3D Documentation of a Clandestine Grave: A Comparison Between Manual and 3D Digital Methods

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ABSTRACT

The purpose of this research was to compare manual and 3D digital methods for documentation of a clandestine grave located at the University of Toronto Mississauga. Measurements were taken using manual trilateration as well as digitally using a total station and a terrestrial laser scanner. Comparisons were made between each method using 14 landmarks on a buried skeletal cast. Twenty-five measurements were taken across the 14 landmarks using Rhino, a 3D modelling software, as well as FARO Scene. These measurements were compared and found an average difference of 1 mm between the total station and the laser scanner measurements, 10 mm between the total station and manual measurements, and 10 mm between the laser scanner and manual measurements. The results provide investigators with an alternative method of clandestine grave documentation that can be more precise as well as being time and personnel efficient on scene.

Keywords: clandestine grave, trilateration, total station, laser scanner, crime scene survey, crime scene reconstruction, forensic science

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Introduction

Cases that involve buried skeletal remains incur many additional challenges, compared to traditional death investigations. If the case involves buried human remains, it is the job of the investigators to excavate and document the grave, its contents and the surrounding area, in coordination with the medical examiner's or coroner's office [1, 2]. Law enforcement officers can choose to rely on the expertise of a forensic anthropologist if the case requires it [1, 2]. To document the grave, forensic practitioners traditionally employ hand mapping techniques such as trilateration, triangulation, and baseline methods using measuring tapes, line levels, and plumb bobs [3]. Although these manual methods are accepted by the court system and forensic professions as accurate, easy to perform, and cost effective; they are time consuming, personnel intensive, and give a limited visualization of the grave. With the emergence of 3D mapping technologies such as terrestrial laser scanning and hand-held structured light scanners, the process of grave documentation could be drastically improved.

A clandestine grave or burial can be defined by the process of concealing a body in the ground [3, 4, 5, 6]. Crime scenes wherein a clandestine grave is located are unique in that they require a specialized set of techniques and tools to properly excavate, document and recover the human remains, and associated evidence buried within the grave. Unlike documenting a traditional crime scene in a residence or an outdoor scene where contextual information can be preserved throughout the documentation process, as soon as the clandestine grave excavation begins, there is an immediate risk of destruction for contextual information within the grave [3]. Soil must be removed from the grave, in a controlled, methodical manner, to ensure that all evidence is properly documented and collected.

A large amount of investigative information can be recovered from a clandestine grave if properly excavated and documented. Alternatively, when a clandestine grave is improperly documented and excavated, clues about the sequence of events, body position, and valuable pieces of evidence may be lost forever. Once a piece of evidence is removed from the grave, its contextual value is lost, meaning its relationship to other items in the grave as well as its depth can no longer be accurately determined and subsequently documented [3, 4, 5]. Therefore, proper training in following a sound methodology for grave excavation is paramount to the integrity of the evidence within a grave.

A proper documentation method to accurately and efficiently capture the specific location in three-dimensional space of items within a grave and the context surrounding those items is as important as a proper grave excavation technique. Depending upon the circumstances under which the human remains were placed in the grave, investigators rely heavily on the evidence found within the grave as well as the position in which the body was placed to reconstruct the events surrounding the burial. Valuable evidence can include weapons, clothing, cigarette butts, jewelry, identification, ligatures, and biological material. As an example, if a three-dimensional footwear impression is discovered below the body, one may infer it was created by the individual who dug the grave and therefore becomes a valuable piece of the reconstruction and subsequent identification of a suspect.

The relationship between the body's head, torso, and extremities may shed light on the manner in which the body was placed into the grave and is largely dependent upon the size of the grave, as well as the strength and number of individuals involved with the burial [3]. The position of the body inside the grave can also highlight pertinent case information such as whether or not the individual's hands or feet were bound. For example, if an individual was found with their hands behind their back, it can be inferred that the individual was bound, as ligatures (depending on the material used) tend to decompose faster than skeletal remains. Likewise, if there was any dismemberment, either pre-burial or post-burial, the position of the remains within the grave may help reconstruct these events [7]. Body position may also tell whether the burial is a primary burial (i.e. the body was placed within the grave and left undisturbed) or a secondary burial (i.e. the body was moved from one grave to another after a period of decomposition) [3, 6]. If the remains are found disarticulated, an investigator may be able to draw the conclusion that the burial is a secondary burial. Hence, the importance of properly documenting the remains' position within the burial is of great importance and could be lost if the remains are not properly documented.

This study compared manual and 3D digital methods for documenting a clandestine grave containing a casted set of human remains. More specifically, this research compared manual measurements of a skeleton using trilateration and digitally using a FARO X330 laser scanner and a Sokkia 530 R3 total station [8, 9]. The results of each measurement method were compared and analyzed in an effort to demonstrate which method might provide the greatest benefits in ease of use, accuracy and thoroughness of documentation, required personnel, and visualization capabilities.

