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Laser Scanning Efficiency of Outdoor Crash and Crime Scenes

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THE FARO FOCUS 3D LASER SCANNERS are being used by forensic reconstructionists when there is a need to quickly open important traffic routes or situations of rapidly deteriorating evidence. The details of a large outdoor scene can be captured in minutes with a laser scanner.

Overview

The use of the laser scanner at crime and crash scenes offers different workflows with varying degrees of time required at the scene. In cases where speed of capture and efficiency are factors, the approach taken at the scene must change to minimize the number of scans and overall time required, without sacrificing the necessary level of detail and area covered by the scanner. In this paper, scanning and point cloud registration methods are discussed to determine the most efficient approach to capturing data at a crime or crash scene. The optimum distance between laser scanner set-up locations and the distance between the scanner and target spheres is also explored. The time required to scan a scene and process the data using targets is compared to the time required to capture the same scene using targetless, cloud-to-cloud, registration. The results show that it is possible to scan an overall area of 120 m (i.e. maximum distance on the roadway surface) in as little as 10 minutes, with sufficient detail to create an accurate drawing of the scene.

Introduction

Laser Scanning of crime and accident scenes is undoubtedly a useful and important task when complex and detailed documentation is required for an investigation. In many cases, minimizing the time to document the scene is not an issue and the scene may be held for long periods of time. However, when the documentation effort impacts main arteries of traffic, local businesses and the general public, there is greater pressure on police to reopen the roads and get things back to a state of "normal flow".

The paradigm for documentation with a laser scanner is significantly different than with a total station, GPS or UAV-photogrammetry based methods. Each has its strengths and weaknesses with a minimum time required for setup, capture and processing of data. Common total station and GPS based systems are limited to capturing one point at a time, so it requires more time to capture greater detail. Therefore, it would be unreasonable to compare these systems on the total number of data points captured since the laser scanner would be the clear winner in this category. Unlike the total station or GPS based systems, the laser scanner is indiscriminate in what it captures. As long as sufficient resolution or point density is chosen, millions of points can be collected within a radial region around the scanner. The level of detail of these scans should be enough to locate critical pieces of evidence/measurements and to create an accurate drawing. Although there are other possibilities for analysis with laser scan data, a court-ready, 2D, drawing is still one of the most requested deliverables from police.

The general workflow and time required to document a scene with a laser scanner can be affected by any number of reasons such as the required level of detail, type of analysis being performed, desire to have color capture, or the final deliverable (such as a camera fly-through or virtual tour). In most situations, having a greater number of closely positioned scans increases the coverage of point data without voids and will provide a visually appealing point cloud. However, taking more scans also equates to more time at the scene, reducing speed and efficiency. In situations where the requirements are some basic measurements and a 2D drawing using common mapping software, the level of detail and number of scans required may be greatly minimized. This is primarily because all line work is created by tracing over the point cloud data and it may not be necessary to capture high resolution point data for general roadway features such as curbs, signs and structures. As a result, the amount of time the scanner is deployed at a scene can be greatly reduced while still capturing acceptable data.

When approaching any scanning project, there are two types of workflows that may be chosen. The first requires the use of targets, or some form of external control. The other takes advantage of targetless (or cloud-to-cloud) registration.

In situations where a targeted solution is preferred, spheres and checkerboard targets are a proven method of registering scans and have other benefits in post-processing since they are a completely automated solution in some software packages. On the other hand, cloud-to-cloud registration has an efficient workflow since all time spent in the field is on scanning and not placement of targets. Fully automated registration is possible in many instances, but may require additional input from the user in the post processing phase.

This study looks to determine the maximum range and time to scan a typical outdoor scene with only two scan positions using both external references (i.e. spheres) and a cloud to cloud approach. A large elevated tripod was used to increase the range on the ground. The additional time required to obtain color photographs has also been taken into consideration.

Large, Elevated Tripods

Elevation of a tripod is a key factor when trying to maximize the range of points to be scanned on the ground. Typically, the higher the scanner position, the greater the angle of incidence the laser signal makes with the ground and hence, the greater the likelihood of a stronger return signal to the scanner. A surface situated at 90° to the emitted signal will provide the strongest return signal to the scanner. Angles lower than 90° gradually become weaker until very little or no signal is returned to the scanner.

Therefore, a higher scanner position relative to the ground means that the scanner will capture points at greater distances than when the scanner is closer to the ground. ***Figure 1***, below, shows the relative difference in angle to the ground at a distance of 10m (32.8 ft) from the scanner. ***Figure 2*** shows a much smaller angle of incidence as the laser hits the surface of the ground at a distance of 50 m (164 ft). Since we wish to maximize the angle of incidence in all directions from the scanner, the best option is to use a tripod with increased elevation.

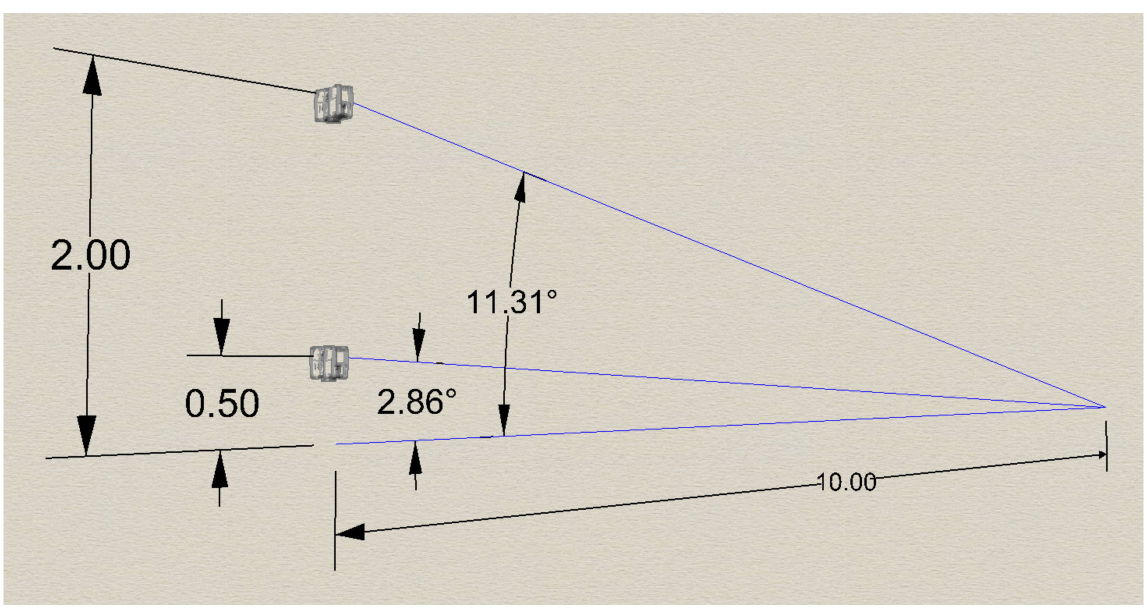

Figure 1. *Angles of incidence at 10m for scanner heights of 0.5m and 2.0m respectively. Note: All dimensions in meters.*

