Comparative Study of Two Approaches for Application of Terrestrial Laser Scanner in Structural Health Monitoring and Damage Assessment

Shakhzod M. Takhirov[a]
Department of Civil and Environmental Engineering, University of California, Berkeley, 337 Davis Hall, Berkeley, California, U.S.A.

Keywords: Laser Scanning, Displacement Tracking, Laser Targets, Structural Health Monitoring, Corner Detection and Tracking, Structural Damage Assessment.

Abstract: The main objective of the paper was to evaluate two approaches aimed at tracking small displacements. The first approach is based on the usage of laser targets commonly used for stitching point clouds together. The second approach is based on the estimation of a corner of a prismatic shape and utilizes thin horizontal slices of the shape's point cloud. The corner's location is estimated as an intersection of two straight lines best fitted to the point clouds before and after the corner. It was shown that for both approaches a sub-millimetre accuracy can be achieved. The first approach requires the installation of two laser targets in order to measure the change of the distance between them. The second approach offers more flexibility because it does not require the installation of a laser target. Hence it can be used in the quantitative assessment of structural damage in the aftermath of natural disasters such as earthquakes, fires, tsunamis, landslides and hurricanes, to name a few.

1 INTRODUCTION

The application of terrestrial laser scanners and drones in structural health monitoring and structural assessment in the aftermath of a natural disaster is steadily increasing. Terrestrial laser scanners usually acquire point clouds with a better accuracy than those collected by the drones. It is quite common that the laser scanners deliver a few millimetres accuracy. While this accuracy might be sufficient for most applications such as tracking large surfaces, it is not adequate for monitoring small displacements. The option of utilizing laser scanning targets can increase the accuracy of tracking. This is related to the fact that their vertices can be acquired with a better accuracy based on complex manipulations of the target's point cloud. Because of that, they are commonly used as reference points for stitching the point clouds to each other. Based on the specifics of the target's shape and colouring pattern, their vertices can be acquired with much greater accuracy and their displacement can be tracked with a sub-millimetre accuracy. This high accuracy was reported earlier (Takhirov, 2009) for a single field measurement comparing the displacement of the target from laser scans acquired by ScanStation 2 (Leica GeoSystems AG, 2007) to that obtained by accurate position transducers. This adequate accuracy for the Trimble laser scanner (Trimble, 2016) was confirmed for a series of measurements conducted in the laboratory environment (Takhirov, Gilani, and Allen, 2021). This paper is focused on the evaluation of this approach for the Faro Focus^{S} (Faro, 2021) laser scanner. In addition, this approach was compared to another approach based on tracking the corner points of the prismatic structural elements or components. This approach was developed earlier (Takhirov and Mosalam, 2014) and evaluated for ScanStation 2 in the reconnaissance effort following the 2010 Haiti Earthquake (Mosalam, Park, and Takhirov, 2014). It was also evaluated for a cost-effective scanner (Takhirov, Gilani, and Allen, 2020). Recently this approach was developed further for applications in quality control of construction (Takhirov, 2021).

[a] https://orcid.org/0000-0002-4396-7946

Takhirov, S.
Comparative Study of Two Approaches for Application of Terrestrial Laser Scanner in Structural Health Monitoring and Damage Assessment.
DOI: 10.5220/0010992000003121
In *Proceedings of the 10th International Conference on Photonics, Optics and Laser Technology (PHOTOPTICS 2022)*, pages 166-171
ISBN: 978-989-758-554-8; ISSN: 2184-4364

Point clouds collected by the C10 laser scanner (Leica GeoSystems AG, 2010) was used in the latter study.

This paper is focused on the evaluation of both approaches for point clouds collected by the Faro Focus^S laser scanner (Faro, 2021).