3D Technologies for Clandestine Graves

Manual measurement methods have served crime scene investigators for years and continues to be a low cost and simple means of documenting crime and accident scenes. However, with simplicity comes some limitations on what can be documented since using measuring tapes requires coming into contact or close proximity to all items of evidence and points being measured. Thus, there is always a risk that evidence may be contaminated and/or disturbed. There are also limitations on how accurately or precisely a piece of evidence may be measured on sloped or irregular terrain. Using tape measures, plumb bobs, and string are suitable on indoor crime scenes and smaller outdoor scenes with flat surfaces, simple geometry and open spaces. However, there are many situations where it is practically impossible to give an accurate representation of a crime scene from manual methods due to the complexity of the environment. For example, evidence located on the side of a cliff or steep slope would be difficult to accurately document. The same can be said in areas with dense vegetation or obstructing objects. This is perhaps one of the greatest advantages when using 3D technologies such as laser scanners, structured light scanners and photogrammetry. The ability to reach and measure surfaces to a high degree of accuracy and repeatability over great distances is highly beneficial.

Total Station

The total station has been in use on crime and accident scenes since the 1990s [10]. This instrument is a laser-based device that sends out modulated laser signals which are reflected back to a receiver. The 3D position of a point can be calculated and reported directly to the operator. The unit is in effect two instruments in one with the electronic distance measuring (EDM) unit and the theodolite (to measure the vertical and horizontal angles). The obtained data is collected in spherical coordinates and automatically converted into 3D Cartesian used by CAD programs.

One of the benefits of the total station is that it can be used over very long distances (well over 1000 m) using a target prism and pole. The operator places the bottom tip of the pole over or next to any piece of evidence and once the pole is leveled, a measurement can be taken. Traditionally, the total station requires two people to operate (one to aim the unit and one to hold the prism pole), however there are several models available which are robotic and can be operated by one person that controls both the unit and the prism pole level. Robotic units can automatically track the prism pole and follow the operator as they move about a crime scene. That being said, most modern total stations allow for reflectorless operation which is a "point and shoot" operation. The operator looks through the eye piece and places the crosshairs on an object that they wish to measure. Once aligned, a sample measurement can be taken. Reflectorless measurements often have less range (roughly 500m or less) and can be subject to greater error because of the method being used to measure the distance. Total station manufacturers often provide error calculations based on the method of measurement in their respective specification sheets. Although the reflectorless total station may incur errors over larger scenes, it removes the additional variable of a rodman holding a pole unsteady and allows for measurements to be made at elevated positions (e.g. top of poles, upper floors of buildings).

The data captured with a total station is often restricted to distance and positional data. This data shows up as a table of points which can be exported to other software for creating plan drawings or sketches. The main limitation of using the total station is that capture time is relatively slow and documentation can be rather tedious. Only one point at a time can be captured and then the instrument needs to be targeted to the next position. As a result, areas where there are a lot of densely packed and complex pieces of evidence can be time consuming or simply impossible to capture with a high degree of detail. In addition, the setup time and process of moving a total station around the corner of a building or through a doorway to access areas that are out of the line of sight can be tedious and time consuming. Tight spaces with many obstructions means that the total station must be in the direct line of sight of evidence or at least the prism should be visible to the total station.

The Laser Scanner

There is no other instrument in existence today which can capture as many measurements/points of a crime scene in as little time as the laser scanner. Millions of tightly packed points can be captured of a scene in what is referred to as a "point cloud" which gives a representative and accurate view of the geometry or environment in a 360° window from the perspective of the laser scanner, with the only missing information being directly under the scanner. By aligning multiple scan positions together like pieces of a puzzle, an entire indoor or outdoor scene can be aligned together into a full 3D environment. As a result, more can be done with laser scanner data than when using manual measurements or a total station.

The laser scanner uses LiDAR (Light Detection and Ranging) technology at its core and there are different modes of operation. At the most basic level, the laser scanner operates in much the same fashion as the total station. The laser scanner sends out multiple signals to a surface and once these signals are reflected back to the receiver, it can calculate the angles and distance [11]. Unlike the total station, the laser scanner is fully automatic and does not require the operator to aim or target a specific object. The laser scanner rotates to capture the environment in a 360° fashion and has the additional option of capturing photographs.

When multiple scan positions are taken, there are different methods in which the scans can be aligned or "registered." Registration is a method of alignment where all the scans are brought into the same coordinate system to reflect and provide an accurate representation of the scene. There are basically two methods of registering scans together using special targets or simply the existing geometry in the environment. The use of spheres or checkerboard targets is a customary practice and well suited for clandestine graves since the area being documented may be relatively small with considerable foot traffic in the area which can block the scanner from seeing the full environment. In addition, documenting an environment which is subject to rapid change (such as melting snow or moving vegetation) can benefit from the use of fixed and stationary registration targets. Stationary targets are beneficial because the software can detect the target locations as found in each scan. However, it should be noted that targets must be fixed on rigid structures. Targets must not move throughout the excavation process and hence, must be semi-permanent and resistant to the elements for an extended period of time.

