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A Validation Study of the Measurement Accuracy of SCENE and SceneVision 3D Software Programs

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A VALIDATION STUDY OF THE MEASUREMENT ACCURACY OF SCENE AND SCENEVISION 3D SOFTWARE PROGRAMS

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Abstract

This descriptive study sought to determine the measurement accuracy of two 3D modeling software programs used in crime scene processing and reconstruction. These two programs are FARO's SCENE and 3rdTech's SceneVision 3D. This study compared the measurement difference means to guidelines published by the National Institute for Standards and Technology (NIST). A statistical analysis was performed by subtracting the manual measurement from the measurements from SCENE and SceneVision 3D. These differences were used in a paired *t*-test. The measurement difference means for each program were found to be within the NIST guidelines. The outcome of the paired *t*-test showed a statistical but not practical significance in the measurement differences. SCENE was found to be slightly more accurate than SceneVision 3D.

Chapter One
Introduction

Introduction

Understanding the series of events that may have occurred during a crime can be critical in the field of forensic science, and crime scene reconstruction plays an important role in this. Crime scene professionals use knowledge of the physical scene, the evidence found within a scene, and the relationship between the two to come to a conclusion. Crime scene reconstruction allows judges and juries to make critical decisions based on the evidence by depicting the scene for them with critical details. Unfortunately, revisiting the scene of the crime to make an analysis is not always possible by crime scene professionals. To reconstruct a scene, crime scene professionals typically must use case narrative descriptions and photographs in conjunction with sketches or mappings of the scene prepared by the crime scene investigators. In more recent years, the forensic science community has begun working with 3D technologies used by other scientific disciplines such as archeology, medicine, gaming, and especially engineering. Three-dimensional technology allows a crime scene professional to view the scene particulars without being at the actual location of the scene itself.

A 3D model is a three-dimensional representation of items that appear flat to the human eye giving the form width, depth, and height. Many technology companies are producing numerous hardware products and software programs for 3D modeling for this emerging market. Unfortunately, the forensic science community has not tested and validated many of these software programs and hardware products for use in crime scene reconstruction because the forensic field has not always been a primary market. The forensic science community has not performed the validation of the accuracy of these software programs for the use in crime scene reconstruction. Accuracy however, is a key consideration for admissibility in court.

Because a validation study is vital for use in the forensic science community, this descriptive study sought to do this. This study was designed to validate two software programs, FARO's SCENE and 3rdTech's SceneVision 3D while using the FARO Focus 3D laser scanner for all data acquisition within mock crime scenes. A typical scan takes three to five minutes and captures up to 11,000,000 measurements in about two minutes for a 180º rotation capturing forward and behind the scanner (360º total). If parameters are changed (outdoors/indoors or number of measurements), the time for each scan can be affected. The scanner houses a camera that simultaneously takes 85 pictures after the laser scanning is completed. This provides concurrent photos of the scene that provide additional perspectives of the scene. The cost of the Focus 3D used in this study was $25,000. This cost included SCENE (the 3D modelling software produced by FARO), a pair of protection glasses, a transport case, a tripod, a car adapter, and the first year's warranty.

In general, a laser scanner is a device that generates polygon meshes or dense point clouds by measuring the physical world using lights, lasers, or x-rays ("3D Scanners," n.d.). Essentially, they take hundreds of thousands or millions of measurements to capture the geometry of physical objects ("3D Scanners," n.d.). There are two main types of laser scanners that a professional could use during the processing of a crime scene. Pulse-based scanners and phase-shift scanners both use time-of-flight calculations to obtain measurements within a scene. Pulse-based scanners pulse a laser beam outward. When the beam bounces back to the scanner from an object or structure, the scanner uses the length of time the beam spent round-trip in flight to calculate the distance from the object or structure to the scanner. Pulse-based laser scanners can typically capture up to 50,000 points per second ("Laser Scanning," 2012).

Phase-shift scanners also pulse a laser beam. Instead of an almost straight beam found in pulse-based scanner, phase-shift scanners modulate the wavelength of the beam. The distance between the object or structure is then calculated based on the analysis of the phase shifts in the wavelength of the returning beam compared to the emitted beam. Phase-shift laser scanners typically capture up to 976,000 points per second ("Laser Scanning," 2012). This makes phase-shift scanners more accurate than pulse-based scanners. The FARO Focus 3D being used in this study is a phase-shift laser scanner.

For the main purpose of this research study, two software programs were chosen for comparison and validation in the areas of accuracy for crime scene reconstruction. SCENE is a software program that is designed for use by many different disciplines that may use a 3D laser scanner. SceneVision 3D is a fairly new program that can use acquisitioned data from a 3D laser scanner to create 3D models of crime scenes for the purpose of crime scene reconstruction. SceneVision 3D when purchased currently costs around $16,000. This includes 13 licenses and training by a representative of the manufacturer, 3rdTech. Using scanned data acquired using the Focus 3D at a mock crime scene, a descriptive study of these two software programs was undertaken. An analysis was performed concerning which software program created the most accurate 3D model. There are three goals the study seeks to reach. First, this study seeks to assist law enforcement agencies in evaluating the software which best suits their department, and which satisfies their legal requirements for admissibility. A secondary goal is to assist the manufacturers in improving their product. The third and final goal is to validate the reliability of the model produced for admissibility in court.

