A Comparison of the Terrestrial Laser Scanner & Total Station for Scene Documentation

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ABSTRACT

The use of the laser scanner for documentation at crime and collision scenes has grown significantly over the past ten years. Many law enforcement agencies and private firms who have traditionally used hand measurements or total stations have migrated over to the laser scanner because of the speed, ease of use, and amount of data it can capture. Unlike the total station, the laser scanner requires post processing to align all the separate scans. Depending on the method chosen, differences in accuracy may be noted. However, the use of external references such as spheres or checkerboard targets allows for a robust registration of scan data. Rather few studies have been published that look at the differences in accuracies between laser scanners and total stations. Therefore, this study looks to make a comparison between 20 distance measurements obtained by each instrument at a small to medium outdoor “scene”. The data obtained shows that, on average, the laser scanner and total station provide measurements that are within 0.8 mm of each other with a standard deviation of 2 mm. In one instance there was a maximum difference of 6 mm while in three cases the measurement errors were 0.000 mm.

Keywords: Crime scene survey, total station, laser scanner, crime scene reconstruction, accident reconstruction, forensic science

Introduction

The use of the total station in crime and collision scenes date back to the early 1990s where it was first claimed to be used in collision scene documentation [1]. The range and speed of the total station at the time allowed for greater accuracy, speed, and range when compared to traditional hand measurements using tape measures and plumb bobs. Similarly, one of the first reported uses of the laser scanner in a forensic capacity was in 2004 by German police to map a serious truck fire that damaged the underlying steel structure of a bridge [2]. Again, the speed and amount of data captured allowed for measurements to be taken at a safe distance from the scene and subsequently a short video fly through animation was created showing the captured data from different perspectives. Since then, the laser scanner has grown in use at law enforcement agencies and private firms all over the world. Germany, England, France, The Netherlands, and Switzerland are very well known for their use of the laser scanner in crime and collision scene documentation. Both Canada and the United States are continuing a rapid adoption of the laser scanner at police agencies and major government departments, thereby creating a shift in the way data is captured and presented in court.

To date, there are dozens of criminal and
civil cases where the laser scanner has been used in some capacity at trial. The International Association of Forensic and Security Metrology (IAFSM) website provides a list of case citations for which there are currently 20 confirmed cases which have gone to trial. It is estimated that this number represents only a smaller portion of the overall number of cases that have gone to trial since the Case Citations page is voluntary and by IAFSM members only [3]. Questions about the admissibility of data, calibration of the instrument, and knowledge of the operators plus other factors, which were previously of similar importance to the total station are now facing the laser scanner. Scanner data accuracy is often a complex question because of the way in which manufacturers report accuracy, which is not easily translated into a practical setting. There are many variables that can affect the accuracy of laser scanner data such as how far the surface being captured is from the scanner, how light or dark the surface is, how glossy or reflective a surface may be, how transparent (e.g. glass), and also how the individual scans are registered in the overall data set.

Registration is a term used to describe the process of placing individual scans together like pieces of a puzzle so that all the data is aligned in one coordinate system and closely resembles how things were captured in reality. There are many techniques to achieving registration, but the two most common are through the use of artificial targets and through the scan data itself, often referred to as “cloud-to-cloud” registration. Each method has its advantages and disadvantages depending on the type of environment one is situated in. Targeted registration often uses spheres or flat checkerboard targets that need to be inserted throughout the scene such that they can be detected in more than one laser scan. The software that normally accompanies the laser scanner hardware is used to identify these targets in each of the scans and subsequently the scans are aligned based on the similar positions of the targets. However, placing targets in a very large scene can be cumbersome while in smaller scenes the placement of targets may increase the risk of contamination.