The second type of registration, targetless registration, does not require the use of any fixed targets; however, it does require that there is sufficient overlap and unique geometry in the scene. Wide open areas which are void of any vertical structure like an open field or a flat, sandy beach are not the best options for targetless registration. In addition, areas with dense vegetation are not well suited for this type of registration either since moving the scanner only a short distance could create a completely different environment with little to no overlap from the previous scan position. However, the benefit of this type of registration is that it is minimally invasive and saves time in the placement of the target spheres or checkerboard targets. In most areas such as an indoor apartment or outdoor area where there are buildings and other structures around, targetless registration works very well. Ultimately, either method could be used for successful documentation depending on the environment and application.

Upon successful registration of the individual scans, the scene can be visualized in a realistic fashion. Virtual tours, 3D prints, and even virtual reality are all possibilities when the data has been captured using a laser scanner. Additionally, diverse types of analysis can be performed using laser scanner data. Cross sections, deviation analysis, bullet trajectories, bloodstain patterns, volume calculations, and witness perspectives may all be tested or analyzed. Although these analyses have been done for decades using total station or manual measurement data with the 3D generated computer models, the arrival of the laser scanner has made them easier to perform.

Structured Light Scanners

Structured light scanners represent a group of 3D technologies which use a known pattern projected on a surface so that its geometry may be captured. At the very minimum a projector and a camera with a known position to one another are used, but there are systems which work with multiple cameras and varying types of patterns to provide more accurate data. Structured light scanners are often used for smaller scale scenes or smaller pieces of evidence. Many of these systems have been incorporated into hand held devices which can be moved about an object as large as several meters or as small as a suspect's shoe or weapon. These instruments are often quite fast in terms of their capture time and they can range in accuracy from the centimeter to sub-millimeter scale.

Two types of structured light scanners are white light and laser light scanners. White light scanners use traditional bulbs or LED lights to emit rapidly alternating patterns while laser light scanners often use a projected series of dots which is in the infrared, non-visible range. As a result, one limitation of each technology is that they perform poorly in sunny or very bright conditions since the camera must resolve the emitted infrared pattern against the sun's ambient light. When working in direct sunlight, data may be incompletely captured or in more extreme cases, impossible to capture unless some cover or shade is provided. The difference between the skeletal remains being captured with a structured light scanner with and without cover can be seen in Figure 1.

Speed of capture is of primary benefit since a hand held structured light scanner can be deployed each time a new piece of evidence is found. When considering a clandestine grave, a newly excavated layer may contain some evidence which, in a matter of a few minutes, can be documented as a 3D data set and a chronological record can be stored indefinitely. Similar to the laser scanner mentioned above, 3D data allows for diverse ways of analyzing and presenting evidence either in a recreated physical form or as a virtual model. The smaller scale and rapid capture with hand held structured light scanners integrates well with other technologies such as the total station, laser scanner, and photogrammetry.

Photogrammetry

Modern day photogrammetry is attractive to crime scene investigators because of the relative simplicity of use and automated processing of data. The basic premise is that multiple, overlapping photographs of a scene or piece of evidence may be input into software and processed to create a digital and photorealistic 3D model. This is especially useful in cases where color, staining, or marking is visible but not as a protruding, geometric mark, such as soil staining on uncovered skeletal remains.

Commercial drones have provided a resurgence and interest in photogrammetry because of the relative ease of access to higher elevations and the possibility of creating large scale digital models of entire crime scenes. In comparison to laser scanning, photogrammetry is typically much faster in terms of the documentation time since all that is necessary is a series of strategically placed overlapping photographs. Post-processing on a computer is often intensive but this is seen as less of a problem since the loss of time is off site and not while the scene is being processed.

With respect to clandestine graves, a combination of photogrammetry and other technologies is easily employed and it is possible to combine 3D data from various sources.

Figure 1: Comparison between the resulting 3D models using the Dot Product handheld structured light scanner. Left: Captured when the grave was covered (from sunlight) with a pop up tent and tarps; Right: Captured without anything covering the grave.

Photogrammetry can be employed immediately around the grave location and if overlapping photographs are taken in a "ring" around the grave, they are easily processed to create a full 3D model. Similarly, video from mobile phones or tablets may also be employed to capture a grave. One would only need to walk around the grave and by pointing the camera in the direction of evidence, the resultant frames are already overlapping and focused on the object of interest. The individual frames may be extracted and then processed like regular photographs. Although this method has not been evaluated for accuracy, preliminary tests have shown that the resulting videos from the mobile phone produce visually accurate models.

Materials & Methods

Grave Set Up, Excavation & Documentation

A plastic cast teaching skeleton was placed in a 1 × 0.5 × 0.75 m grave in the backyard of the Crime Scene House teaching lab at the University of Toronto Mississauga. Leaf litter and surface debris was placed over top the grave to make it as realistic as possible. The grave was left undisturbed for one week prior to excavation. With daily precipitation during this week, the grave could settle some. Photographs were taken at the scene upon arrival as well as six scans with the FARO X330.

A 3 × 4 m grid was set up around the burial site. Traditionally, grids are held up with a metal stake in each of the four corners and grid intersection points, however, for this experiment, a stake was mounted through a small sphere (a lacrosse ball) and then put in the ground. These "grave spheres" acted as permanent targets to help with scan registration.

