xyz coordinates, these xyz coordinates and their associated intensity values are known as a "Point cloud". The LiDAR 3-D technology is becoming increasingly useful in geology and engineering.

Kemeny et al. characterized rock masses using LiDAR and automated point cloud processing, and also analyzed rock slope stability using LiDAR and digital images [14, 15], including measuring and clustering discontinuity orientations. LiDAR was used by Mikos et al. to study rock slope stability [16]. Lim et al used photogrammetry and laser scanning to monitor processes active in hard rock coastal cliffs [17]. High resolution LiDAR data was used by Sagy et al. to quantitatively study fault surface geometry [18]. Enge et al. illustrated the use of LiDAR to study petroleum reservoir analogues [19]. Using a combination of LiDAR and aerial photographs, Labourdette and Jones studied elements of fluid depositional sequences using LiDAR [20].

Figure 4: Rock faces with 100% coverage of natural joint surfaces (a) and with significant ambiguity as to the location of natural joint surfaces (b).

Automated algorithms used to generate discontinuity orientations are in general fairly sophisticated and can give excellent results under certain conditions. In places where rock faces are virtually 100% bounded by discontinuities they work well; in places obscured by vegetation, rock projections, or surfaces created by recent fracturing because of blasting or weathering not so well (Figure 4). In the latter case the algorithms will break down. Although vegetation removal algorithms could be used, this adds another layer of difficulty to both the data collection and analysis sides. It is often better just to manually identify discontinuities on the LiDAR point cloud.

Figure 5: Leica ScanStation 2 LiDAR unit.

Table 1: Features and specifications of the ScanStation 2 unit (modified from Leica webpage, 2012)

Feature	Specification
Laser scanning type	Pulsed; proprietary microchip
Color	Green
Laser Class	3R (IEC 60825-1)
Range	300m at 90% ; 134 at 18% albedo
Scan rate	Up to 50,000 points/seconds maximum instantaneous rate
Scan resolution	
Spot size	From 0 - 50 m : 4 mm (FWHH-based) 6 mm (Gausian - based)
Selectability	Independently, fully selectable vertical and horizontal point-to-point measurement spacing
Point spacing	Fully selectable horizontal and vertical; < 1 mm minimum spacing , through full range; single point dwell capacity
Maximum sample density	< 1 mm
Field of view	
Horizontal	Maximum of 360 degrees
Vertical	Maximum of 270 degrees
Aim/Sighting	Optical sighting using QuickScan botton
Scanning optics	Single mirror, panoramic, front and upper window design
Digital imaging	Low, Medium, High automatically spatially rectified
Camera	Integrated high-resolution digital camera
Scanner Dimensions	265 mm x 370 mm x 510 mm without handle and table stand
Weight	18.5 kg
Data storage	On laptop through ethernet cable
Power supply	36V; AC or DC
Power consumption	Averagely less than 80W
Typical duration	Greater than 6hrs of continuous use

For the purposes of this research, a Leica ScanStation 2 LiDAR unit was used. The unit consists of a scanner controlled by a laptop, a tripod stand and a portable generator (Figure 4, Table 1). It has 50,000 points per second maximum instantaneous scan speed, and the ability to conduct full-dome scans using its oscillating mirror with front and top-window design.

2. THE LIDAR VIEWER

2.1. Purpose of the LiDAR Viewer

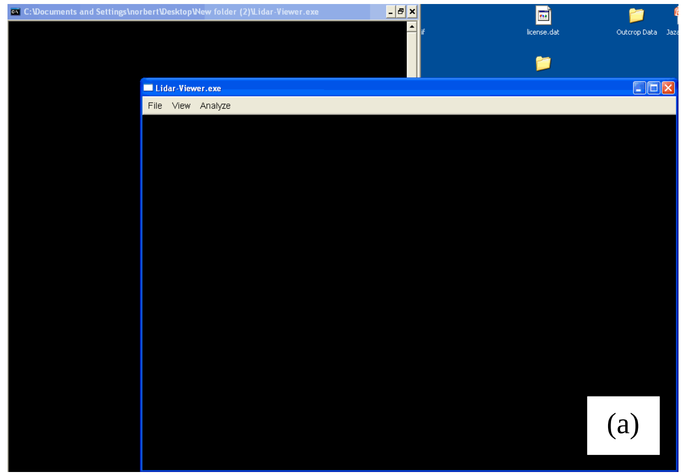
The simplest way to use LiDAR point clouds to generate discontinuities is to have a way to view the LIDAR data in three dimensions by having a viewer that allows the visualization of point cloud from different angles and distances, so that the location and extent of a discontinuity can be isolated. Furthermore once having identified and isolated the discontinuity, the user needs to be able to select three non-linear co-planar points on the surface of the discontinuity, and export those points to be used to calculate the orientation of the discontinuity using the three point method commonly used in geology.