Cloud-to-cloud registration does not require any use of targets, but it does require that there is a uniqueness to the geometry of the environment. The more unique the geometry and overlap between adjacent scans, the stronger the registration may be. Symmetrically-shaped rooms or areas where there is a lack of vertical structure can cause a poor registration of laser scan data. Also, a significant amount of overlap between adjacent scan positions is required in order to find enough similar geometry to create a strong alignment. A very long and straight hallway with a rectangular profile would be a poor choice for a cloud-to-cloud registration as would be an open and flat field void of any buildings or walls in the vicinity. This is often a common problem for collision scenes that are in rural areas where there is a relatively flat and straight section of roadway with very little structure on either side of the road. In these cases, it would be preferable to use a targeted registration solution with spheres or flat checkerboard targets.

Regardless of which registration method is chosen, aligning multiple scans means that there will be additional inherent errors when compared to measurements taken in a single scan. Continuing on the example of a long, straight stretch of roadway, if the first and last scans are connected through several other scans which are aligned to one another (like links in a chain), then there will be an accumulation of error which is propagated to the last scan. Normally, a least square error adjustment (or bundle adjustment) is made by the software to minimize alignment errors and reported in a registration report from the software. However, these reports are often based on statistical measures and do not account for all factors of measurement. Many points will have accuracies better or worse than what is found in the report. The difficulty that an operator faces in the field or in the office is that there are few practical ways of checking how these errors compare to a known, reference measurement that represents data from multiple scan positions and has a known precision relevant to that of the scanner.

Reference poles with marked targets on either end have been suggested by scanner manufacturers as a means to check the accuracy of the scanner. However, these poles are normally less than 2 m in length and do not span farther than a single scan. In some cases, people will place a steel measuring tape that spans several meters in the vicinity of the scanner as a reference measurement to compare against. This reference measurement
also does not span farther than a single scan and neither method takes into account what effect multiple registered scans have on accuracy. Perhaps a better method of capturing a reference measurement would be to use a laser distometer. The precision and accuracy of currently available distometers is described by ISO Standard 16331-1. Many commonly purchased brands have manufacturer stated accuracies of 1-3 mm over the stated distance range [4]. By setting up and measuring between fixed points over larger distances of 40 m or more, multiple scans could be checked to allow for some of the registration errors to be factored into the overall accuracy.

To validate the accuracy of the laser scanner’s registered point cloud it could be compared to an established technology, the total station. Utilizing the total station to measure between common points allows for a tangible method of comparison over very large distances. However, this is not always a practical method since it requires more manpower and equipment in the field. However, it is important to understand what relative accuracies are between the total station and the laser scanner when the total station data is taken as the ground truth.

**Method**

Twelve checkerboard targets (Figure 1) were used as common points and placed throughout a mock scene. The total station occupied a location such that all of the checkerboard targets were in view and it did not interfere with the laser scanning process. Traversing is the act of occupying a new location to increase range or collect currently obstructed data. Traversing the total station tends to introduce small amounts of error and this was avoided by placing the targets in locations which were all visible to the total station within a single setup [5]. A traverse was also avoided with the understanding that many crime or collision scenes can potentially be surveyed with one occupy location. A fixed back sight was established using a -30 mm offset prism on a prism pole and bipod. The backsight was placed in the scene among the checkerboard targets, just over 20 m to the east of the total station. This backsight was the first point collected and was collected again at the end of the survey to display any error in the total station and its operation.

Once the back sight was set, checked, and collected as point one, the twelve checkerboard targets were located around the scene in a counterclockwise manner and shot in reflectorless mode. The survey concluded with a check of the back sight. This process was repeated three times, collecting three separate data sets. The data set used in comparison to the laser scan data was the set which displayed the smallest difference between the two back sight shots. The smallest difference would indicate the most accurate operation of the device over the course of the survey, reducing the possibility leveling was disturbed at the total station and providing the most accurate data possible for comparison. In this case, the second survey was used.

The scanning process was set up as to traverse the laser scanner through the scene in a counterclockwise manner as seen from the total station point of view. To aid in the point cloud registration process, reference spheres (Figure 2) were used throughout the scene such that three common reference spheres could be recognized from each scan position. The chosen resolution settings required that the laser scanner was within 18 meters of the common reference spheres and the spheres were arranged throughout the scene to allow this. This distance was also used as a guide when locating the laser scanner to capture each of the twelve checkerboards. The scan parameters were set to ¼ resolution and 3× quality. Color was not applied as it would greatly increase the time for each scan and was deemed to provide no added value to the experiment. Fifteen scans were performed to adequately document the entire scene, focusing on the locations of the twelve common point checkerboard targets also located by the total station.