The grave was excavated in 10 to 15 cm intervals, stopping each time to take photographs and 3 to 4 scans with the FARO X330. In some of the layers, small pieces of evidence (a necklace, animal bone, and a lighter) were placed into the grave for documentation. Additionally, a series of photographs was also taken at some layers to make photogrammetry models.

Once the human remains were visible, multiple methods of data capture were used to image the grave, including standard photography, the FARO X330, the FARO Freestyle, the Dot Product DPI-8X, and then photogrammetry using a DJI Phantom 4 drone and slow motion video using an iPhone 6+ [8, 12]. However, due to time restrictions, only the laser scanner, total station, and manual measurements were used as the focus of the analysis.

The laser scanner, a FARO X330, was placed on a wooden rig and suspended upside down. This can be visualized in Figure 2. The scanner was set to a resolution of 1/5 with a quality setting of 3 times. The resolution setting is a ratio of the maximum capture capacity of the scanner and also defines what the spacing between measured points would be at a distance of 10 m from the scanner. In this case, a setting of 1/5 results in a point spacing of 7.67 mm at 10 m. Objects that are closer to the scanner will have a smaller point spacing while the inverse is also true. The quality setting is a measure of how many times the same point is measured. As the quality setting is increased, the time to scan increases.

The total station, a Sokkia 530 R3 [9], was set up in a location that would adequately capture the entire skeleton as best as possible, with only one setup, as moving the total station could result in additional errors. A reference point, denoted as a nail in the ground, was setup

Figure 2: Wooden rig that was set up to invert the FARO laser scanner. This allowed for the scanner to be closer to the grave and the skeletal remains, eliminating the extra noise of the surrounding scene.

directly below the scanner. This ensured that the reference point never moved throughout the documentation process. The reference point established a vertical line which passed through the instrument. The height of the instrument was also measured and recorded in case any total station measurements needed to be redone. In addition, a backsight point was established which allowed the operator to check if the total station had moved any significant amount during the documentation process. A backsight point establishes a reference point and direction and can be demonstrated with a nail, or target. Similar to the reference point, it should remain in place until all points have been measured. Once the total station was set up, each point was targeted through the telescopic lens and captured by the operator by centering the crosshairs on the skeletal landmark. A reflectorless total station was used in this research because using a prism would have increased the chances of items moving in the grave and would have contributed to additional errors.

Figure 3: Target markers denoting the location of each of the 14 landmarks.

Grave Measurements

Target markers (circular stickers with a 1.9 cm target circle) were placed on 14 different osteological landmarks across the skeleton (visualized in Figure 3). The target markers acted as references for making discrete measurements and to avoid ambiguity in the measurement location across the three main methods. The three instruments/methods used were the FARO X330 scanner, the Sokkia 530 R3, and manual measurements using tape measures, string, levels, and plumb bobs in conjunction with the trilateration method.

Measurement Comparison

From the 14 landmarks, 25 measurements were chosen across the skeleton. These points were chosen to assess the length and width of certain bones, or to assess the length and width of the skeletal cast as a whole. Both small and larger measurements (which spanned across the length of the skeleton) were considered and subsequently measured by the total station, manual, and FARO X330 laser scanner data. The landmarks and measurements can be found in Table 1.

Total Station. The total station data was imported into Rhino, which is a mapping software that allows for easy and accurate point-to-point measurements. Rhino has a snapping option which, when activated, constrains the cursor to a specific part of an existing object, i.e. a point or vertex. This was activated when measuring each of the 25 measurements, which ensured consistency when measuring each point. The resulting measurements can be found in Table 2.

Manual Measurements. The manual measurements were taken in the field and then imported into CAD Zone. This program took the 14 landmarks and placed them into

Table 1: Description of the 25 distance measurements based on 14 point pairs and a description of the associated skeletal landmarks.

#	Point A	Landmark	Point B	Landmark	#	Point A	Landmark	Point B	Landmark
1	P2	Sagittal/ coronal suture	P10	L proximal femur	14	P14	L proximal humerus	P8	R distal tibia
2	P2	Sagittal/ coronal suture	P7	R proximal femur	15	P12	L proximal fibula	P5	R distal femur
3	P14	L proximal humerus	P7	R proximal femur	16	P5	R distal femur	P6	R innominate
4	P2	Sagittal/ coronal suture	P6	R innominate	17	P9	L talus	P8	R distal tibia
5	P14	L proximal humerus	P6	R innominate	18	P2	Sagittal/ coronal suture	P13	L distal humerus
6	P13	L distal humerus	P14	L proximal humerus	19	P14	L proximal humerus	P12	L proximal fibula
7	P5	R distal femur	P7	R proximal femur	20	P14	L proximal humerus	P5	R distal femur
8	P12	L proximal fibula	P8	R distal tibia	21	P13	L distal humerus	P12	L proximal fibula
9	P7	R proximal femur	P10	L proximal femur	22	P13	L distal humerus	P5	R distal femur
10	P2	Sagittal/ coronal suture	P14	L proximal humerus	23	P6	R innominate	P7	R proximal femur
11	P13	L distal humerus	P6	R innominate	24	P7	R proximal femur	P8	R distal tibia
12	P14	L proximal humerus	P10	L proximal femur	25	P9	L talus	P10	L proximal femur
13	P14	L proximal humerus	P9	L talus					

Table 2: Resulting measurements from each of the three methods.