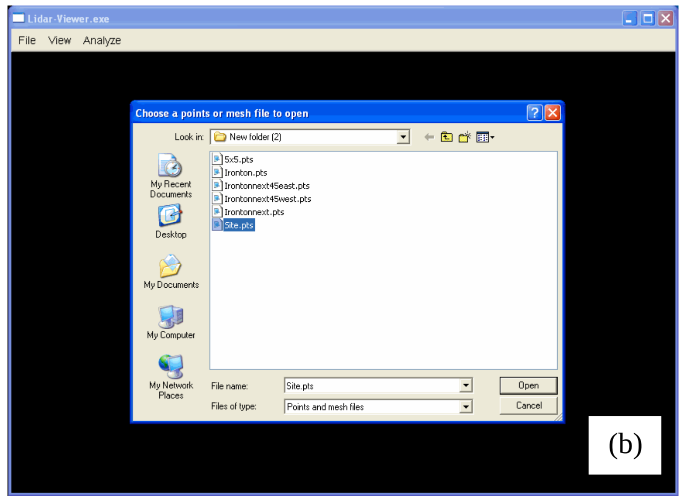
2.2. Operation of the LiDAR Viewer

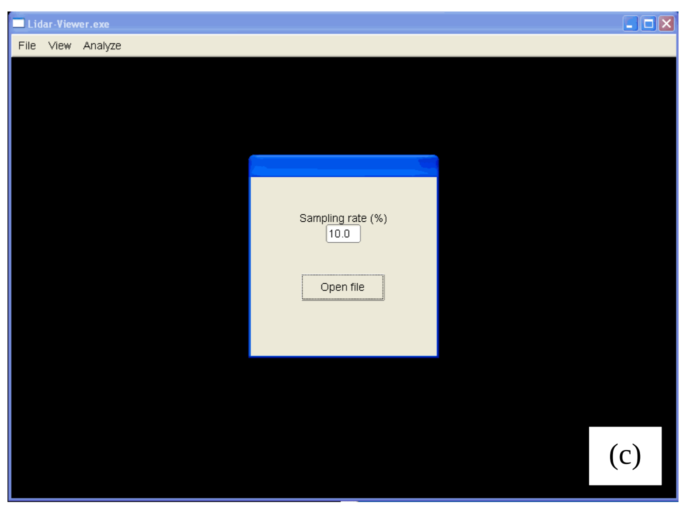
The LiDAR viewer generally allows point cloud data to be viewed in 3-D by use of a 3D projection on the screen. It computes the unit normals of selected discontinuity surfaces (facets) when the user picks any three non-co-linear points on that surface. The 3-D orientations of the facets (exposed discontinuity surface) can then calculated from the unit normal. Data points need to be in a .PTS (Leica ASCII) format in order to carry out analysis with this viewer. The viewer comes with two windows; the “command window” and a “(black) display window”. Analyses are carried on the command window and the results are shown on the display window. The “main window” has 3 tools namely; “file”, “view”, and “analyze”.

File tool

The “file” tool enables data to be loaded into the viewer. Options to either “open” a data file or to “quit” the viewer are provided. When opening a file, the user is prompted to enter a “sampling rate”. This allows the user to sub-sample the data to facilitate faster graphics processing when moving through the image or rotating around it. The display window records the name of the data opened and the number of points loaded.