2 EXPERIMENTAL SETUP

The laser scanning project was conducted in a laboratory environment and a special experimental setup was assembled for the project. The setup consisted of a linear bearing rail with two carriages that can slide along the rail's axis. One of the carriages was fixed and the other one was displaced in respect to the fixed one. A rigid block was mounted on top of each carriage. To imitate the typical texture and colouring of the material commonly used in construction, two concrete blocks were used. As noted earlier, both were placed on the carriages of a linear bearing system as presented in Figure 1. One of the blocks was larger in size with overall dimensions of 394 mm by 197 mm by 89 mm. Two laser scanning targets (LT and LB) were installed on this block as shown in Figure 1. The second block was smaller with overall dimensions of 292 mm by 292 mm by 51 mm. This block had only one laser scanning target (RB) and the block and the target were used as a reference. For this purpose, the block was installed on a fixed carriage of the linear bearing system that did not move during the experiments.

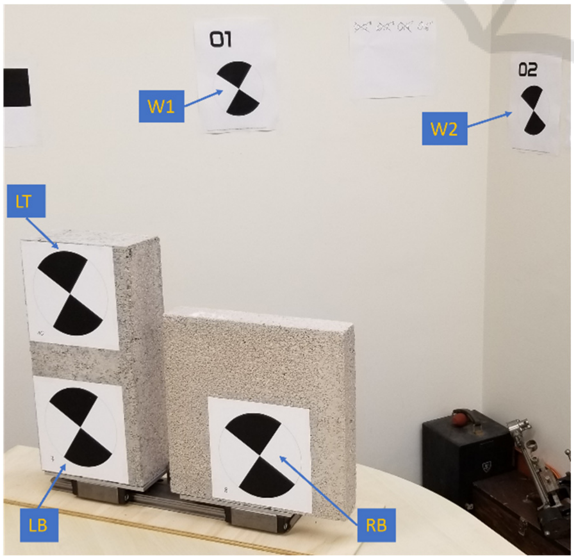

Figure 1: Setup: two concrete blocks on a linear bearing system with a few targets.

Two additional fixed laser scanning targets were used in the study. They were mounted on the wall as shown in Figure 1 and they were labelled W1 and W2, respectively.

The tall block was left free to move in respect to the fixed one, but it was restrained to only move along the linear bearing system by its attachment to the movable carriage in the system. The displacements were imposed in an incremental way by inserting high-precision blocks (Mitutoyo, 2016) between the carriages as presented in Figure 2.

Figure 2: Displacement between carriages set by high-precision blocks.

As shown in Figure 3, the terrestrial laser scanner, Faro Focus^S (Faro, 2021), was used to collect point clouds of both blocks at each displacement.

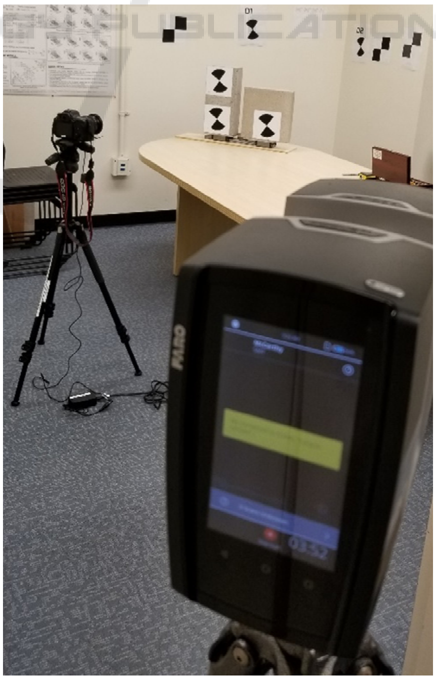

Figure 3: Terrestrial laser scanner used in the setup.

The laser scanner was placed at about 3.8 m away from the blocks and it was not moved during the experiment. The scanner was installed at about 45 degrees to the planes of the concrete blocks. It had a setting of 1/4 resolution and 3x quality (in the scanner specific options selectable for a scanning process). The laser scanner was levelled during the scans ensuring that the vertical axis of all scans coincided with the true gravitational axis.