Point Pair #	Total Station (m)	Manual Mapping (m)	Laser Scanner (m)
1	0.621	0.60	0.6203
2	0.609	0.59	0.6090
3	0.611	0.60	0.6100
4	0.531	0.53	0.5313
5	0.572	0.57	0.5717
6	0.271	0.26	0.2711
7	0.362	0.36	0.3625
8	0.319	0.33	0.3177
9	0.168	0.17	0.1672
10	0.223	0.21	0.2216
11	0.412	0.43	0.4112
12	0.565	0.54	0.5645
13	0.481	0.47	0.4788
14	0.560	0.55	0.5581
15	0.121	0.14	0.1210
16	0.299	0.31	0.2999
17	0.106	0.11	0.1063
18	0.404	0.40	0.4041
19	0.252	0.25	0.2517
20	0.318	0.31	0.3164
21	0.163	0.17	0.1633
22	0.283	0.30	0.2830
23	0.118	0.11	0.1196
24	0.072	0.07	0.0711
25	0.095	0.09	0.0965

a Cartesian coordinate system, as shown in Figure 4. The resulting points were then exported to Rhino and measured. The resulting measurements can be found in Table 2.

FARO Measurements. The laser scanner data was imported into FARO Scene, where the individual scans were registered together. Scene has a Measure tool that allows for the measurement between two points. This was used for the 25 measurements (results can be found in Table 2).

Results

The resulting measurements from each of the 25 measurements were compared across the three groups. Table 3 demonstrates the differences for the three groups: manual trilateration compared to the total station, manual trilateration compared to the laser scanner, and the laser scanner compared to the total station. The final column in Table 3 demonstrates the average error which is the sum of each of the 25 differences divided by 25.

When looking at which points had the greatest difference for each instrument comparison, it is evident that the manual measurements are the source of the greatest difference. When examining the points with the largest degree of difference between two instruments, the top 5 measurements were consistent when the manual method was included (manual to total station and manual to laser scanner). None of the measurements with the greatest degree of difference between the laser scanner and total station coincided

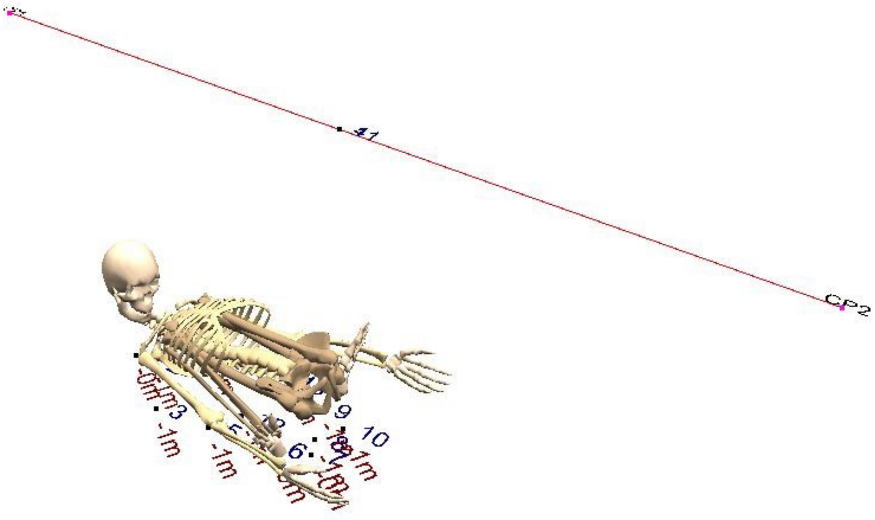

Figure 4: Hand mapped coordinates shown on a Cartesian plane with skeletal model overlaid. Drawing created in CAD Zone.

Table 3: The absolute values for the differences between the three instruments for the 25 point pairs.

Point Pair #	Manual vs. total station (m)	Manual vs. laser scanner (m)	Laser scanner vs. total station (m)
1	0.02	0.02	0.000
2	0.02	0.02	0.000
3	0.01	0.01	0.001
4	0.00	0.00	0.000
5	0.01	0.00	0.000
6	0.01	0.01	0.000
7	0.01	0.00	0.001
8	0.01	0.01	0.001
9	0.00	0.00	0.001
10	0.01	0.01	0.001
11	0.02	0.02	0.001
12	0.03	0.03	0.001
13	0.01	0.01	0.002
14	0.01	0.01	0.002
15	0.02	0.02	0.000
16	0.01	0.01	0.001
17	0.00	0.00	0.000
18	0.00	0.00	0.000
19	0.00	0.00	0.000
20	0.01	0.01	0.002
21	0.01	0.01	0.000
22	0.02	0.02	0.000
23	0.01	0.01	0.002
24	0.00	0.00	0.001
25	0.01	0.01	0.002
Avg.	**0.01** (10 mm)	**0.01** (10 mm)	**0.001** (1 mm)

with those that included the manual method. This can be visualized in Table 4. The average difference for the laser scanner compared to the total station measurements was 1 mm, whereas the average difference between the comparisons that included the manual method were 10 mm when compared with the total station and 10 mm when compared to the laser scanner.