Statement of the Problem

There is a clear void in the literature concerning the accuracy of laser scanning software for forensic applications. Before a crime scene professional can have any forensic evidence admitted for a court case, the professional must ensure the validation of the tools, programs, and techniques to obtain that evidence. The professional must also ensure the tools are reliable. There are certain standards put into place to ensure that this happens. If the forensic science community wants to move forward in using laser scanners and 3D modeling software programs, the profession must conduct a validation of the software. The most important aspect for validation is the accuracy of the measurements obtained utilizing these software programs. The National Institute for Standards and Technology (NIST) requires accuracy to be within +/- 0.25 inches for all devices used to obtain measurements (Crime Scene Investigation: A Guideline for Law Enforcement, 2012). The accuracy of FARO's SCENE and 3rdTech's SceneVision 3D is not readily available to the public. There is a clear need to validate the measurements obtained using these programs and make them known to the forensic science and legal community.

Purpose of the Study

The main focus of this descriptive study is validation of the measurements obtained using the two chosen software programs. The measurements obtained using the software programs were compared with the measurements obtained through traditional methods. Both sets of results were run through n a statistical analysis to obtain significance. This was to determine if the results were within the NIST guidelines for admissibility in court concerning accuracy. It is intended that the results of this study be submitted for publication within one or more professional journals to establish credibility to those in the forensic science community who utilize and rely on these devices.

Research Question

How accurate are the laser measurements obtained within each software program compared to manually acquired measurements in a basic, single focal point crime scene with one scan, and in a complex, multi-focal point crime scene using multiple scans?

In any analysis of a crime scene or the evidence found within a crime scene, accuracy is one of the most important aspects to consider. Inaccuracies can cause problems for all those involved in crime scene processing and analysis, and in the criminal justice process. When considering new hardware and software for crime scene documentation, a professional must know that the reliability and accuracy are valid before introduction in court. Again, NIST describes accuracy to be within +/- 0.25 inches to be admissible in court cases (Crime Scene Investigation: A Guideline for Law Enforcement, 2012). The research to date is void of documentation for the accuracy of SCENE and SceneVision 3D. This study validates the accuracy of each of these software programs when compared to the measurements taken manually within the mock crime scene. Table 1 and Figure 1 display the types of measurements taken in this study.

Table 1

Types of Measurements Obtained during Study

Type of measurement	Number of measurements (Basic, Single focal point)	Number of measurements (Complex, Multi-focal point)
Vertical – Vertical (**Blue**)	5 from floor to 5 on ceiling (25 measurements)	10 from ceiling, 13 from floor (68 measurements)
Horizontal – Horizontal (**Red**)	5 on walls (10 measurements)	15 on walls (42 measurements)
Horizontal – Vertical (**Yellow**)	5 from wall to ceiling (25 measurements), 5 from wall to floor (21 measurements)	15 from wall to ceiling (53 measurements), 15 wall to floor (67 measurements)

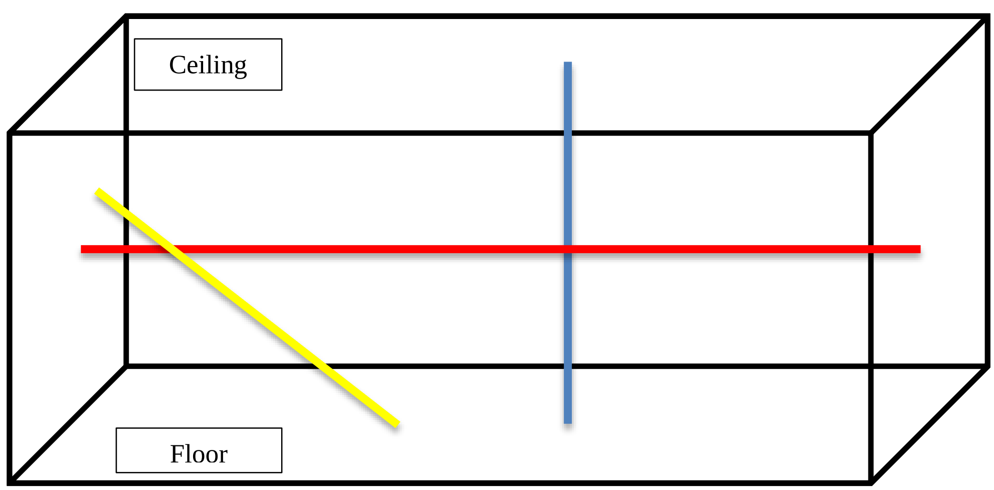


Figure 1: Diagram showing types of measurements to be obtained.

Significance to the Field

In the past, crime scene professionals had to create detailed sketches using paper and pencil. They were able to use photographs taken and sketches drawn by those processing the crime scenes. As computers gained prominence, these crime scene professionals created detailed sketches on computers. These detailed sketches were still two-dimensional, top-down views of the scene. A professional can produce a detailed sketch in very little time and may not even need to draw it to scale. Unfortunately, there are many aspects to a crime scene that could make it difficult to convey the information needed to a jury when only using a sketch or description of a scene. While a crime scene professional acquires critical measurements during the mapping process, it is impossible at the time the scene processing to foresee what future legal issues or questioning may arise concerning measurements.

With technological advances and television shows that display high-tech gadgets in forensic science, there is push to utilize technology that gives the jury something that grabs their attention. In recent years, many hardware and software developers have created new products for other scientific disciplines which have the application possibilities within the forensic science disciplines. Laser scanning and three dimensional modeling are two techniques for which developers are creating products. Unfortunately, many of these products are difficult to use as well as time consuming. Some developers have seen the need to develop products that are easier and faster to use for those in the forensic science disciplines. SceneVision 3D is a software program recently marketed for use in the area of crime scene reconstruction to create 3D models. The FARO Focus 3D laser scanner is one of the hardware products on the market that is advertised for use in the forensic science disciplines. SCENE is the software provided with the Faro Focus 3D laser scanner for use in creating 3D models but was not specifically designed for crime scene professionals.