3 TWO APPROACHES

Two approaches were evaluated in this study. The first was based on tracking the centres of laser scanning targets and the second was based on monitoring the displacements of the concrete block's corner in respect to the corner of the fixed block.

3.1 First Approach

The first approach for tracking the displacements of the blocks was based on utilization of the laser scanning targets. In each laser scan the centres of the targets were estimated by using Cyclone software from Leica GeoSystems (Leica GeoSystems AG, 2018). A result showing all the targets for one of the typical scans is presented in Figure 4. The target vertices are indicated by crosses. In this paper, the point clouds are presented in a local coordinate system ensuring that the X-axis is parallel to the direction of displacements and the Z-axis is parallel to the true gravitational vertical axis.

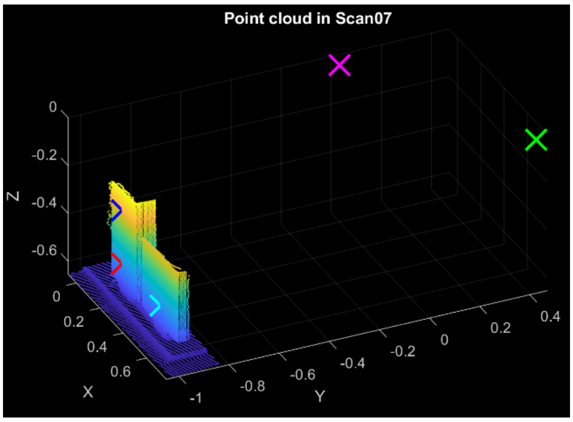

Figure 4: Vertices of laser scanning targets and the point cloud.

The acquired target centres were exported in ASCII format and all remaining data reduction was conducted in the Matlab environment (MathWorks, 2016). Estimates of the distances between the vertices are presented in Figure 5 for LB to RB targets as a typical example.

It is worth noting that the point cloud data and the location of vertices does need to be transformed into a new coordinate system because the distances between the vertices are not dependent on a selection of a coordinate system.

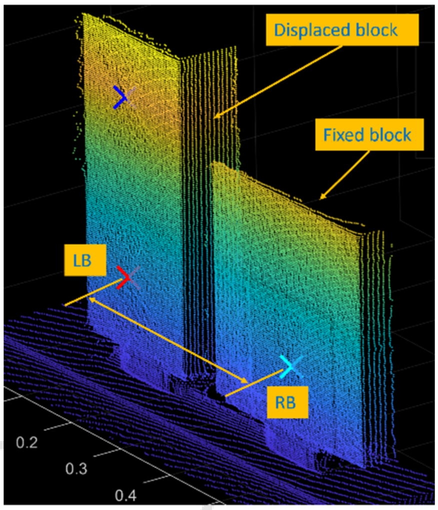

Figure 5: Approach 1: distance between vertices of targets.

This procedure was applied to all five targets in the study. The targets fixed to the wall were used for estimation of accuracy of the approach since the targets were not moving in respect to each other.

This approach was evaluated earlier (Takhirov, Gilani, and Allen, 2021) for a terrestrial laser scanner Trimble TX6 (Trimble, 2016) and it was shown to be an adequate correlation with displacements measured by accurate position transducers.

3.2 Second Approach

The second approach for tracking the displacements of the blocks was based on finding a corner of the moving block at the elevation of the target's centre, and tracking its displacement from scan to scan. In this case, a thin horizontal slice of the point cloud at the elevation of the target's centre was analysed as shown in Figure 6. In this case, the corner of the fixed block was used as a reference.

A plan view of a typical horizontal slice is shown in Figure 7. The point cloud corresponding to the front and the side surfaces of the block are separated from each other. These subsets of point clouds were individually best fitted to straight lines by the least square method. An intersection point of these two straight lines was considered as a corner of the block.