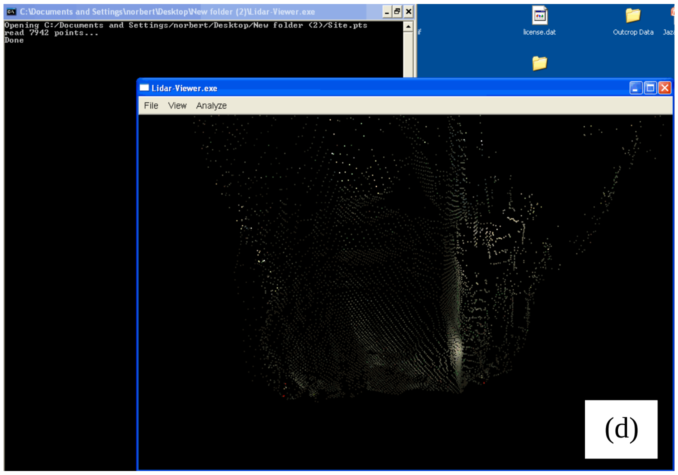


Figure 6: Screen shots of the LiDAR viewer showing the data loading process. (a) Initial opening window, showing the main and back windows (b) Selecting data from a group (c) selecting the sampling rate (d) data name and number of points opened recorded by back window.

Figure 6 shows the data loading process. At this point the user can rotate the view using the mouse and “zoom in” and “zoom out” an opened data data set using the “w” and “s” keys.

View tool

The “view” tool gives the user an option to change the color of the points being viewed, and to also increase or decrease the size of the points being viewed (Figure 7).

Analyze tool

The “analyze” tool provides four options; “point operation”, “find normal”, “reverse normal”, and “save normal” to file (Figure 7). The “point operation” option under the “analyze” is the main analysis tool and has options on its own which include “select point mode”, “delete point mode”, and “normal mode” (Figure 7). The select “point mode” allows the user to select point on a rock facet of interest, the “delete points” mode allows points to be deleted, and the “normal mode” allows the user to view and move around the data set.

The select point mode allows the user to identify 3 different points on a discontinuity surface that are co-planar but not co-linear Figure 8. Thus, any three points that form a triangle could be selected, and it could take less than 30 seconds to select these points. After that the “find normal” option generates a normal vector to the discontinuity surface.

The “reverse normal” option allows the user to change the direction of the calculated normal.

The “save normal” to file option allows the user to save the calculated normals to an existing file. The orientation of the facets (dip and the dip directions) can then be externally calculated from the unit normals.

The calculation of the discontinuity facet orientation is based on the classic “three point problem” in structural geology which starts with the generation of a unit normal vector from the 3 points. This technique is fully described in Maerz et al. [21], and can easily be accomodated using a spreadsheet.

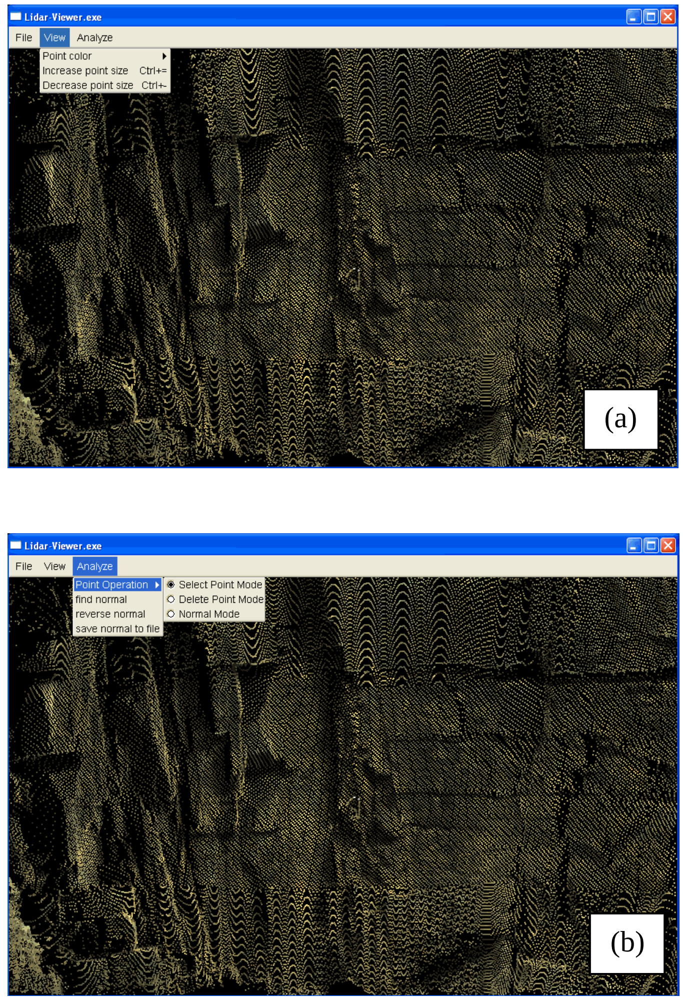


Figure 7: Screen shot from LiDAR Viewer showing data points from a site and (a) options available from the view tool (b) options available from the analyze tool.