To date, there has not been any research to validate the accuracy of measurements for either software program. There is a clear need to validate the accuracy. This is the issue addressed by this validation study. This study will provide needed information to law enforcement agencies for choosing the best software product to use when creating a crime scene model for use in a criminal case. The software product manufacturers can use the information gained through this comparative study to improve their product specifically for use in crime scene reconstruction.

Following this study's completion, an article will be submitted for peer review and publication. The purpose of the article will be to inform law enforcement agencies, the legal community, and manufacturers of the results. This study will provide these professionals with data concerning how accurate the measurements within the model are. This study will provide FARO and 3rdTech with information on how their products compare to each other and if their products meet the guidelines for accuracy as dictated by NIST and required of the criminal court system.

Definitions

3D model - A three-dimensional representation of an object, building, or area that appear flat to the human eye giving the form width, depth, and height.

Alignment – The method of aligning two objects in a common coordinate system.

Dynamic environment – An environment where the surroundings are changing.

Laser scanning – The method of graphically capturing physical elements of an object, building, or area and applying surveyed information to each point.

Mesh – A polygonal subdivision of the surface of a geometric model.

Moiré – An independent usually shimmering pattern seen when two geometrically regular patterns (as two sets of parallel lines or two halftone screens) are superimposed especially at an acute angle.

Pattern projection – A pattern generated by a display within a projector.

Photogrammetry – The method of taking precise measurements by using digital photos and coded targets.

Radiosity – A method of rendering using a detailed analysis of light reflections off diffuse surface (Martin, n.d.).

Registration – The method by which separate laser scans are oriented to a defined coordinate system (3D Laser Scanning LFM Software, n.d.).

Resolution – The smallest visible feature on a target.

SCENE – Software provided with the FARO Focus 3D for creating 3D models from laser scans.

SceneVision 3D – Software from 3rdTech for use with the FARO Focus 3D for creating 3D models from laser scans.

Single point triangulation scanner – A scanner that illuminates a point on an item and creates an image of the point on the sensor. As the item moves the image moves with the sensor, by measuring the location of the point. The distance of the item from the scanner can be determined using the baseline length and known angles (OMC Technical Brief, 2001).

Slit scanner - A method in which a moveable slide containing a slit is inserted between the scanner and the object being scanned.

Static environment – An environment where the surroundings remain the same.

Time of flight scanner – A scanner that contains a laser range finder that finds the distance between objects and the laser by calculating the round-trip time of the light pulse.

Limitations

A limitation to this descriptive study is specifically related to external validity. The study sought to validate the measurements obtained using FARO’s SCENE and 3rdTech’s SceneVision 3D. However, not every crime scene is the same and different items will require measurement in each scene. This study tries to generalize these measurements as being the same as those in the field, but this is not realistically possible.

Outline of Chapters

There are four additional chapters to this study besides the current chapter: Chapter Two: *Literature Review* consists of the previous literature available concerning laser scanning for crime scene reconstruction. The first section of Chapter Two describes the use of crime scene sketches/mappings and photographs for use in crime scene reconstruction. The second section addresses research on laser scanners and software in use in the general scientific community. Finally, the third section of Chapter Two discusses research on laser scanning and software with forensic science applications.

Chapter Three: *Methods* describes the steps taken during this study. The setting is described in which this study was conducted. The sample size for each scene is given. A description is given of the materials used during this study. Measurement instruments along with their validity and reliability are provided. The procedure for data collection is described as well as the data analysis conducted.

Chapter Four: *Results* contains the results of the study. Any tables and figures are discussed. This chapter contains quantitative data in the form of descriptive statistics and inferential statistics. The significance of the statistical analysis is also described.

Chapter Five: *Discussion* consists of a discussion on what the results mean to those in the forensic science community. The limitations found within the software programs and within the study itself are examined. Recommendations for further research concerning these two programs as well as laser scanning in forensic applications is discussed within this chapter. Lastly, the conclusion reached from all the detail concerning this study and its results is provided.

Chapter Two
Literature Review

Introduction

Crime scene reconstruction plays an important role in understanding the series of events that may have occurred during a crime. Crime scene professionals use knowledge of the physical scene, the evidence found within a scene, and the relationship between the two to come to a conclusion. Unfortunately, crime scene professionals cannot always go back to the scene of the crime to make their analysis. In many cases, crime scene professionals must use case narrative descriptions in conjunction with sketches or mappings of the scene prepared by the crime scene investigators to reconstruct a scene. In recent years, the forensic science community has been incorporating into their investigations 3D technologies used by other scientific disciplines such as archeology, medicine, and especially engineering. Within the area of crime scene reconstruction, 3D technology allows the analysts to be at a scene without being at the physical location of the scene. With the emergence of this market, many technological companies are producing numerous hardware products and software programs for 3D modeling. Some of these products have been tested and validated within the general scientific community, but not by the forensic science community for use in crime scene reconstruction. The forensic science community has yet to compare these products in a forensic science setting for determining the best software programs for use in crime scene reconstruction instead for use in other scientific disciplines.

This chapter addresses three areas of research related to 3D software program comparisons for crime scene reconstruction. The first section discusses the use of crime scene sketches/mappings and photographs for use in crime scene reconstruction. The second section addresses research on laser scanners and software in use in the scientific community. Finally, the third sections discuss research on laser scanning and software with forensic science applications.

Prior Research

Crime scene reconstruction using sketching and photogrammetry.