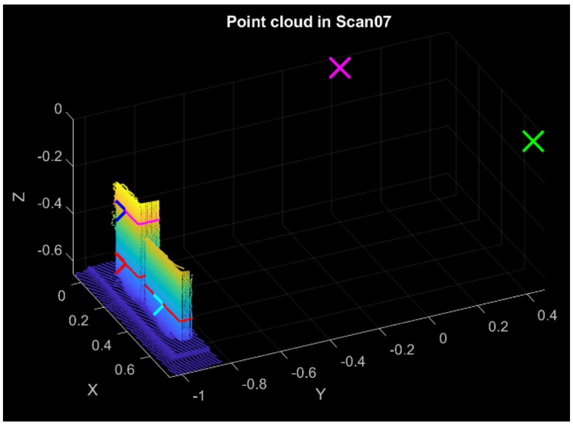

Figure 6: Horizontal slices of point clouds at elevations of target centres (LB and RB).

To increase the accuracy, the points right next to the corner were removed to minimize the effects of the corner's imperfections. The points in shaded boxes shown in Figure 7 were used for best fitting to the straight lines.

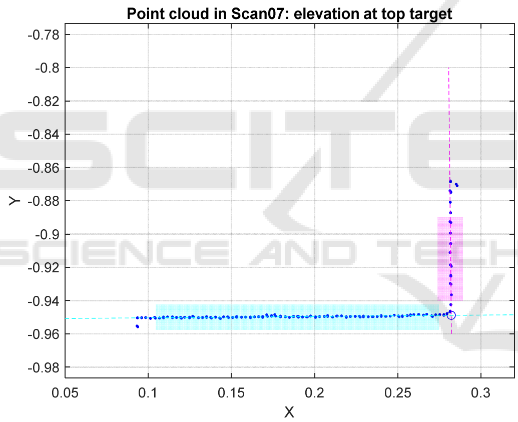

Figure 7: Typical result for a corner estimation.

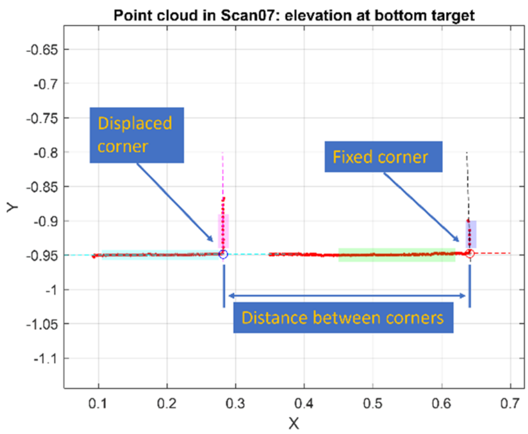

Figure 8: Approach 2: distance between the corners is estimated.

A corner of the fixed block was estimated in the same way. The distance between two corners was estimated as shown in Figure 8 and it was tracked from scan to scan.

This approach was introduced earlier for the estimation of residual drifts of columns in a reconnaissance effort conducted soon after the 2010 Haiti Earthquake (Mosalam, Park, and Takhirov, 2014). This study was conducted by means of a ScanStation 2 laser scanner (Leica GeoSystems AG, 2007). The application of this approach for the quality control in construction was recently studied (Takhirov, 2021). In the latter case, a point cloud collected by the C10 laser scanner (Leica GeoSystems AG, 2011) was used.

As mentioned earlier this paper is focused on the evaluation of both approaches by the Faro Focus^{S} laser scanner (Faro, 2021).

4 RESULTS AND DISCUSSION

The approaches described in the previous section of the paper were compared to each other.

The distance between two targets mounted on the walls of the laboratory (W1 and W2) must remain the same. The distances between those targets measured from the laser scans using the first approach provided information about its accuracy. A variability of the estimates of distances between wall-mounted targets is presented in Figure 9. This variability is shown in respect to the average of all distances. This result shows that the variability stays within ±0.6 mm for all eleven scans.