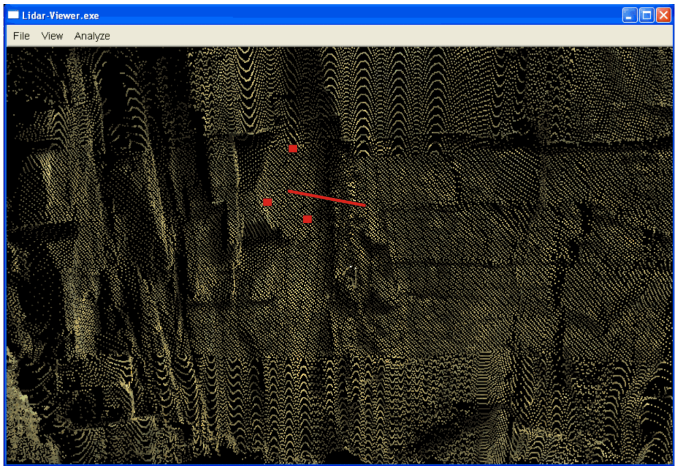


Figure 8: Three user selected points on a discontinuity surface and the resulting unit normal vector.

3. TEST SITES

3.1 Golden Gate Canyon Road

Three sites located on the Golden Canyon Road, Colorado, were selected for the test. All three sites are rock cuts and located at latitude and longitude coordinates of 039° 49.85' and 105° 24.63'. Images of the test sites are shown in Figure 9.

Figure 9: Images of the test sites, (a) Site 1 (b) Site 2 (c) Site 3. Safety cones in the images represents the boundries of the site.

4.0 RESULTS

Results from the LiDAR Viewer on randomly selected facets from the test site when compared to field measurements were almost the same (Tables 1, 2, 3, and Figure 10). Results of the orientations are reproducible when different sets of points are selected.

Table 1: Dip and dip directions of randomly selected facets from site 1, calculated from the viewer and compared to field measurements

Facet	X	Y	Z	Unit Normal	Field Dip/Dir	Viewer Dip/Dir
5	1881.87	9387.54	3547.87	0.33	50/245	52/245
	1071.88	8145.96	2539.80	-0.72		
	2657.02	8758.49	2402.90	0.62		
16	1202.90	6555.08	734.06	-0.35	56/65	59/66
	944.85	6603.23	488.59	0.78		
	1406.92	6743.37	588.17	0.52		
23	585.71	7106.15	993.79	-0.92	88/161	89/157
	531.23	7263.65	477.01	-0.38		
	725.01	6807.58	258.66	-0.02		

Table 2: Dip and dip directions of randomly selected facets from site 2, calculated from the viewer and compared to field measurements

Facet	X	Y	Z	Unit Normal	Field Dip/Dir	Viewer Dip/Dir
10	-1996.47	9638.91	3425.22	-0.37	50/244	49/244
	-2910.79	8239.07	2547.86	0.66		
	-1283.41	8553.68	1936.96	-0.66		
8	272.09	9058.71	4561.29	0.81	83/332	83/329
	-14.53	9316.65	3923.44	0.57		
	489.45	8611.76	4004.13	-0.14		
14	-4695.04	8324.49	1240.68	-0.37	54/67	52/66
	-4963.54	8539.97	811.28	0.72		
	-4582.06	8679.52	880.54	0.59		

Table 3: Dip and dip directions of randomly selected facets from site 3, calculated from the viewer and compared to field measurements