For many years, when a crime scene professional could not revisit a crime scene, the professionals had to use the case narrative descriptions, photographs, and sketches/mappings prepared during or after the initial visit to the scene. There are some variances of opinion on what the difference is between a sketch and mapping. Some professionals view them as the same, while others view them as two separate types of diagrams. For those that view them differently, a sketch is a not-to-scale, 2D top-view freehand drawing or computer-made diagram. When measurements from the site of a scene and the items within a scene are fixed and drawn to-scale, some professionals refer to this as scene mapping (Gardner, 2012). Some crime scene professionals refer to mapping as the final sketch. For the purpose of this chapter, a final sketch will refer to mapping. A crime scene investigator usually prepares a rough sketch of a crime scene after the photographer takes photographs of the scene and before another investigator collects the evidence. Once a rough sketch is drawn, a final sketch can be prepared. Evidence in the scene is "fixed" or located through a measuring process. The three most common methods for fixing evidence for a final sketch on a diagram are rectangular coordinates, baseline coordinates, and triangulation. These methods provide a more accurate description of the scene, the evidence, and the interrelation between the two. A final sketch along with photographs can help a crime scene reconstruction professional when a reconstruction is necessary to determine the events that likely occurred at a scene. When someone requests a 3D version of a scene, a crime scene professional can use software programs to create a final sketch.

Another way of gaining information for a 3D version of a scene is with photogrammetry. The Merriam-Webster dictionary defines photogrammetry as "the science of making reliable measurements by the use of photographs and especially aerial photographs (as in surveying)." This mathematical process has been around since the development of photography in the 1800s. The term was coined by a German geographer, Dr. Otto Kersten, in 1855 and later introduced in a published work by Albrecht Meydenbauer in 1867 (Ghosh, n.d.). Photogrammetry uses mathematical concepts that have been in use much longer than photographs, the most notable concept being the geometry of projections. Professionals can conduct photogrammetry by using single images, stereo images, and multiple images. To create a scale model using photogrammetry, at least one object within the photo must have known measurements. From this one object, other measurements can be determined without ever touching the objects. Calibrated cameras are a must if avoiding distortion. Photogrammetry and image-based modeling have many applications such as engineering, cultural heritage, cartography, and criminology. The actual date of use for criminology and crime scene reconstruction is unknown. With the invention of the computer, photogrammetry became easier and allowed for digital model building. There are many software programs on the market today that use photogrammetric algorithms and processes.

The previously mentioned processes for 3D modeling by crime scene professionals require a great deal of effort and time to create a product that for use in an investigation. To create a 3D model from a sketch, a crime scene professional must take many measurements and must take care to not disturb evidence while obtaining the measurements. To create a 3D model using photogrammetry, a professional needs at least one photograph, but he or she needs training in how to use the mathematical process of photogrammetry. There has not been much research conducted on sketching or photogrammetry for 3D modeling unless it is in conjunction with software programs. This will be discussed this in the final section of this chapter.

Laser scanning and software for 3D modeling.

Many scientific disciplines have used laser scanning in many applications such as surveying, heritage sites, medicine, and archeology. The growing interest has developed many different types of laser scanners as well as various types of software with which to use the acquisitioned data. This section will discuss research on the developments in 3D laser scanners, accuracy of laser scanning, and using range and image data for 3D modeling.

Three-dimensional laser scanning has been around and evolving for several years. Companies are developing commercially sold laser scanners to be more user-friendly, but they still come with a high price tag. As laser scanners become more useful for applications that were previously not thought of, the price should drop with the demand. Blais, Beraldin, El-Hakim, and Godin (2003), found that with the widening of applications for laser scanners, scanners have moved from static systems to systems that can handle dynamic natural environments. The researchers also found that color texture, portability, and registration (a method by which separate laser scans are oriented to a defined coordinate system) are also areas that have evolved and become important.

This aforementioned study was a review the various types of 3D methods while providing the advantages and disadvantages from an optical point of view for the most popular methods (Blais et al., 2003). The researchers discussed color texture projection systems and methods as well as hand-held systems. Blais et al. (2003) conducted this study at the National Research Council in Canada. The researchers discussed the advantages and disadvantages of five different types of scanners or methods such as: slit scanners, pattern projection and Moiré, single point triangulation laser scanners, time-of-flight systems, and equations needed to evaluate 3D principles. The Merriam-Webster dictionary defines Moiré as "an independent usually shimmering pattern seen when two geometrically regular patterns (as two sets of parallel lines or two halftone screens) are superimposed especially at an acute angle." The researchers also mentioned the reconstruction of color textures and multiple views and then discussed a hand-held scanner.

Blais et al. (2003) examined the inexpensive slit scanner which is a triangulation-based 3D laser camera. This scanner's advantage was lower cost and availability. The disadvantage was a compromise found between depth resolution and field of view as well as limited immunity to ambient light and poor intensity dynamic range (Blais et al., 2003). For pattern techniques, the researchers discuss Moiré patterns and coded patterns, and found advantages such as the availability of projectors and the use of incoherent light reducing speckle noise. The disadvantages were a small depth of field and focus, reduced dynamic range in intensity, and cost. With single point triangulation scanners, the researchers found higher resolution, accuracy, and large dynamic ranges with the only disadvantage being cost. Time of flight systems have a longer range for measuring but are bulkier compared to other scanners. The researchers considered range accuracy against volume and field of view. When it came to the physics, the researchers determined that to increase accuracy while conserving field of view other aspects would have to increase as well. Unfortunately, this could mean the scanner could be slower, more expensive, and bulkier.