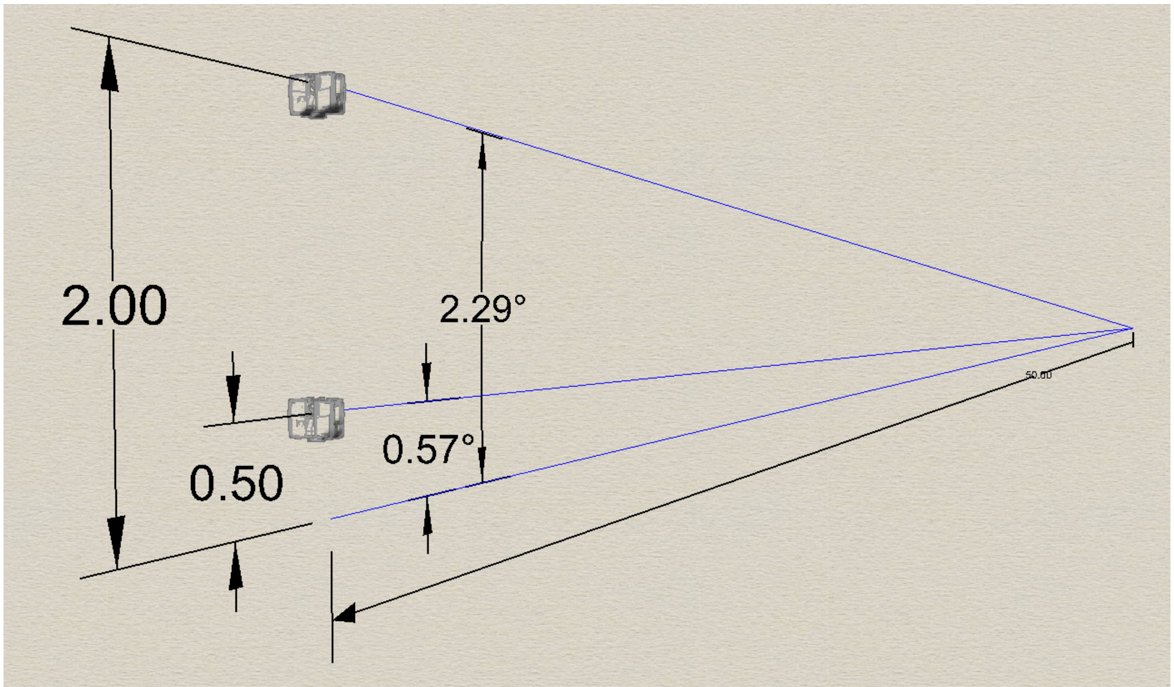

Figure 2. *Angles of incidence at 50m for scanner heights of 0.5m and 2.0m respectively. Note: All dimensions in meters.*

In this study, a 4 m (13.1 ft) tripod was used. The center column and the telescoping legs were all extended to roughly their maximum position. Some adjustment was made to account for the non-level ground of the asphalt and parts of each leg may have been raised or lowered as necessary to get a rough level of the instrument within ±5 degrees. Within this range, the onboard inclinometer corrects for being off-level. It would be tedious and time consuming to manually level the instrument at an elevation of 4 meters. This is not required since the inclinometer automatically adjusts the scan data, which saves the user a significant amount of time.

Resolution and Quality Settings

Resolution of the scanner can be thought of as the spacing between "sweeps" of the laser at a specified distance. In the case of the FARO scanner, this is specified by default at 10 m (32.8 ft) for any particular resolution setting. The resolution settings are given in fractional numbers in relation to the maximum possible point capture speed of the scanner (i.e. 976,000 points per second)[1] . Therefore, a ¼ resolution setting results in a point spacing of 6.13 mm at 10 meters (0.24 in at 32.8 ft) and captures points at a rate of 122,000 points per second. This was the setting chosen for all the scans done in this study.

Quality is a determination of sampling frequency and typical values used in practice vary from a setting between 2X and 4X. As the quality value is increased, a point is sampled a greater number of times and, statistically, should result in a better value with less noise. However, in terms of producing a 2D drawing, (possibly over several hundred meters), it is difficult to quantify how the reduced quality actually effects the final 2D drawing. While there may be some additional noise of scan points, in practice, it is a negligible amount. This justifies the time savings that results from using the lower quality setting of 2X which we used in this study.

"Super Spheres"-Targeted Registration

The choice of registration method is often related to the type of environment being scanned. Indoor crime scenes and urban outdoor areas where there are plenty of vertical structures can often be registered without the use of any external targets. However, there are situations where the use of targets is recommended, such

1 FARO X330 Specification Sheet, https://www.repro-products.com/pdfs/brochures/faro/x330.pdf

as on country roads or interstate highways where moving tree branches and the lack of vertical structures will reduce the effectiveness of cloud-to-cloud registration. Spheres are often a better option than checkerboards since they can be scanned from any direction to provide the center point of the sphere. The size of the sphere and the resolution setting of the scanner are the two factors that determine the maximum distance a sphere may be reliably placed from the scanner. Using the largest spheres available allows scans to be taken farther apart, minimizing the time required capture a scene.

The spheres used in this study were made by Koppa Targets[2] and had an overall diameter of 400 mm (15.7 in). The outer surface was coated with a highly durable matte white coating and the spheres themselves were provided with an adapter on the bottom post that could be fixed to a standard survey tripod. Previous tests with this sphere at ¼ resolution resulted in a maximum "safe" distance from the scanner of approximately 40 m (131 ft). When registering point clouds in FARO SCENE software, it is ideal when the software can detect a minimum of 80 points on the surface of the sphere. This situation is shown in SCENE with a "green light", and it indicates that there is a strong, statistical fit to the centroid of the sphere. Below 80 points, the sphere becomes "yellow" as a warning to the user that the spherical fit may not be acceptable for registration. To ensure that SCENE can successfully use the spheres for registration; it is recommended to keep the spheres within 40 m of the scanner or increase the resolution in the scan settings.