As is the nature with documenting human remains, a source of error could come from the round/uneven surfaces of the skeletal elements. The differences in the measurements seen in Table 4 could be attributed to the fact that the documentation technique could not adequately capture the landmark. For example, because the skeletal remains were found to be commingled (as opposed to anatomical position), there could have been other skeletal elements on top, obstructing the view of the total station, laser scanner or when using a plumb bob for manual measurements. Likewise, the round/uneven nature of the human remains could have made it difficult to pinpoint the exact location, regardless of using the target stickers.

The differences between the methods at each individual measurement can be visualized in Figure 5. This table demonstrates that for the majority of the measurements, the laser scanner and total station data were most similar compared to the manual measurements. This demonstrates that regardless of accuracy, measurement capabilities between digital

TABLE 4: Top five measurements with the largest degree of difference for each of the three instrument comparisons.

Manual vs. Total Station		Manual vs. Laser Scanner		Laser Scanner vs. Total Station	
Point Pair #	Difference (m)	Point Pair #	Difference (m)	Point Pair #	Difference (m)
1	0.02	1	0.02	13	0.0022
2	0.02	2	0.02	14	0.0019
11	0.02	11	0.02	20	0.0016
12	0.03	12	0.03	23	0.0016
15	0.02	15	0.02	25	0.0015

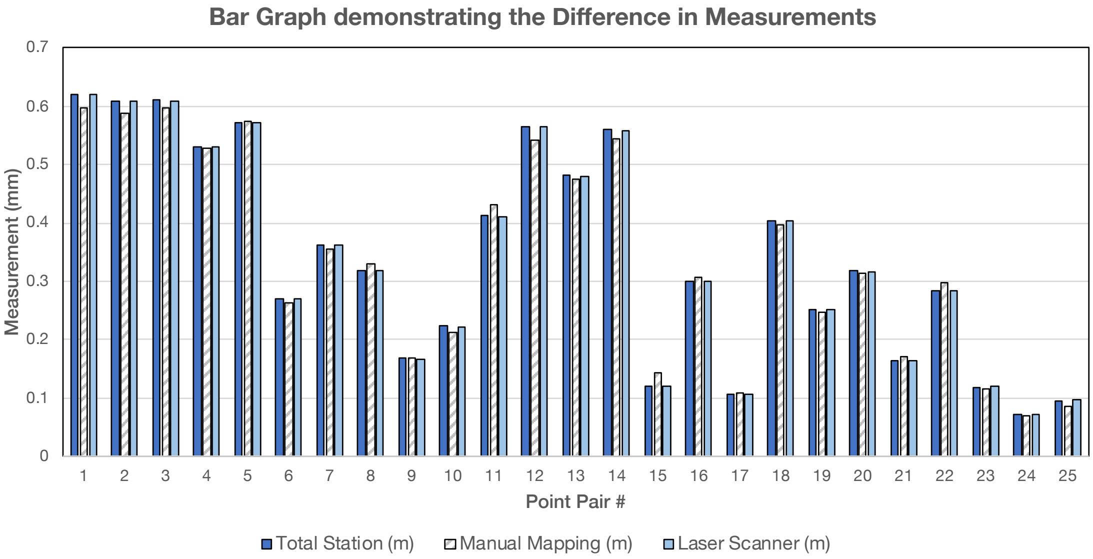

FIGURE 5: Differences between the instruments for each of the 25 measurements for the three measurement techniques.

methods are more similar than that with manual methods.

To assess statistical significance, a Wilcoxin signed rank test and a two-way ANOVA was performed. Both tests showed that the differences between the three methods were not significant. This result is not surprising as the sample size (1 grave) is small and the generated measurements from each method did not differ an extreme amount. A box and whisker plot was also created to assess for any outliers within each comparison of documentation techniques (shown in Figure 6) which showed that there were no measurements that were drastically different.

Discussion

The present study did not assess the accuracy difference between the three methods, as this

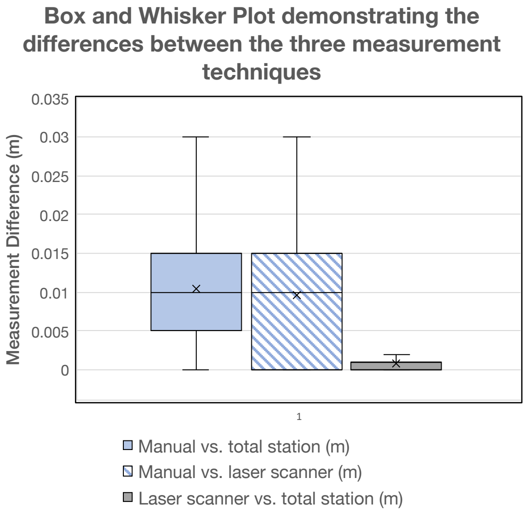

FIGURE 6: Box and whisker plot demonstrating the distribution of each of the 3 measurement comparisons.

kind of study would require a 'ground truth', such as a laser tracker or other instrument of higher accuracy. Instead, this research analyzed the comparability of the measurements produced by each of the three methods. Moreover, this research also assessed each method on the basis of its ease of use, thoroughness of documentation, required personnel, and visualization capabilities. The results of this research demonstrated that the total station and laser scanner had comparable results, with the average error being less than a millimeter. Alternatively, manual methods differed from both the laser scanner and total station data by an average of 10 mm. It is important to note here that although the differences in the manual measurements were much higher than that of the laser scanner and total station, being able to achieve sub-cm accuracy with a tape measure is a noteworthy result.