The researchers discussed combining color texture to acquired data. The researchers mentioned several of methods that are used for color texture mapping, image perspective and reflectance modeling. Image perspective methods use perspective projection to directly map conventional color photographs onto a 3D model (Blais et al., 2003). The drawback mentioned by the researchers was low visual quality due to low resolution video cameras and difficulties with calibration and registration. Another disadvantage was that perspective projection had trouble integrating colors from different views in different lighting conditions. Blais et al. (2003) described reflectance modeling as using the physical properties obtained from the color and shape of an object that are consistent with its color properties. The researchers proposed a way of increasing color accuracy by adding to a single point laser scanner color by joining a RGB (Red, Green, and Blue) laser with the optical fiber that supplies the source of light in the 3D camera. Blais et al. (2003) mentioned very high resolution scanning as a disadvantage due to the impracticability of use of large objects.

In the final section of the study, Blais et al. (2003) examined a hand-held scanner. The researchers discussed the removing of constraints associated with rigidity or positioning to solve stability problems with a hand-held scanner. A solution mentioned uses coded pattern projection methods followed by ICP (Iterative Closest Point) based methods, but ICP algorithms tend to assume rigid, accurate, and stable data in a view. The disadvantage of the method proposed to solve this would decrease accuracy. Because accuracy is important, Blais et al. (2003) suggested synchronization principles to remove constraints and provide an accurate system along with a large field of view and high depth of measurement. This would also allow the system to be optically suitable for use with time-of-flight systems allowing extension of the range. When put into the perspective of crime scene reconstruction, the use of a hand-held laser scanner could be helpful but would be less impractical. A professional might see using a hand-held scanner as more intrusive than a laser scanner on a tripod.

Blais et al. (2003) demonstrated with this study that ranging methods can have high accuracy geometry, dynamic imaging, and high-resolution color texture, as well as hand-held capabilities. The researchers examined several methods used to achieve these results along with the disadvantages of each method. The researchers used complex, expensive machines to create accurate 3D models with high resolution. The importance of accuracy and cost can be critical for certain scientific fields using laser scanners.

If a laser scanner is to be used to acquisition data for the purpose of crime scene reconstruction, then the scanner must be accurate in the measurements collected. A crime scene professional uses the information acquired from the laser scanning to determine objects and their positions. Using this information, a professional can build a

3D model. During a criminal investigation requiring crime scene reconstruction, the accuracy of the laser scans can be extremely important. Boehler and Marbs (2003) discuss this accuracy in their study.

The Boehler and Marbs (2003) study's purpose was to investigate the accuracy of measurements of laser scanners from different manufacturers. The researchers conducted standardized testing that allowed for comparison of a laser scanning instrument from one manufacturer with other manufacturer's instruments at the same time. The testing investigated scanning different types of surfaces and materials at different ranges. The researchers also took into account various aspects of scanning such as resolution that could affect the outcome of the data.

The Boehler and Marbs (2003) study took place at The Institute for Spatial Information and Surveying Engineering Fachhochschule Mainz (i3mainz) and the University of Applied Sciences in Mainz, Germany. Boehler and Marbs (2003) tested a total of 13 laser scanners with three of those scanners being duplicates of three scanners. Of the 13 scanners, the manufacturers supplied five, users supplied six, and i3mainz owned two. The 10 different scanners represented five different manufacturers. The five manufacturers were Callidus, Leica, Mensi, Riegl, and Zoller & Froehlich. Each laser either used the modulation, time-of-flight, or triangulation principle.

During the analysis, the researchers used sphere-shaped targets. The researchers used these spheres to determine distance and to give the laser scanners something to model. Boehler and Marbs (2003) conducted surface and range noise investigations using plane boards. The analysis was prepared in a way that allowed the researchers to record all objects in one scanning with each laser scanner. A stone stairwell, a wall, and a hallway with steel lockers were places that had targets attached for modeling. The researchers tested angular accuracy by scanning in the stairwell and in the room with the targeted wall. Boehler and Marbs (2003) tested range accuracy by scanning in the stairwell and the hallway with targets 60m away and on the lockers. The researchers created a target to test resolution. This target contained slots with varying widths and then is scanned (Boehler and Marbs, 2003). The researchers tested edge effects using a board placed in contrast to a sky background for edges and a vertical, cylindrical pipe for cylinders. Boards painted with paints of varying degrees of reflectivity were scanned to test the influence of surface reflectivity. The researchers kept the environmental conditions constant at favorable conditions and at a temperature of 20ºC when scanning. Boehler and Marbs (2003) chose to keep this constant, but stated that this is a variable that could be examined further. The dependent variables measured during this study were distances orthogonal to range, distances in range direction, resolution, edge effects, and influence of surface reflectivity. The researchers used Mensi’s 3Dipsos software to create models after scanning with each laser scanner.

Variables examined varied the results. When researchers measured noise on a surface with 40% reflectivity at different range distances, it was easy to determine that the Riegl LMS-Z210 was the most affected by noise at any range distance. It was also determined that the scanners manufactured by Leica were the least affected by noise at any range distance. Boehler and Marbs (2003) found the same when measuring distances orthogonal to range and distances in range direction. The researchers tested resolution at two different ranges, 6 meters and 22 meters. The goal was to be able to see the star-shaped pattern of the target. The star-shaped pattern was visible from most of the scanners at 6 meters with the exception of the Callidus and Riegl LMS-Z210 scanners. At 22 meters, the star-shaped pattern was visible from the same eight scanners that could visualize at 6 meters, but the quality began to fall short in some. When the researchers measured edge quality, they found that none of the scanners could produce high quality, but most produced average quality. There were three that were of low quality: Callidus, Riegl LMS-Z210, and Zoller & Froehlich Imager 5003. Moehler and Marbs (2003) conducted testing on the influence of surface reflectivity with eight different surfaces which produced varying results on each laser scanner.