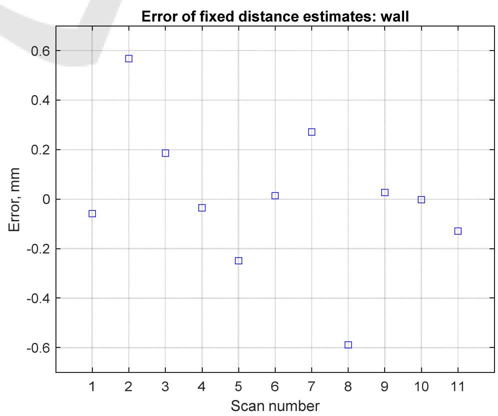

Figure 9: Variability of estimates of distances between wall fixed targets (W1 and W2): in respect to the mean.

The distances between the targets mounted on the movable block (LT and LB) must also remain the same. The variability of the distance measurements is presented in Figure 10. The variability of distances between those targets is also very close to ±0.6 mm for all eleven scans. The slight difference between the two variabilities can be related to the accuracy of the scanner or the spacing differences in the horizontal direction (wall-mounted targets) and vertical direction (left block mounted targets).

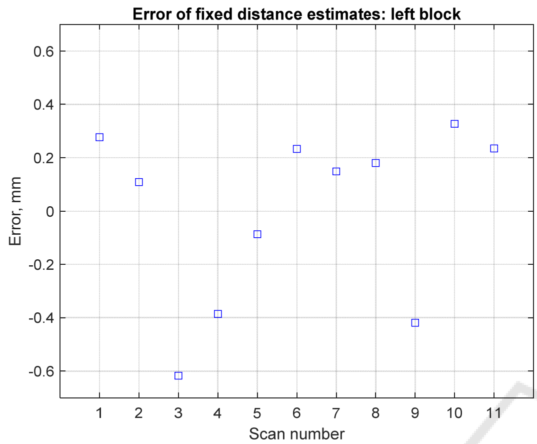

Figure 10: Variability of distances between LB and LT: in respect to the mean.

Figure 11 shows the displacements measured by both approaches compared to the displacements set by the high-precision blocks (noted as HP-blocks in the plot).

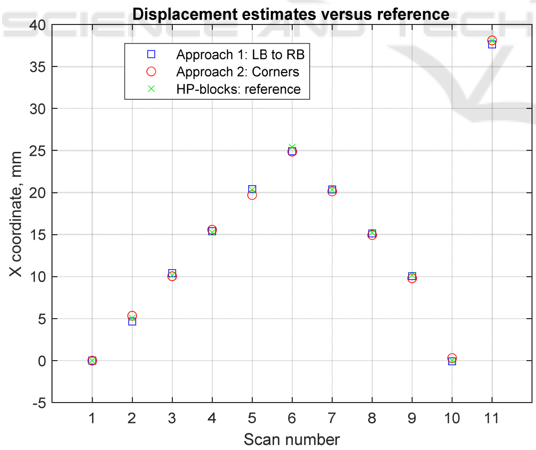

Figure 11: Displacement estimates: two approaches.

The error between the two approaches is presented in Figure 12. As shown in the plot, the error of the displacement estimate stays within ±0.55 mm.

As shown in Figure 12, both approaches have about the same sub-millimetre accuracy. The approach using the laser scanning targets has slightly better accuracy with the error remaining within a ±0.40 mm range around its average. In the approach based on tracking corners, the error varies within a ±0.55 mm range around its average.

Figure 12: Errors for two approaches (in respect to the mean).