The terrestrial laser scanning method was by far the easiest to execute while still maintaining optimal results. Capturing an outdoor scene with a terrestrial laser scanner can be done by a single person, instead of having at least 2 people on scene to manually measure and document. In total, the laser scanner performed approximately 15 scans of the scene at differing levels of the grave. At the quality and resolution settings mentioned above, each scan took about 6 minutes. This resulted in a total of 90 minutes of active scanning time. In these 90 minutes the ground surface and 3 subsequent layers of the grave, including that which contained the human remains, were fully captured. In comparison, to manually document the layer containing the skeletal remains, it took 5 personnel approximately 20 minutes. If the grave were to be manually measured at each of the layers that the laser scanner documented (3 prior to and 1 at the level of the skeletal remains), it would take approximately 60 minutes in total. Although the active documentation time was shorter when manually measuring, it required 5 times the personnel. In addition, only the 14 skeletal landmarks were measured and documented, whereas the laser scanner was able to capture millions of measurable points.

When documenting a clandestine grave with a laser scanner, the operator places the scanner, sets the resolution levels, and presses the start button. No other on-scene action is required. Alternatively, when manually mapping a clandestine grave, personnel are holding multiple tape measures, strings, and a plumb bob, and must still be able to read each of the tape measures. The process is hectic and can be tedious when ensuring that all tape measures and strings are taut and the measurement is taken at the correct point. When using manual methods, the measurements are then used to create hand drawn 2D maps. Although this can be done off-scene, map drawing is a long process, wherein the final product may have limitations with respect to the realism of the scene and the inability to view the scene from different angles (which can be done with a laser scanner). The laser scanner also involves quite a bit of off-scene work, as each of the scans need to be cleaned up and registered together. This process can be time consuming depending on the number of scans being registered together, the storage available, the RAM, and the power of the computer being used.

The total station, although considered a digital method of documentation, is not automatic and must be fully executed by an operator. This technique requires a very specific set up, and note taking and labeling throughout the process. Each point should be documented with written notes in case the total station data gets lost or corrupted. The reference and backsight points must be placed in a way that will ensure no movement, as this will increase the errors of the points being measured. Similarly, it is incredibly important to ensure that the total station itself doesn't move, as any points taken afterwards would be invalid (this point is also true of the reference spheres when using the lase scanner). In this project, a reflectorless total station was used, as to minimize movement within the grave, however, it was difficult at times for the machine to capture each target. This was not a fault of the machine as any experienced user could encounter the same issue. Some of the targets that were placed on skeletal elements that were rounded or slanted in some way. The targets were placed before the total station was set up, and therefore could not be moved because the points were already captured with the laser scanner and manually. In cases where the total station was unable to capture the target, that point was discarded from the analysis.

Another factor that must be considered for each of these methods is the expertise of the operator. A less experienced operator could take longer to document a clandestine grave than a more experienced operator. In addition, it is possible that there are errors contributed by a less experienced operator that would not be present by a more knowledgeable operator. In terms of documentation time, a terrestrial laser scanner has the least amount of influence from the operator as the only active task is to move the scanner position and press the start button. This is not the case when using a total station or manual method as both require substantial set up and/or active documenting. Thus, a less experienced practitioner may take longer as well as contribute greater errors in the documentation process when compared to someone with more experience.

When crime scene investigators, or a forensic anthropologist/archaeologist, must excavate and document an outdoor scene consisting of a clandestine grave, the methods portrayed in this research can be used, some of which will provide a faster and easier way of documentation. That being said, the method of excavation should remain the same regardless of the documentation technique. Excavation should be done step by step in a very meticulous manner, to avoid any movement of evidence or destruction of the grave wall. Although the methods presented in this paper are solely for documentation, when using the laser scanner, it may eliminate the need for a grid, as the resulting scans will be able to identify the location of each piece of evidence. A grid, however, may be beneficial when photographs are being taken, as the grid lines will help the viewer assess and measure the exact location of the evidence.

The implementation of 3D digital methods for documenting clandestine graves comes with both pros and cons, when compared to the traditional manual methods. As mentioned above, laser scanners and handheld structured light scanners may provide better accuracy, are time and personnel efficient, and are optimal for visualization purposes. One of the major benefits of employing a laser scanner that documents multiple layers of a clandestine grave, is that each scan is able to be overlaid to demonstrate the step by step nature of the excavation process. Each layer could show a different piece of evidence with the final layer being either the skeletal remains or the empty grave (once the skeletal remains are removed). This can be visualized in Figure 7.