Facet	X	Y	Z	Unit Normal	Field Dip/Dir	Viewer Dip/Dir
12	2181.57	8231.78	1404.23	-0.57	51/242	49/242
	1582.56	8331.68	2036.84	0.53		
	1385.54	7619.39	1613.99	-0.63		
27	970.44	7701.71	5513.87	-0.61	53/74	53/74
	-8.03	7376.28	4547.08	0.69		
	1227.96	8387.89	4682.95	0.38		
31	-924.31	8730.01	6463.44	0.86	85/334	83/332
	-1039.55	8661.90	4865.68	0.50		
	-339.52	7560.30	5472.74	-0.08		

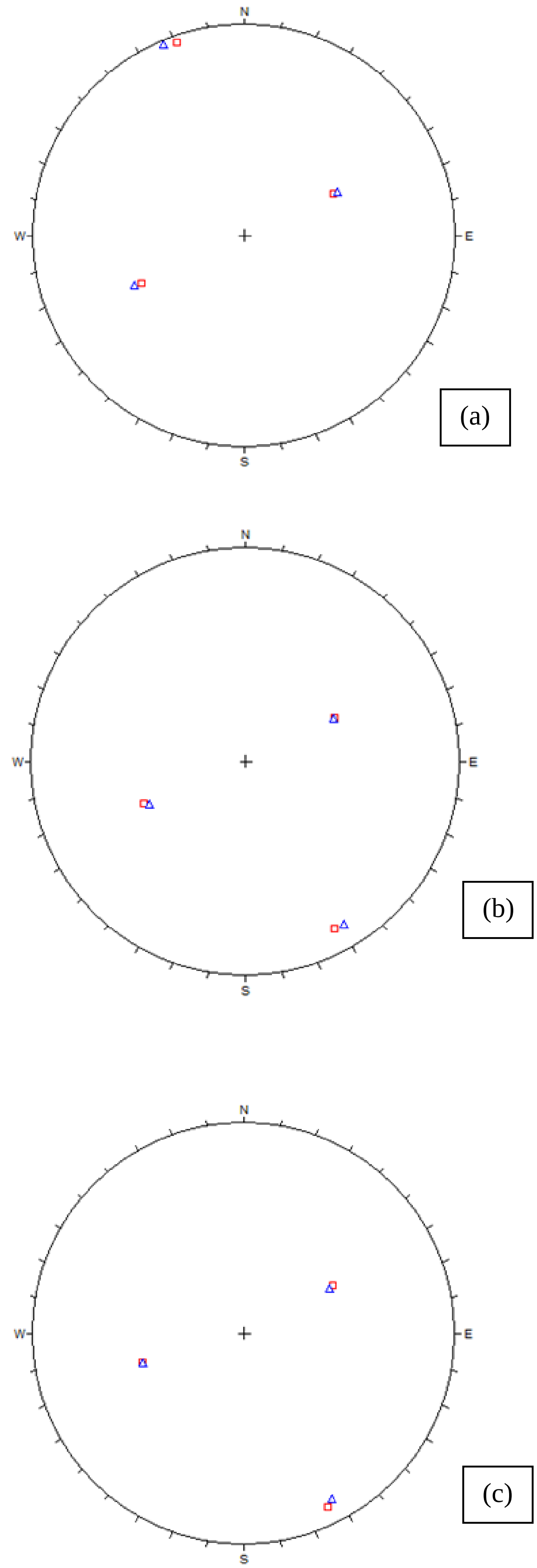


Figure 9: Dip and Direction of field measurements (red squares) and measurements using viewer (blues triangles) for the test sites, (a) Site 1 (b) Site 2 (c) Site 3.

5.0 SUMMARY AND CONCLUSIONS

Orientation data on discontinuities in rock masses is very necessary in civil and mining engineering projects because the potential of failure to occur can depend on the orientation of the discontinuities, individually or in combinations. Thus, knowing the orientations of the discontinuities can lead to successful stability predictions. The traditional honored method of orientation measurements with Brunton compasses is both time consuming and often inconvenient given issues such as restricted access to measurement areas. This paper is part of an ongoing research, it presents a simple test of a LiDAR point cloud viewer on three rock cut in Colorado. LiDAR data was collected using a Leica ScanStation II scanner that provides both optical and LiDAR images. LiDAR point clouds were exported in PTS format and loaded into the viewer for simple and quick analysis of facet orientations.

4. ACKNOWLEDGEMENTS

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