5 CONCLUSIONS

The main objective of the paper was to evaluate two approaches aimed at tracking small displacements. The first approach is based on tracking displacements of laser targets commonly used for stitching point clouds to each other. The second approach is based on the estimation of corners of thin horizontal slices of a prismatic shape's point cloud. The corner's location is estimated as an intersection of two straight lines best fitted to the point clouds beyond the corner. It was shown that for both approaches a sub-millimetre accuracy can be achieved. The first approach requires the installation of two laser targets to measure the change of the distance between them but offers slightly better accuracy of ±0.4 mm. The second approach offers more flexibility because it does not require the installation of a laser target. Hence it can be used in the quantitative assessment of structural damage in aftermath of natural disasters such as earthquakes, fires, tsunamis, landslides, and hurricanes, to name a few. Based on the results of this work, the error of this approach is about ±0.55 mm greater than that of the first approach.

ACKNOWLEDGEMENTS

Special thanks are due to Faro for providing an access to the Faro Focus[S] laser scanner. Special thanks are due to Holly Halligan of UC Berkeley for editing the paper.

REFERENCES

Faro (2021). https://media.faro.com/-/media/Project/FARO/FARO/FARO/Resources/TechSheet_Focus_Laser_Scanner/TechSheet_Focus_Laser_Scanner_EN.pdf?rev=1291d7f5ef814fe99d471dde60321833.

Leica Geosystems AG (2007). https://w3.leica-geosystems.com/downloads123/hds/hds/ScanStation/brochures/LeicaScanStation%202_brochure_en.pdf.

Leica Geosystems AG (2011). Leica ScanStation C10. http://w3.leica-geosystems.com/downloads123/hds/hds/ScanStation%20C10/brochures-datasheet/Leica_ScanStation_C10_DS_us.pdf.

Leica Geosystems AG (2018). Cyclone Version 9.2.1.

MathWorks (2016). Matlab Version R2016b.

Mitutoyo (2016). https://www.mitutoyo.com/wp-content/uploads/2016/09/E-section-Gage-Blocks.pdf last retrieved on 11/23/20.

Mosalam, K.M., Takhirov, S.M., and Park, S. (2014). Applications of Laser Scanning to Structures in Laboratory Tests and Field Surveys. Journal of Structural Control and Health Monitoring, Volume 21, Issue 1, pages 115–134, January 2014.

Takhirov, S.M. (2009). Video, Still, and Laser Imaging at nees@berkeley: Case Studies, *Presentation at Bi-annual Hybrd Simulation Workshop*, August 2009.

Takhirov, S.M., and Mosalam K.M. (2014). Applications of Laser Scanning to Structural Testing and Field Survey in Earthquake Engineering. *10th US National Conference on Earthquake Engineering, Frontiers of Earthquake Engineering,* Quake Summit 2012, July 21-25, 2014, Anchorage, Alaska.

Takhirov, S.M., Gilani, A., and Allen, J. (2020). Experimental Evaluation of Novel On-Demand and Smart Real-Time Structural Monitoring of Buckling Restrained Brace's Deformation with Laser Scanners. EWSHM2020. The 10th European Workshop on Structural Health Monitoring. Palermo, Italy, July 6-9, 2020.

Takhirov, S.M. (2021). Control of Construction Quality by a Terrestrial Laser Scanner: Example of Steel Frame Building. *HORA-2021, the 3rd International Congress on Human-Computer Interaction, Optimization and Robotic Applications*, June 11-13, 2021, Turkey.

Takhirov, S.M., Gilani, A., and Allen, J. (2021). Comparative Evaluation of Laser Scanning and Image Tracking for Deformation Monitoring of Buckling Restrained Brace. *10th International Conference on Structural Health Monitoring of Intelligent Infrastructure*. 30 June - 2 July, 2021, Porto, Portugal.

Trimble Inc (2016). The Trimble TX6 laser scanner. http://trl.trimble.com/docus hare/dsweb /Get/Document-82496 5/022516-282_Trimb leTX6 DS_US_1016_LR.pdf. Accessed 3 Jan 2020.