![Figure 1: Example checkerboard target (6 × 6 in).](image-url)
Registration was performed using the FARO Scene software target-based registration using the reference spheres. Although target-based registration can be performed with checkerboard targets as well, that option was not utilized, as the checkerboards were being used as evidence markers within the mock scene that the registration software can easily recognize as having a centrally located data point and it was unclear if error would be introduced by registering with the measurement points themselves. The target-based process was almost completely automated and completed successfully on the first iteration. While different registration software offers different methods of calculating and displaying registration statistics, FARO Scene uses a Scan Manager to display mean target tensions, among other statistics, which describes how well the individual targets that were visible in each scan fit with the registered cloud. While the exact quality criteria for registration is not stated it was intended to use the software as outlined in the associated manual.

Once registration was successfully completed through the target based process, checkerboards T1 through T12 were manually located within the registered scans with the Scene checkerboard tool and measurements between objects were taken to determine the distance between various checkerboard pairs. Twenty pairs were selected to have a variety of distances as well as angles relative to the area that was scanned. The survey data was copied from the data collector and imported into the CAD software package Rhino. The aligned distance command was used to measure the same twenty target pairs as were measured in both scene projects.

Registration of the survey points and the scan data was not performed as some sort of reference would need to be established and by doing this, certain target points could be forced to align with each other, thereby propagating or transferring errors they had elsewhere. It was important to be able to establish how and why any significant error did occur by removing any direct relationship between the scan and survey data.

The Scene

The area chosen for the scene was a section of parking lot outside the Origin offices in Liberty Lake, Washington. The general layout is shown in Figure 3. The area measured approximately 30 meters from east to west and 70 meters from north to south. The scene also exhibited a visible inclination from north to south, however the exact change in elevation was not measured. This section was chosen because of the variety of geometries offered by the west entrance of the office building that included the shipping and receiving areas. The area also maintained low vehicle and pedestrian traffic allowing us to perform the experiment efficiently and without interruption. The total station occupied a location slightly west of the center of the scene with a clear line of sight to all the checkerboard targets. The checkerboards were placed at various heights on a large company sign, a sign pole, a utility pole, a refuse bin, a trailer, and multiple locations on the building that was the east edge of our scene.
Equipment
- Nikon P-322+ Total Station
- Spectra prism target with pole and bipod
- Nomad data collector with Survey Pro software
- FARO Focus x330 Laser Scanner
- FARO checkerboard targets
- ATS 139 mm sphere targets

The Nikon P-322+ has the following distance precision, as described in the Instruction Manual:

Prism
- 1.5 m to 5 m ±(5 + 3 ppm × D) mm
- Over 5 m ±(2 + 3 ppm × D) mm (ISO17123-4)
- Over 5 m ±(2 + 2 ppm × D) mm (-10 °C ~ 40 °C)

Reflectorless
- 1.5 m to 5 m ±(10 + 3 ppm × D) mm
- Over 5 m ±(3 + 3 ppm × D) mm

Note: ppm refers to parts per million, D is the distance range.

The tech sheet for the Faro x330 notes a ranging error of ±2 mm. This ranging error is defined as a systematic measurement error at around 10 m to 25 m, one sigma.

Results
Registration of the scan data was performed and the scan results were provided in the ScanManager of the FARO Scene software (Figure 4). The target tensions represent the error in meters to where a specific target’s center position has been calculated between two scans. Once the indicator showed a “green light”, the results were inspected and accepted with a mean error of 0.0021 mm. The minimum error indicated in this registration was 0.0000 mm with a maximum error of 0.0090 mm. It should be noted that this result does not directly translate to errors for the measured targets and is merely an indicator. An acceptable result in the software is dependant on a number of factors including a user value for “threshold”. Typically, projects that provide a mean error in the centimeter range are closer to a “yellow indicator” or warning of a poorly registered set of scans. Ultimately, it is up to the user to accept or reject the scan results by

![Figure 3: Target layout configuration.](image)
looking more closely at the individual statistics, plus inspecting the actual data in 3D to ensure there are no obvious signs of misalignment.