Cloud to Cloud Registration

Cloud to Cloud registration is one of the most efficient workflows for crime and crash scenes since all time at the scene is focused on scanning and not spent planning and placing targets. There are many variables to consider when scanning without targets as each environment can be rather unique. The basic requirement is that there are solid, stationary and vertical structures within the range of the scanner which can be used to identify common points between neighboring scan positions. This is usually the case in urban settings where the edges of buildings are captured in the scans. Large, open expanses are poor candidates for cloud to cloud registration as they are void of vertical structure. Other considerations are environments which are non-static such as high traffic areas with pedestrians or vehicle traffic. Vegetation may also be problematic, such as in forested areas where tree branches and leaves are moved by the wind. In these cases, the movement of objects from one scan to another makes it difficult to use cloud-to-cloud registration successfully.

Overlap and similarity between scans is desired for a strong registration result. When the amount of overlap diminishes to less than 30%, registration results may prove to be weak and it will be difficult to accurately register the scans. Overlap percentages greater than 60% are more likely to yield strong results. In addition, the distance between adjacent scan positions is a factor since the farther apart the scan positions, the less overlap and less similarity exists between the scans. Typically, the greater the distance between scan positions, the greater the potential difficulty registering the scans. Eventually a point will be reached where the results exceed an acceptable value or the scans simply fail to register to one another.

Scan Positions and Sphere Layout

With the maximum distance of the spheres known at a resolution of ¼, it was possible to create a sketch of what the test setup might look like in the field. ***Figure 3*** shows that with 25% overlap in the scans, the distance between scanners is approximately 60 m (197 ft). The overlapping area results in an "eye-shape" with its major axis at approximately 53 m (174 ft) and its minor axis at 20 m (65.6 ft). Three spheres were placed in this area such that they were well spread out, but also in arbitrary locations.

2 http://www.koppatargets.com/store/p59/400mm_KoppaTuff_Target_Sphere.html

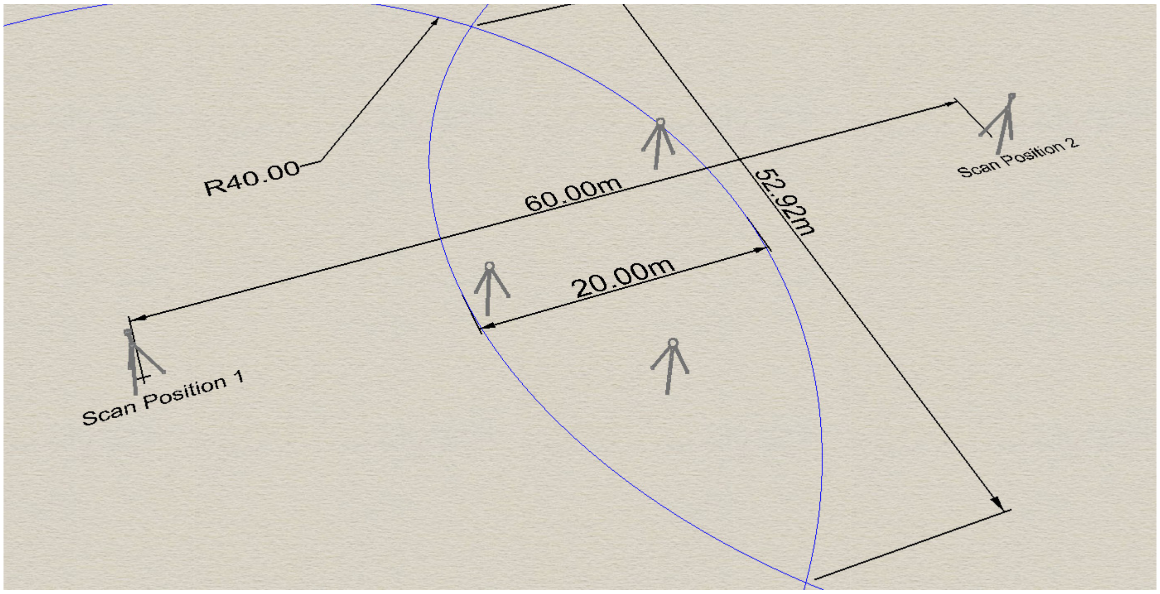

Figure 3. *Scanner Test Preplanning Layout: Note: All dimensions in meters*

Results-Targeted Scanning

Testing was done for the targeted scans in Vaughan, Ontario on a rural road with minimal traffic. The ambient conditions were overcast with a temperature of -5° Celsius and a 35km/hr headwind. The planned scan positions were marked in chalk on the roadway surface as a reference and the operator was timed to determine how long it took from the moment the equipment was removed from the storage containers until the final scan was complete. These segments were broken out and are described as follows:

- Spheres Set-Up – Removing the spheres from their bags, setting up on the tripods and moving them into position on the roadway.
- Scanner Set-Up – Removing the scanner from the case, removing and installing the scanner on the tripod, powering up, setting up a project file, entering all the scan settings and ensuring the Wi-Fi connection was operational.
- Scanner Positioning – Moving the scanner to position, extending the center column, extending the lower legs, rough leveling of legs.
- Scanning 1 – The portion of the scanning operation which is only scan point collection.
- Pictures – The portion of the scanning operation that included photo collection
- Re-Position Scanner – Lowering legs, carrying 60 m to new location, extending legs
- Scanning 2 - The portion of the scanning operation which is only scan point collection.
- Color Capture 2 - The portion of the scanning operation that included photo collection

The final operation was the removal of the SD card and processing of all data. This operation was done separately in an office environment and the processing time is included in the calculations. The breakdown of times is as follows:

Table 1. *Recorded times for operations and processing using targets*

Operation	Time (min)
Sphere Set-Up	2.00
Scanner Set-Up	4.50
Scanner Positioning	3.25
Scanning 1	2.17
Color Capture 2	3.33
Re-Position Scanner	2.00
Scanning 2	2.17
Color Capture 2	3.33
Processing	7.00

Targeted Registration Results

The processing results were found to be acceptable on the first attempt and no other modifications were made to the scan registration results. ***Figure 4*** shows the actual ScanManager in FARO SCENE (registration results in meters).