Boehler and Marbs (2003) found that under certain conditions most laser scanners will show significant errors. The researchers concluded that accuracy should not be the only aspect of a laser scanner that should be given consideration. Price, support, warranty, and calibration were suggested for consideration as well. Overall of all the laser scanners that the researchers studied, the Leica HDS3000 seemed to be the best in almost all areas tested. The Riegl LMS-Z210 was the scanner that performed most poorly compared to all others. The researchers mentioned that considering these aspects of the software when purchasing a laser scanner. For the purpose of crime scene reconstruction, the software provided with a scanner in most cases will be supplemented with other software that is more suited to the purpose. For crime scene reconstruction, accuracy is certainly important as well as all the other aspects mention by the researchers.

Sometimes the best course of action in creating 3D models is to combine more than one type of data. In some cases, the data can come from range data and image data, and combined to create a 3D model. Range data is gathered typically by laser scanning while image data typically is gathered through cameras. Allen et al. (2003) conducted a study for creating 3D models of historic sites using range and image data. The researchers discussed a method for registration (coordination of multiple data sets into one system) along with a method for texture mapping.

The purpose of the study conducted by Allen el al. (2003) was to discuss new methods for reducing time and difficulty in creating 3D models of deteriorating historic sites. The researchers discuss the need for 3D models of historic sites as a way to preserve them. In particular, the Cathedral of Saint Pierre in Beauvais, France was the site the researchers chose to model. Allen et al. (2003) worked toward a combination of range and image data to reduce the time as well as the manual effort it takes to create a 3D model of a large site. The researchers used a Cyrax 2400 in the beginning but had to restart with a Cyrax 2500 due to technical issues. This used time-of-flight laser technology to collect point cloud data. Allen et al. (2003) conducted one hundred-twenty interior scans and 100 exterior scans. A digital camera was used to capture intensity images by the researchers.

Once the researchers acquired the data, they needed registration of the range scans. Allen et al. (2003) went about this in a three-step process after segmenting the scans: 1) pairwise registration, 2) global registration, and 3) simultaneous registration of multiple range images. Planar regions and linear features of the connection between adjacent planar structures composed the range segments. The researchers found this helpful for automatic registration, which was the first registration step. Pairwise registration involved registering an overlapping pair of scans. The researchers created a flow chart comprised of stages to follow in this registration process. Allen et al. (2003) carried out global registration after registering pairs. This step involved using the pairs to align all the scans together. The final step used the ICP algorithm to simultaneously register the entire data set. All 120 interior scans and 47 of the exterior scans were used to create the 3D model by registration. The researchers wanted to take this model one step further by adding texture mapping. The intensity images captured by the digital camera were mapped onto a mesh that corresponded to a point cloud.

Allen et al. (2003) were in the process of developing methods to automate registration and to reduce the effort associated with the process when handling large data sets. The researchers discussed the development of an automated process for texture mapping with multiple 2D images. Another aspect discussed by the researchers was sensor planning algorithms used to reduce the amount of scans necessary. One aspect not discussed by the researchers was accuracy. Because Allen et al. (2003) were only looking at large historical sites, accuracy might not have been as important, but for crime scene reconstruction it is very important.

The three previously mentioned studies show a few of the possible processes for laser scanning and software that are possible for creating a 3D model. Two of the studies discussed accuracy as being an aspect that is important when creating these models. The other study discussed the need for a 3D modeling process that uses less time and manual effort but didn’t account for accuracy. Time, manual effort, and accuracy are all important when creating a 3D model for the purpose of crime scene reconstruction.

Application of laser scanning and software for crime scene reconstruction.

Crime scene reconstruction requires the acquisition of a great deal of data if a crime scene professional aims to create a 3D model. With the recent advances in technology, capturing this data has gotten much easier. Laser scanning and modeling software are some of the technological advances that are available for use within the forensic science community. Some manufacturers package software with their laser scanners. Other manufacturers produce software for use with any laser scanner. Some software companies produce software that doesn't require data from a laser scan, but a crime scene professional must create the model themselves based on the information gathered from sketches and photos.

In some instances, crime scene professionals may find a crime scene that is dangerous to walk into due to hazardous materials. In these types of cases, a special team with the proper equipment might be requested to address the situation. Topol et al. (2008) discussed the use of laser scanning and software to create models as well as virtual environments to give professionals available ways to analyze CBRN (Chemical, Biological, Radiological, and Nuclear) scenes. The researchers mentioned the possibility of destroyed evidence from decontamination attempts, the inability of thorough examination of evidence while professionals are wearing personal protective equipment, and the need for quick processes. The researchers also discussed the difficulties with examining single pieces of evidence within a 3D model where everything is integrated into one large mesh during the registration process.

Topol et al. (2008) conducted this study to generate semantic data from 3D scans of crime scenes for crime scene analysis. The Crime Scene Modeler (C2SM) project conducted by the researchers used the iSM (instant Scene Modeler) sensor, composed of a stereo camera created by Se and Jasiobedzki (2006). The iSM uses visible light sensing to produce the data for a 3D model. The purpose of the study was to create software that could use real time data acquisition for quick recreation of scenes in virtual environments. With most modeling software, walkthroughs are available, but a professional cannot usually separate salient objects out from the model for examination. Topol et al. (2008) sought to separate semantic information about these salient objects from 3D models.