That being said, 3D scanners can be expensive and without the financial capabilities of a large institution (such as a university or government agency), they may be difficult to buy. In that case, although manual methods may require more time and personnel on scene, they are incredibly cost effective. Handheld scanners can range anywhere between $5,000 to over $25,000 and laser scanners can range anywhere from $25,000 to over $100,000 (all in USD). In comparison, manual methods may cost a maximum of $30 CAD.

In general, the application of 3D methods to forensic techniques is beneficial for many reasons. Most notably, 3D data can document

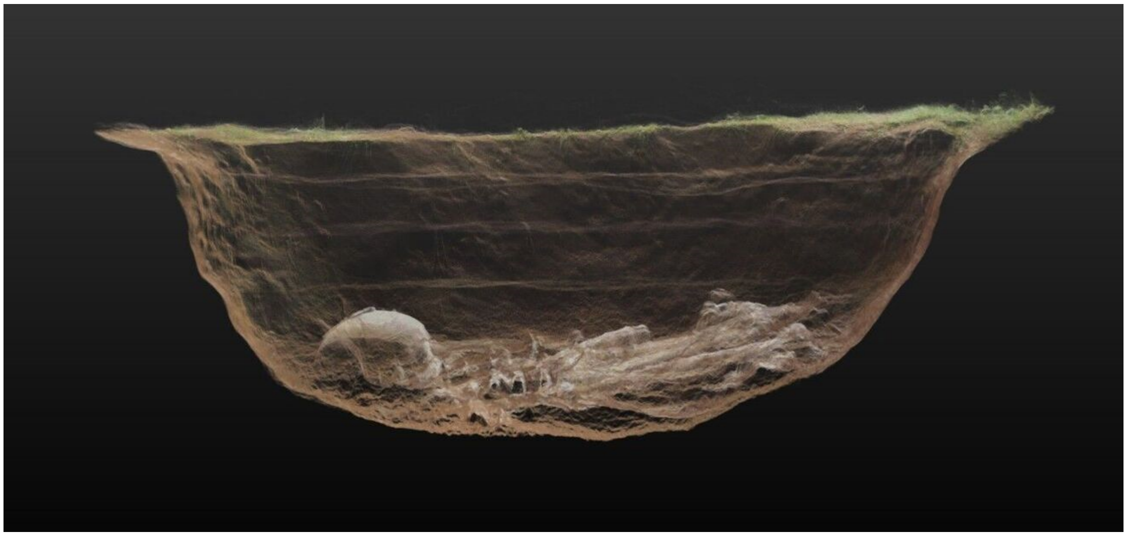

Figure 7: Cross section of each layer of the grave from the laser scanner data.

entire crime scenes with millimeter detail [13]. Secondly, once a scene is scanned and registered, the resulting 3D model can be kept indefinitely leaving a permanent record of the scene [13]. This is beneficial for cases that need to be revisited later on or are going to trial many months or years later. Additionally, 3D documentation can assist with multi-day scenes, as the 3D data can demonstrate what the scene looked like on the previous day.

Once a crime scene is captured, the data can be analyzed in various ways, based on the needs of the case, including blood stain pattern analyses, shooting reconstructions, and clandestine grave documentation. Many police and private agencies within Canada and the US now employ 3D scanning technologists who are sent to document and analyze various kinds of crime scenes. Although the addition of 3D techniques are not always accepted means of analysis in certain areas of forensic science, i.e. blood stain pattern analysis, there are recent research projects that show promise that these 3D techniques can be used in tandem with traditional techniques. For example, Holowko and colleagues [13] demonstrated that the addition of 3D scanning to blood stain pattern analysis was highly beneficial.

Lastly, and very important, 3D models will help the judge and jury to better understand the evidence that is being presented [14]. 3D software's can create "fly throughs" of the model, which can demonstrate the scene as if someone was walking through it in real time. A Dropbox link has been provided to demonstrate a flythrough of the excavated grave at the level of the skeletal remains. At times, 2D maps can make it difficult to capture the location and their relation to the surrounding scene and may cause the members of the court to misunderstand important aspects of the case. With a 3D model, the operator can demonstrate the scene as if each and every individual in the court was there – this will ensure maximum understanding. That being said, the implementation of 3D techniques does not discount 2D diagrams, as they can easily demonstrate the relationship between the scene and the evidence.

Conclusion

The current research project successfully demonstrated three methods for clandestine grave documentation, including manual trilateration methods, a total station, and a laser scanner. Although the accuracy of each method was unable to be assessed, this research showed that manual methods are reliable and cost efficient; however, it is more time and personnel effective to employ laser scanning methods, as they will also produce better visualization of the scene. It was not the goal of this research to discount manual methods, as there are scenes in which the application of 3D techniques would be impossible or detrimental. It is important for investigators to be versatile in their methods of crime scene reconstruction and to be able to fall back on manual methods of documentation if the scene requires it.

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Supplemental Materials

Video 1: Fly through of the clandestine grave and surrounding site, created in FARO Scene available with the article at www.ACSR.org.

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