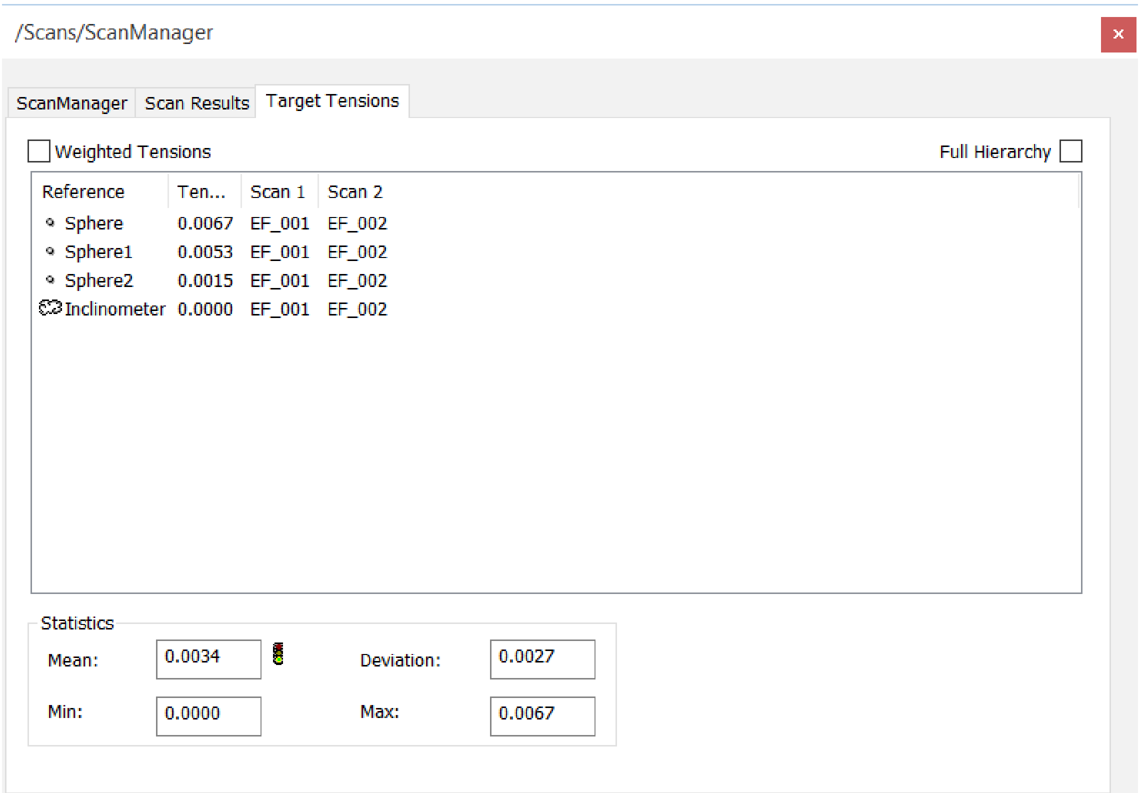

Figure 4. *ScanManager in FARO Scene showing registration results.*

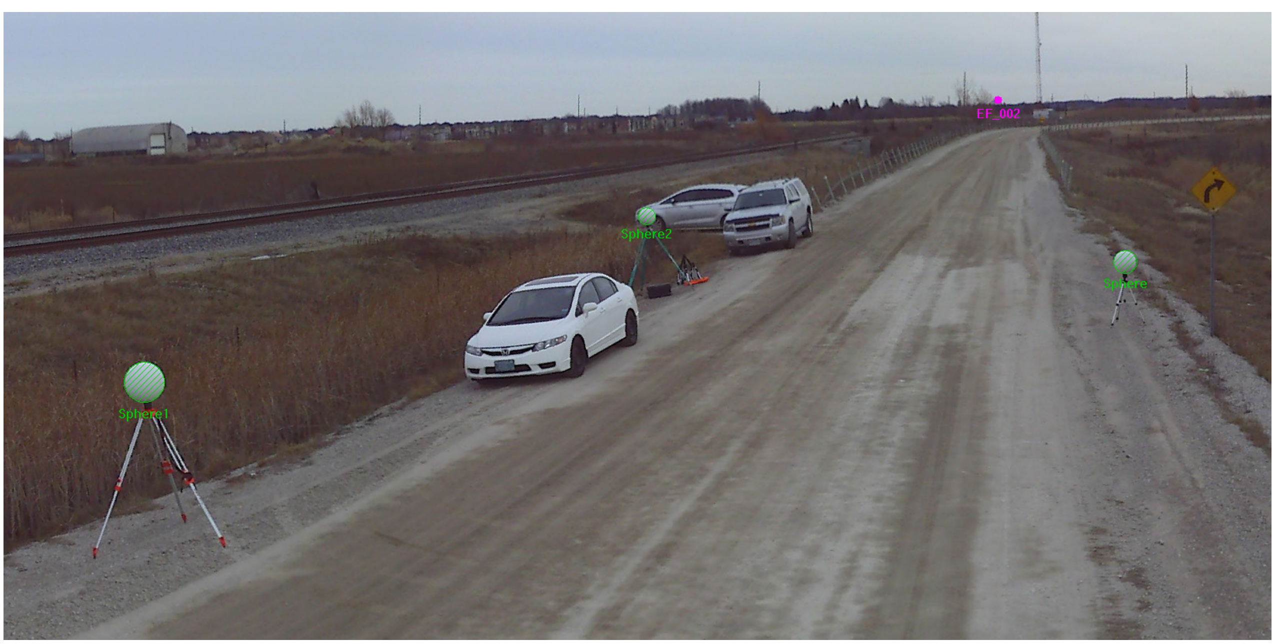

Figure 5. *Screen capture from FARO Scene showing a planar view from the second scan position*

Maximum Scanning Range-Targeted

Once the scans were registered, a measurement was taken from the most extreme points on the roadway. Although the X330 scanner has a range of 330 m (1082 ft), the practical limit on the ground (as explained earlier) was found to be approximately 170 m (557 ft), ***Figure 6***.

Figure 6. *Screen capture from FARO Scene showing a 3D view of the scans.*

Calculated Scanning Times

Based on the workflow times listed in ***Table 1*** above, some estimates, shown in ***Table 2***, for other scenarios can be drawn depending on the type of information required.

Table 2. *Calculated Scanning Times*

Total Time in Field-Scenario (no processing)	Time (min)
With spheres (targeted registration) and no color capture	16.1
With spheres (targeted registration) and color capture	22.8

Scan Positions for Cloud to Cloud Registration

Since there was no discrete way to calculate a successful registration based on the distance between two scan positions, this had to be determined empirically. The approach taken in this study was to scan in one position, move in a linear direction approximately 10 paces and then scan again. This was continued over a distance of approximately 60 m (197 ft). All scans would be registered in an order of 1-2, 1-3, 1-4 etc., thereby increasing the distance between scans and the registration results could be examined for an acceptable level of accuracy, ***Figure 7***.