Topol et al. (2008) conducted their study in Ontario, Canada with their C2SM sensor. The C2SM sensor was comprised of the iSM sensor and had the ability to perform IR, chemical, and radiological sensing. The researchers mounted the C2SM sensor onto a mobile robot platform for scenes with high contamination but could remove it for hand-held capabilities in less contaminated scenes. The researchers formed the 3D point cloud data from a scan into a textured polygonal mesh that the researchers used in combination with other scans in the registration process by automatic and manual procedures. Topol et al. (2008) sought to create salient structures from 3D scans during the C2SM project. The researchers discussed the difficulty of this task for various reasons such as parts of the object not being visible and volume as a part of an object’s boundary. Algorithms to help make this possible are mentioned. Topol et al. (2008) decided to use the Lazy Snapping technique proposed by Li, Sun, Tang, and Shum (2004) and converting the 3D point clouds into 3D voxel (volumetric pixel) grids. Li et al. (2004) describe the Lazy Snapping technique as an interactive image cutout tool. After this process, the researchers performed surface reconstruction to extract the object in the foreground.

Topol et al. (2008) discussed how a lower voxel resolution left the resulting object with a jagged appearance, but a higher voxel resolution left a portion of the background around the object. Another limitation discussed by the researchers was smaller objects from large space scan appeared at a lower resolution with less detail. The researchers proposed that investigators could re-scan objects at a higher resolution if deeming an object more important for the investigation. The researchers never detailed the amount of time required to go from scanning to the created 3D model with salient objects even though this aspect was mentioned it in the beginning of the study. They also did not discuss accuracy of these models. This type of modeling has certain applications, but professionals will not use it often in most cases. However, with the prevalence of dangers from clandestine drug labs, it may be useful.

Sometimes laser scanning is not a viable form of data acquisition to build a 3D model of a crime scene. As mentioned in the first section of this literature review, a crime scene professional would need to have software that allows him/her to create a model from sketches, photographs, and narrative descriptions. This means that the professional must create the model on his/her own by taking the known and adding it into the model. One aspect of this type of model is the ability to navigate anywhere within the scene, which is not always possible with models built from laser scans. Murta, Gibson, Howard, Hubbold, and West (1998) sought to create a model that would allow for this ability for movement.

The intent of the study conducted by Murta et al. (1998) was to construct a virtual environment that was as close to a real-life crime scene as possible. They sought to accomplish this with the use of the Manchester Scene Description Language (MSDL) which is similar to the Virtual Reality Modeling Language (VRML). This study took place in Manchester in the United Kingdom with the help of the Greater Manchester

Police (GMP). The GMP provided architectural floor plans and photographs. Murta et al. (1998) used the information gathered from these to build their model using the virtual reality system called MAVERIK.

The researcher understood the challenge of building a model from scratch. They took measures to make the process more manageable. Areas that were far from the actual focal point of the crime scene had less detail than those nearest the crime scene. The researchers digitized the floor plans then generated wall descriptions in MSDL from those floor plans. The GMP extracted texture from the photographs provided by the GMP. The researchers also added in other textures in an attempt to create a more real-life effect such as blemishes or accumulations of dirt. Another aspect that Murta et al. (1998) addressed was illumination in a real-life manner. They sought to make the model have more real-life lighting in comparison to video or photographic evidence that contains extra lighting (e.g. flash). The researchers chose to model lighting by using a radiosity algorithm allowing for added illumination not limited by what was present in the photographs. The MAVERIK system generated the simulated walk-through.

Murta et al. (1998) created a modeling process to be fast with perceptually accurate illumination. The aim was to be as realistic as possible with their virtual environment. The response from police officers and forensic scientists that they contacted was favorable. The researchers mentioned accuracy as ‘perceived’ accuracy. Murta et al. based their model from perception which does not always mean accuracy. The researchers did not attempt photogrammetry with the photographs. Inaccuracy could be a limitation with this process and should be considered in any further studies.

One of the most common problems with 3D modeling is the complexity of building them. In most cases, an expert in graphic modeling is needed to build a 3D model of a crime scene or a crime scene professional must take training to use a specific 3D modeling software to build a model on his/her own. Recently, some software manufacturers have been producing 3D modeling software that is easy to use without an expert or extensive training. One such software program is SketchUp. St. Clair, Maloney, and Schade (2012) introduced this product and the aspect of building a model using the product in their study. @Last Software developed SketchUp. Google later acquired it before Trimble purchased it. Trimble currently owns it. A free version is available but professionals may purchase the Pro version.

The objective for the study written by St. Clair, Maloney, and Schade (2012) was to demonstrate the ease of building 3D models using the product SketchUp. The researchers also discussed aspects of the software and presented an example of 3D model they built from a real scene using SketchUp. The researchers created the 3D model using SketchUp from a real scene in Reading, Pennsylvania. The study incorporated the basic concepts, tools, and the 3D Warehouse in creating the real scene example.

Some of the basic concepts of SketchUp are templates, Cartesian coordinate system, camera projection, styles, and layers. SketchUp allows the user to use templates or to use the Cartesian coordinate system when building a model. At any point during the model the user may change these if needed. Choosing the camera projection can be important. The user can use parallel projection and perspective projection for a 2D top-down view and 3D view, respectively. The third camera projection, two-point perspective, is not conducive to crime scene modeling. The user may create a fly-through or walk-through using camera positions. Users use styles to create different textures, surface colors, monochrome styles, or X-ray styles. The user may create layers in SketchUp that the user can turn on or off. This is useful for showing only areas needed at particular times.