The data from the total station and laser scanner were processed and tabulated below. The relative differences between the two sets of data were noted and on average, the results were found to be near 2 mm. In three cases, the result was zero (rounded to third decimal place) while in only one case was there an extreme value of 6 mm. The majority of values fell within a range of 0 to 3 mm. It is important to note that the measurement differences reported below are relative differences between the total station and the laser scanner data. It is not possible to discern which one is more accurate since we do not have an instrument of greater accuracy as the stated reference or “true” value.

**Discussion**

Results from this experiment show that the laser scanner measurements are very comparable to the total station measurements when evaluating the distance between common points. From Table 1, the comparison that showed the highest difference of 6 mm, labeled as Distance 9, had points approximately 14 m apart. These targets, T11 and T12, were the two targets located the furthest behind the total station, assuming the back sight is straight ahead, which may suggest a levelling error or a bad measurement. As a highly sensitive instrument, this error can be inadvertently introduced during the initial levelling of the total station or is caused by an unnoticed disturbance. It was also noted that all of the targets had a distance from the total station in the range of 20 m to 30 m. The only target closer than 20 m to the total station was checkerboard T12 which was 14.4 m from the total station. It could not be ruled out that it may have been an unintended aiming error but it can be noted here that the surveys were performed to represent how the systems would be used at a crime or collision scene and some error arising from this situation would be acceptable to the study.

Locating the checkerboard targets within the point cloud presents a possibility for error due to pixel resolution. The manual selection tool requires the user to locate each checkerboard and select a single pixel point to identify the target center. Sometimes a centrally located pixel is not available and the pixel selected for checkerboard recognition is slightly off center.
Another possibility for human error is the total station reflector-less shots of each checkerboard target. The total station technician must take care to target each checkerboard visually using the total station optics. Any shot taken that is not directly centered on the checkerboard will create a small amount of error in the location data. The combination of these is likely contributed to the 6 mm difference noted with Distance 9.

Table 1 also shows that all of the other measurements have differences of 3 mm or less with an overall average difference of 2 mm, and excluding Distance 9 has a negligible effect on this average. Distance 6, Distance 12, and Distance 13 all showed a difference of 0 mm.

**Conclusion**

The primary goal of this study was to determine if a laser scanner is comparable in accuracy to a total station when measuring evidentiary data at crime and collision scenes. When reference spheres are used for point cloud registration, the error between point cloud and total station measurements becomes negligible.

Laser scanning and total station surveying each have their own advantages and disadvantages; this remains true in a collision or crime scene reconstruction application. Laser scanning is a quick and effective way to obtain all the data of a scene or site. All geometry in the line of sight of the instrument is collected and stored. On occasion, evidence that is seen as unimportant at the time of collection may become critical as new investigative information. A set of registered scans also results in a high quality visualization of the scene without the need for additional processing and modeling, especially if color data is collected. However some extensive processing of the point clouds may be necessary when developing exhibits intended for trial or with point clouds containing noise from moving vehicles, objects, or vegetation, which can also obscure the ground plane from the scanner altogether. Evidence markers that are strategically placed can ensure the scanner collects evidence that could be otherwise missed.