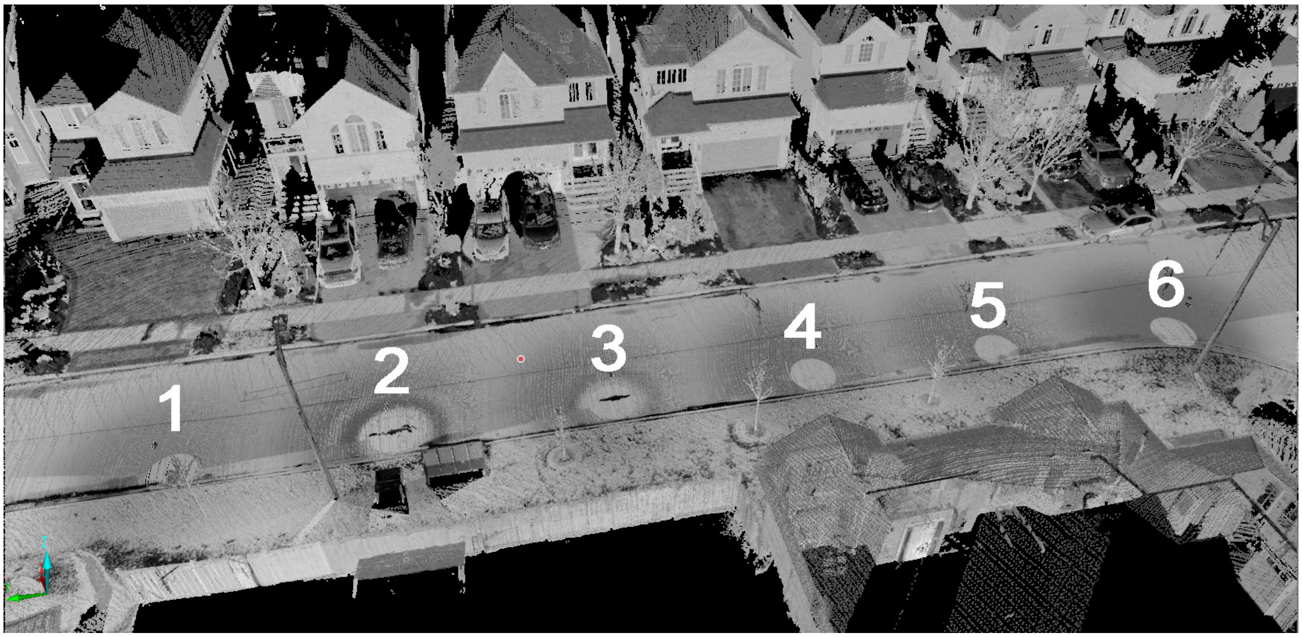

Figure 7. *Cloud to Cloud Scan Position Layout*

Results-Cloud to Cloud Registration

Similar to the tests which were performed with spheres, the operator was timed for scanner setup and scanning activities. Since times for photographs were already known, they were not repeated for cloud-to-cloud registration since this could be estimated. The final operation was the removal of the SD card and processing of all data. This operation was done separately back in an office environment and was included in the calculations. The breakdown of times was as follows:

Table 3. *Recorded times for operations and processing using cloud-to-cloud registration*

Operation	Time (min)
Scanner Set-Up	4.50
Scanner Positioning	0.20
Scanning 1	2.17
Re-Position Scanner	0.20
Scanning 2	2.17
Processing	8.00

Cloud to Cloud Registration Results

The results of the registration were checked between groups of scans in order of 1-2, 1-3, 1-4… etc. Each of these registration results were successful and within 5 mm (0.2 in) except for the last result between scans 1-6. In this case the scan results were greater than 6 mm (0.24 in) and although an attempt was made to minimize the error by adjusting the sampling and search distance, the values did not drop below 6 mm (0.24 in). The registration results for closest and farthest scans (i.e. 1-2 and 1-6) are provided in ***Figures 8 - 9*** below:

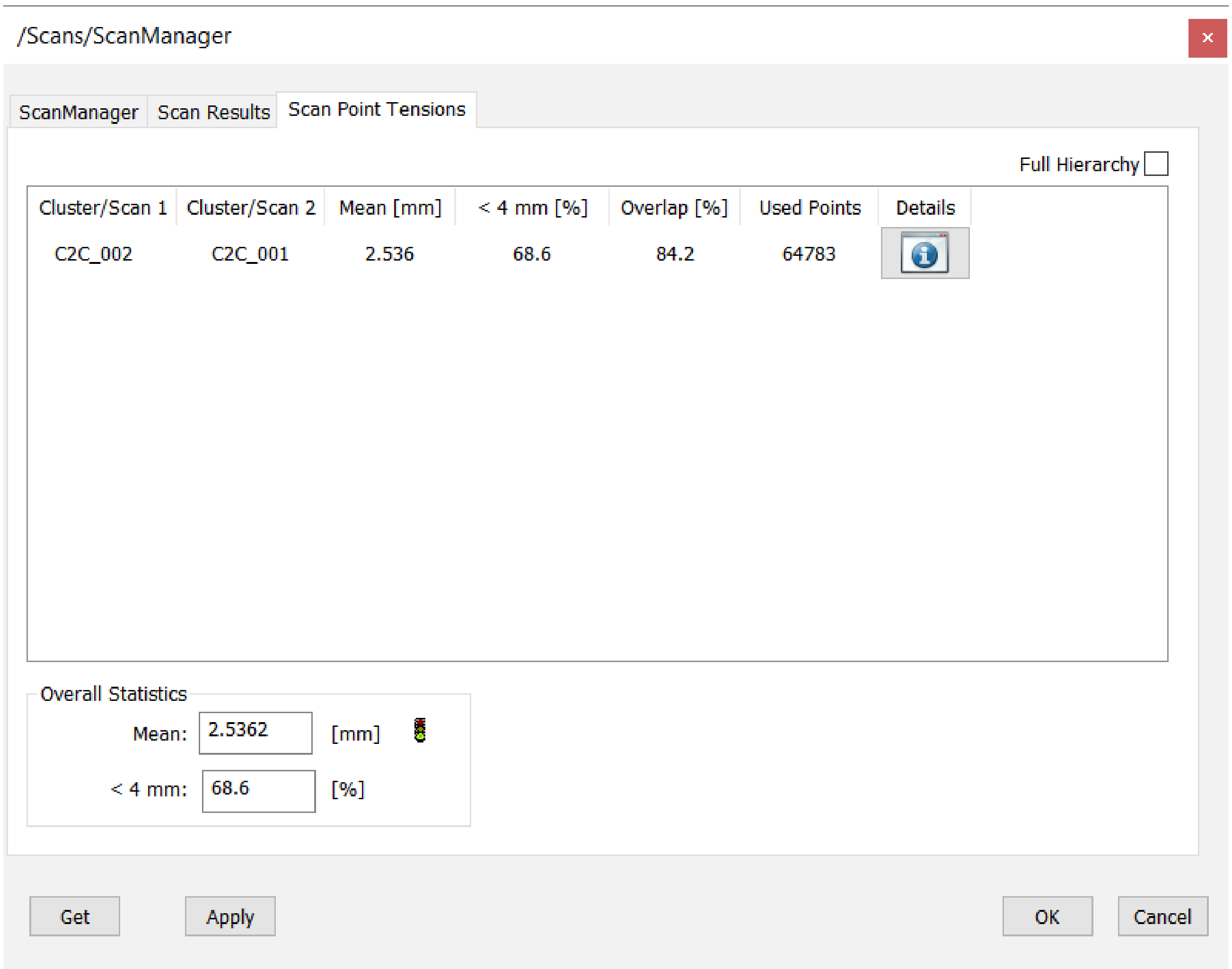

Figure 8. *Registration Results for Scans 1-2 (cloud to cloud)*

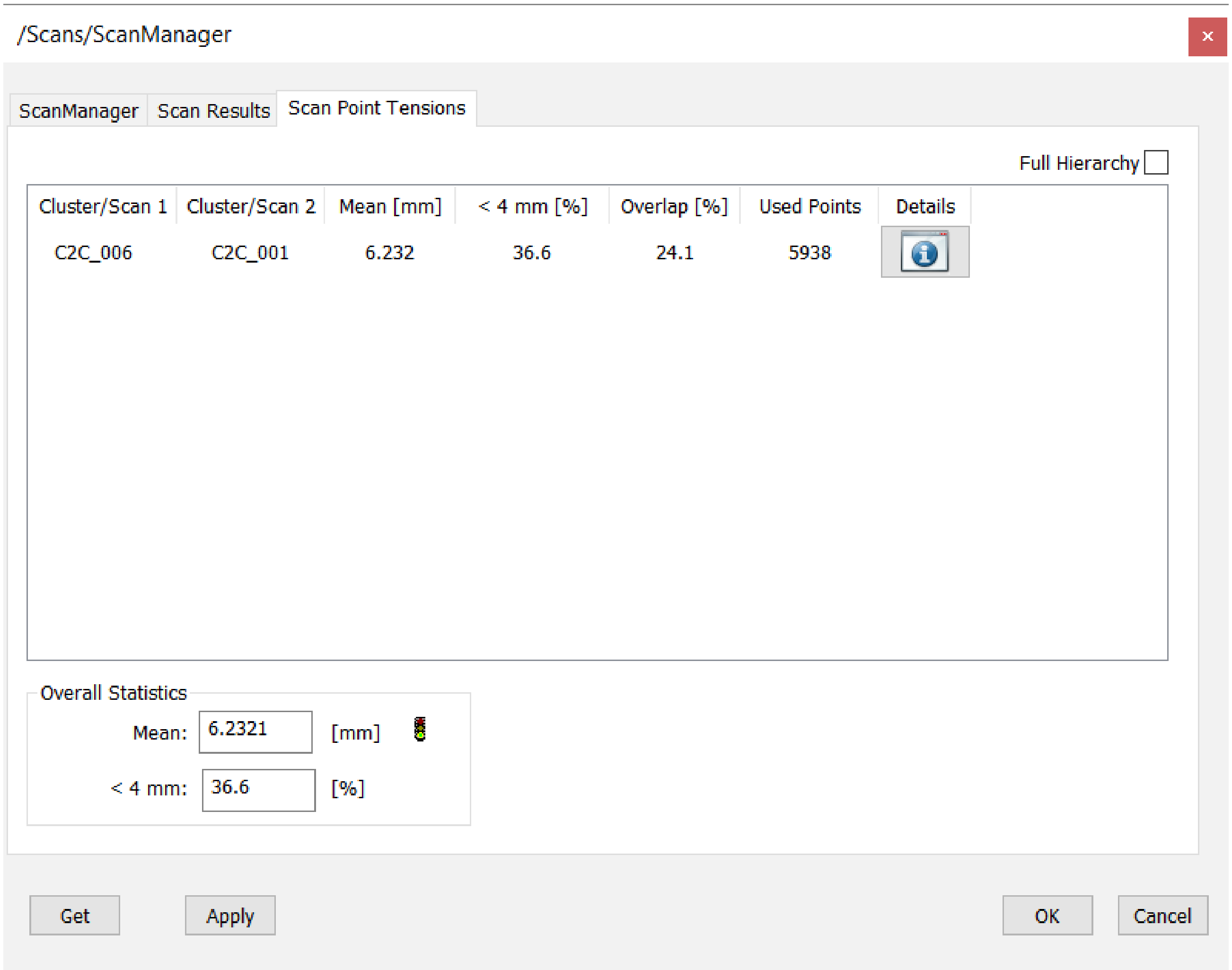

Figure 9. *Registration Results for Scans 1-6 (cloud to cloud)*

Maximum Roadway Scanning Range-Cloud to Cloud

The maximum distance between scans in this test was approximately 46 m (151 ft). The overall range of the scanner from end to end on the roadway surface was roughly 122 m (400 ft). This was accomplished using a tripod at a height of approximately 6 feet. Using an elevated tripod, as in the previous targeted tests, could have improved this result. The image below shows the registration layout. Although it may have been possible to extend the range of the registered scans by increasing the separation distance between individual scan positions, this was not attempted since the registration errors began to climb above a limit of 6mm (0.24 in). In cases where a greater error would be acceptable, the scan positions could be increased, which would result in a time savings at the scene. However, in practice, it is often difficult to make a calculated determination on the maximum scan positions for a cloud-to-cloud approach unless the operator has previous experience or is already familiar with the environment (***Figure 10***).

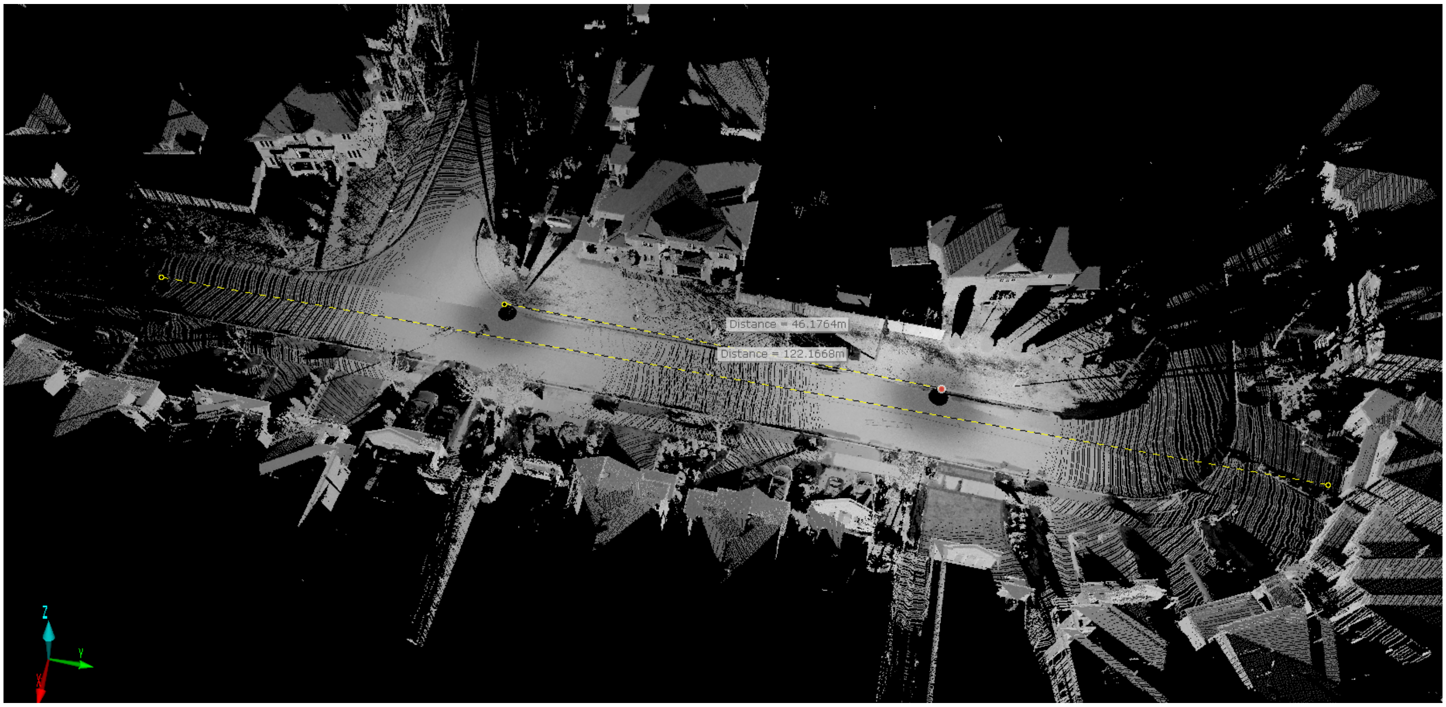

Figure 10. *3D View of Scans 1-6*

Cloud to Cloud Scan Times

Based on the workflow times listed in Table 3, some estimates for cloud to cloud workflows can be drawn.

Total Time in Field-Scenario (no processing)	Time (min)
Cloud-to-cloud scanning with no color capture	4.50
Cloud-to-cloud scanning and color capture	9.2

Creation of a 2D Drawing

As an example of what a final 2D drawing may look like, the data captured from the roadway when using spheres was used to create a 2D drawing in both FARO CrashZone and FARO Reality software. Both of these software programs (and similar programs) provide a method of picking or "snapping" to scan points to provide accurate creation of lines and other objects in the scene, ***Figures 11 - 12***.