### Table 1: Distance measurements and comparison.

<table>
<thead>
<tr>
<th>Distance</th>
<th>Target</th>
<th>Target</th>
<th>Total Station Distance (m)</th>
<th>Survey Point Cloud FARO Scene Distance (m)</th>
<th>Difference [Survey – Scan] (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>T1</td>
<td>T12</td>
<td>44.813</td>
<td>44.814</td>
<td>0.001</td>
</tr>
<tr>
<td>2</td>
<td>T2</td>
<td>T4</td>
<td>11.958</td>
<td>11.961</td>
<td>0.003</td>
</tr>
<tr>
<td>3</td>
<td>T1</td>
<td>T10</td>
<td>61.113</td>
<td>61.116</td>
<td>0.003</td>
</tr>
<tr>
<td>4</td>
<td>T3</td>
<td>T8</td>
<td>37.046</td>
<td>37.045</td>
<td>0.001</td>
</tr>
<tr>
<td>5</td>
<td>T7</td>
<td>T9</td>
<td>10.103</td>
<td>10.105</td>
<td>0.002</td>
</tr>
<tr>
<td>6</td>
<td>T5</td>
<td>T11</td>
<td>29.504</td>
<td>29.504</td>
<td>0.000</td>
</tr>
<tr>
<td>7</td>
<td>T6</td>
<td>T12</td>
<td>27.314</td>
<td>27.312</td>
<td>0.002</td>
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<tr>
<td>8</td>
<td>T2</td>
<td>T11</td>
<td>43.380</td>
<td>43.383</td>
<td>0.003</td>
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<tr>
<td>9</td>
<td>T11</td>
<td>T12</td>
<td>14.406</td>
<td>14.412</td>
<td>0.006</td>
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<tr>
<td>10</td>
<td>T1</td>
<td>T2</td>
<td>19.497</td>
<td>19.495</td>
<td>0.002</td>
</tr>
<tr>
<td>11</td>
<td>T6</td>
<td>T11</td>
<td>25.506</td>
<td>25.505</td>
<td>0.001</td>
</tr>
<tr>
<td>12</td>
<td>T1</td>
<td>T5</td>
<td>39.496</td>
<td>39.496</td>
<td>0.000</td>
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<tr>
<td>13</td>
<td>T8</td>
<td>T9</td>
<td>3.8360</td>
<td>3.8360</td>
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</tr>
<tr>
<td>14</td>
<td>T3</td>
<td>T6</td>
<td>23.878</td>
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<tr>
<td>15</td>
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<td>24.765</td>
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</tr>
<tr>
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<td>T7</td>
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<td>15.627</td>
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<td>34.239</td>
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<tr>
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<td>17.937</td>
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<tr>
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<td>T5</td>
<td>16.051</td>
<td>16.050</td>
<td>0.001</td>
</tr>
</tbody>
</table>

**Average Error** 0.002
The total station is limited in the quantity of data it can obtain. Each point must be selected by the technicians, targeted, collected, and labeled. Each of these steps allow for human error. If the prism pole is not perfectly plumb or if the sight is not set exactly where the target is, error is introduced. To create a visualization of a site, points must be collected, one at a time, for all the geometry of interest. It must then be processed and modeled in a CAD package. Even with these disadvantages the total station remains the best way to collect discrete points. With a total station the technician can place a prism pole right on the point desired and can be sure that it will be in the data. It can quickly survey large distances without needing to set-up stations in between, and total stations can collect accurate surface data regardless of the level of vegetation.

When dealing with crime and accident reconstruction, scene measurements typically do not require precision in the sub-millimeter range. This research would suggest that laser scanner data is just as accurate as total station data for this purpose. In dealing with vehicle crush, scanned vehicles can easily be measured and due to the conventions applied in crush analysis, a 6 mm error will have a negligible effect when performing crush energy calculations. Similarly, tire marks, gouges, and placement of evidence on a roadway is often scattered over a range where an error as seen in Table 1 would have a negligible effect on standard reconstruction computations and reliable evidentiary documentation.

A future experiment may include allowance for a wider range of distances for the checkerboards from the total station/laser scanner. The data point with the 6 mm difference was nearly 5 m closer to the total station than any other target, which were all located from 20 m to 30 m from the total station. There is the possibility that this was a result of human error. Since this study only provides a relative error, using a laser tracker or other instrument capable of measuring over greater distances but at accuracies in the sub-millimeter range would improve this experiment.

The authors have shown that the laser scanner’s accuracy is comparable to that of the total station. Because a laser scanner has the capability to collect large amounts of data that a total station would not practically collect, evidence can be preserved for future analysis that goes beyond that of traditional surveys.

References