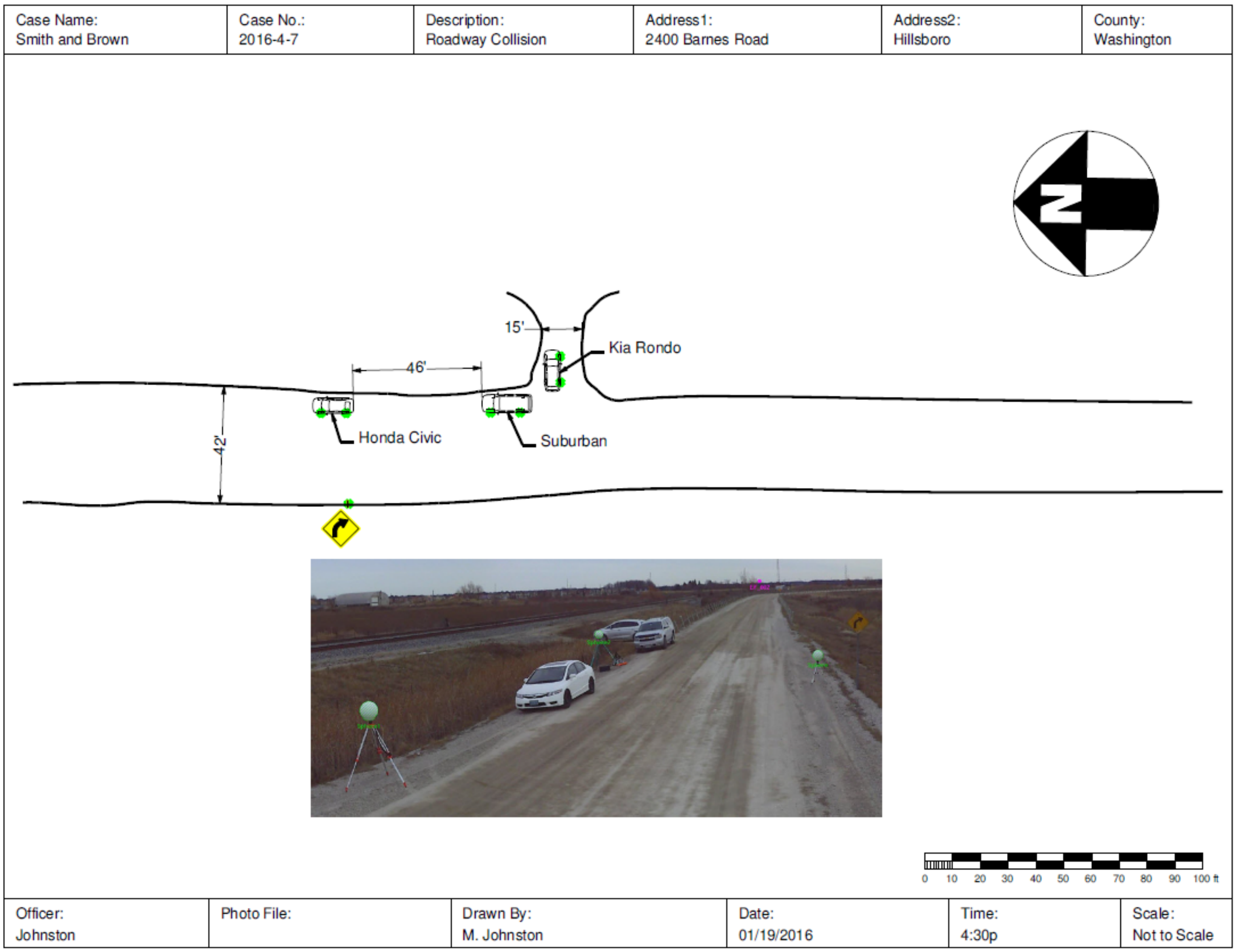

Figure 11. *2D Drawing created in CrashZone using data from roadway scans with spheres.*

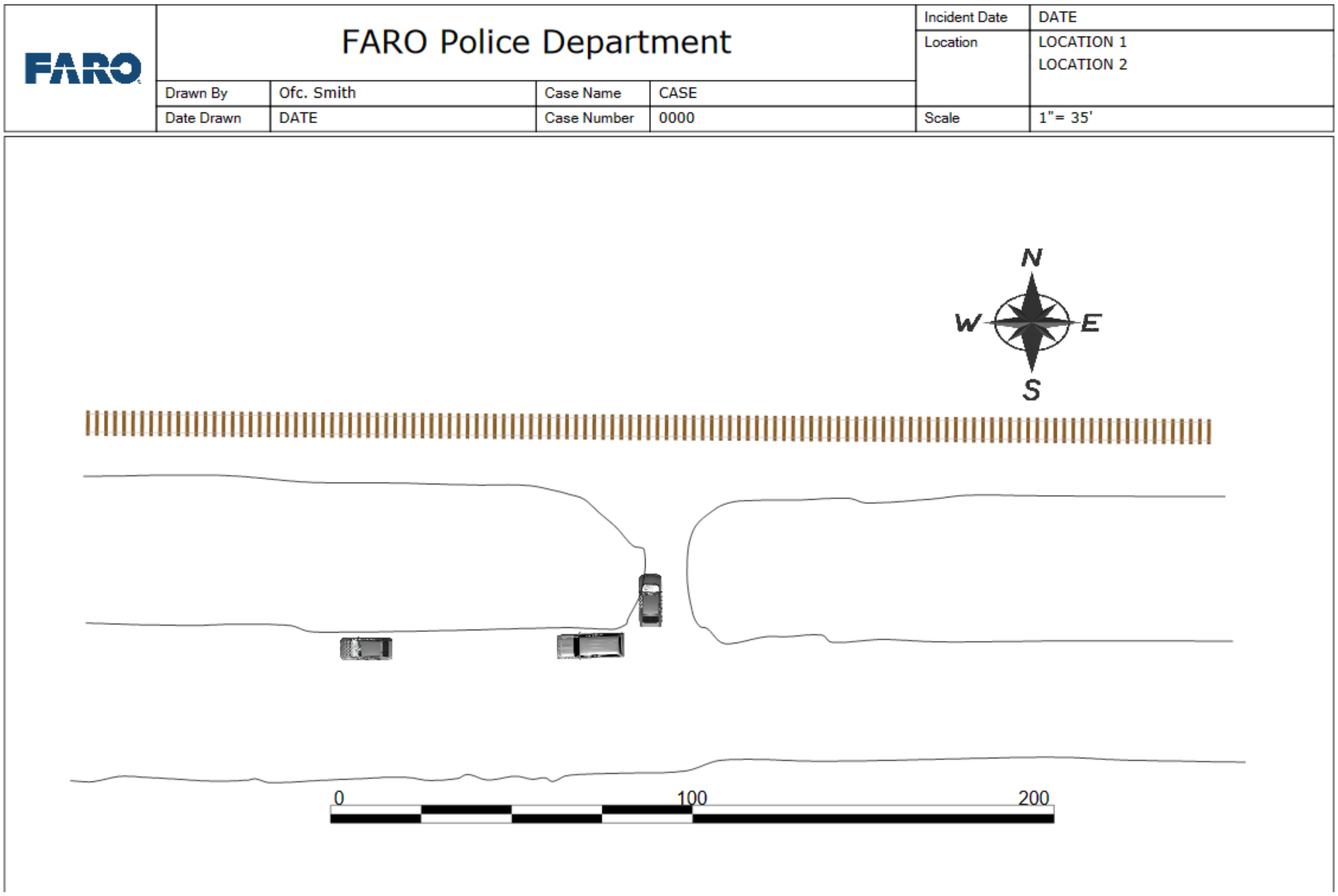

Figure 12. *2D Drawing created in Reality using data from roadway scans with spheres.*

Conclusion

In situations where a quick and efficient workflow is required, using a maximum separation between scan positions and an elevated tripod can significantly reduce the time required to scan a scene. Having a good understanding of maximum targeting range to spheres and the level of detail and resolution required in each scan is very helpful. This study shows that when there is a need to quickly open important traffic routes or situations of rapidly deteriorating evidence, a large outdoor scene between 120 m to 170 m (393 ft to 558 ft) can be captured in minutes. Increasing the scanner resolution increases the time to scan, but it also allows use of additional distance between scan positions and can provide greater range across the surface of the roadway. Using an elevated tripod can also increase the scanner's effective range on the roadway surface.

In this study, a single resolution and quality setting were tested. It has been shown that the minimum time to scan an outdoor scene (excluding processing) of approximately 170m on the roadway surface using a targeted approach varies between 16 and 23 minutes, depending on whether or not color capture is chosen. Additional time could be saved in areas well suited for a cloud-to-cloud approach with a range of roughly 122 m (400 ft). Times for targetless registration were between 9 and 17 minutes. In all cases, processing times for only 2 scan positions was below 10 minutes with successful registration results.

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