St. Clair, Maloney, Schade (2012) discussed the tools available in SketchUp to view, manipulate, and work with a 3D model. They also mentioned the SketchUp 3D Warehouse. The 3D Warehouse is a free, online database that stores thousands of models that users have uploaded. These uploads include almost anything a user would need to create a model such as tables, chairs, couches, etc. The user may edit these models to fit his or her needs, and user may upload his or her own creations.

The scene that was used to create a scene example was an actual scene in which the victim was struck approximately 23 times by two assailants with a hammer and a baseball bat. The victim lay in a doorway between the kitchen and dining room. The researchers used two hand-drawn sketches prepared by detectives as well as photographs taken at the scene. The researchers imported these sketches into SketchUp allowing a side-by-side comparison view. They created a general floor outline from the sketch measurements. The researchers used the 3D Warehouse to find furniture similar to those in the scene in the photographs. St. Clair, Maloney, and Schade (2012) modeled furniture not present in the 3D Warehouse. They placed all the furniture in the model according to measurements taken from the sketches. The researchers also placed evidence markers within the scene which were in a layer of their own. To place the victim's body within the scene, the researchers used a Muryoung Standard Pose poseable body available in the 3D Warehouse. Using the photographs provided, they placed the body in the correct position. St. Clair, Maloney, and Schade (2012) added walls next, followed by details such as windows, doors, and textures.

The final section of the St. Clair, Maloney, and Schade (2012) study discussed advanced topics that pertain to using SketchUp. The researchers addressed the goal of the photographer at a scene. If a user is planning a model, the researchers mentioned taking extra photographs of textures of walls, floors, furniture and other objects. Again, they discuss building a scene animation such as a fly-through. St. Clair, Maloney, and Schade (2012) mention optional software extras and plug-ins possibly available for use with SketchUp. Other models created by other software can be imported into SketchUp, or a SketchUp model may be exported into another software program. The researchers discussed aspects of SketchUp Pro such as the type of files for importation or exportation, the ability to create an attribute report, and the application LayOut. LayOut converts the 3D model into 2D image.

The study conducted by St. Clair, Maloney, and Schade (2012) introduced a modeling software program that is inexpensive and fairly easy to use. The ability to import sketches prepared by crime scene professionals allows them to easily build a model based on those measurements. Modeling becomes even easier by the ability to use previously uploaded models in the 3D Warehouse and to edit the model to fit the measurements in the sketches. If laser scanning is not available, this can be an adequate software program for creating a 3D model by crime scene professionals.

The three articles reviewed in this final section discussed different software programs for use with laser scans. The article by Topol et al. (2008) examined the use of a laser scanner incorporated with other sensors for the use in CBRN scenes and modeling individual items for examination from those scans. They failed to discuss accuracy and the time needed to create these scans. Murta et al. (1998) discussed the creation of models as close to real-life as possible using the MAVERIK system. Again the researchers never address real accuracy within this study. In the final study, St. Clair, Maloney, and Schade (2012) introduce SketchUp for building 3D models. Accuracy is dependent on sketches, and the researchers discuss ease of use and cost as advantages. These are all aspects that can be important in deciding the type of software to purchase for the purpose of crime scene reconstruction.

Summary

Accuracy in crime scene 3D models is imperative for a crime scene professional. If this is not possible, then there is no reason to make a 3D model. The first section of this chapter discussed the processes that have been in use for many years and still used for creating 3D models of crime scenes. Sketching only provides a 2D view of a crime scene unless it used with software to create a 3D model. Photogrammetry needs a calibrated camera and at least one known measurement to create a model. The research studies presented in the second and third section of this chapter have discussed various aspects of laser scanning and software programs that used to create 3D models.

In the second section, one study discussed disadvantages and advantages of some laser scanners while another discussed accuracy of other scanners. The third study in the section discussed reducing time and difficulty. Cost, complex machines and software, time, and lack accuracy are some of the negative issues identified within these studies.

The third section discussed laser scanners and software used in crime scene reconstruction to build 3D models. One study discussed using laser scans to create fast models of individual objects, but the researchers never elaborated on time required. Another study discussed creating virtual environments that are close to real-life, but the accuracy mentioned was 'perceived' accuracy instead of real accuracy. The final study introduced the program SketchUp, which has the ability to incorporate crime scene sketches but does not incorporate laser scanning. More research should be conducted on the accuracy of some of the software programs that are available for use with laser scanning in the area of crime scene reconstruction. This current study contributes to the existing research literature by comparing the accuracy of 3D models constructed from laser scans using two of the currently available software programs.

Chapter Three
Methods

Introduction

This study was divided into five steps. The first step was to create the scenes for scanning and model building within the software programs. The second step was setting up the Focus 3D, scanning the scenes, and breakdown of the scanner. Obtaining manual measurements of each scene was step three. Step four consisted of loading the data into a computer, using SCENE to add color to the scans, and loading the colored data into SceneVision 3D. The fifth and final step was sorting and merging of the data to create a 3D model of each scene in SCENE and SceneVision 3D.

Setting

This study took place in what was a former doctor's office and osteopathic hospital owned by the University of Central Oklahoma at the time of the study. The building occupies the corner of 4th Street and Littler Avenue in Edmond, Oklahoma. Two areas were chosen for the two types of scenes:

<u>Scene 1 – Basic Single Focal Point</u>

This basic single focal point scene took place in a simple room (Figure 2) with one entry. The door was kept closed during scans so as not to capture the hallway outside the room. A forensic mannequin was placed in the middle of the room. This scenario required two scans, one on each side of the mannequin. The room was furnished with a couch which was against the west wall.

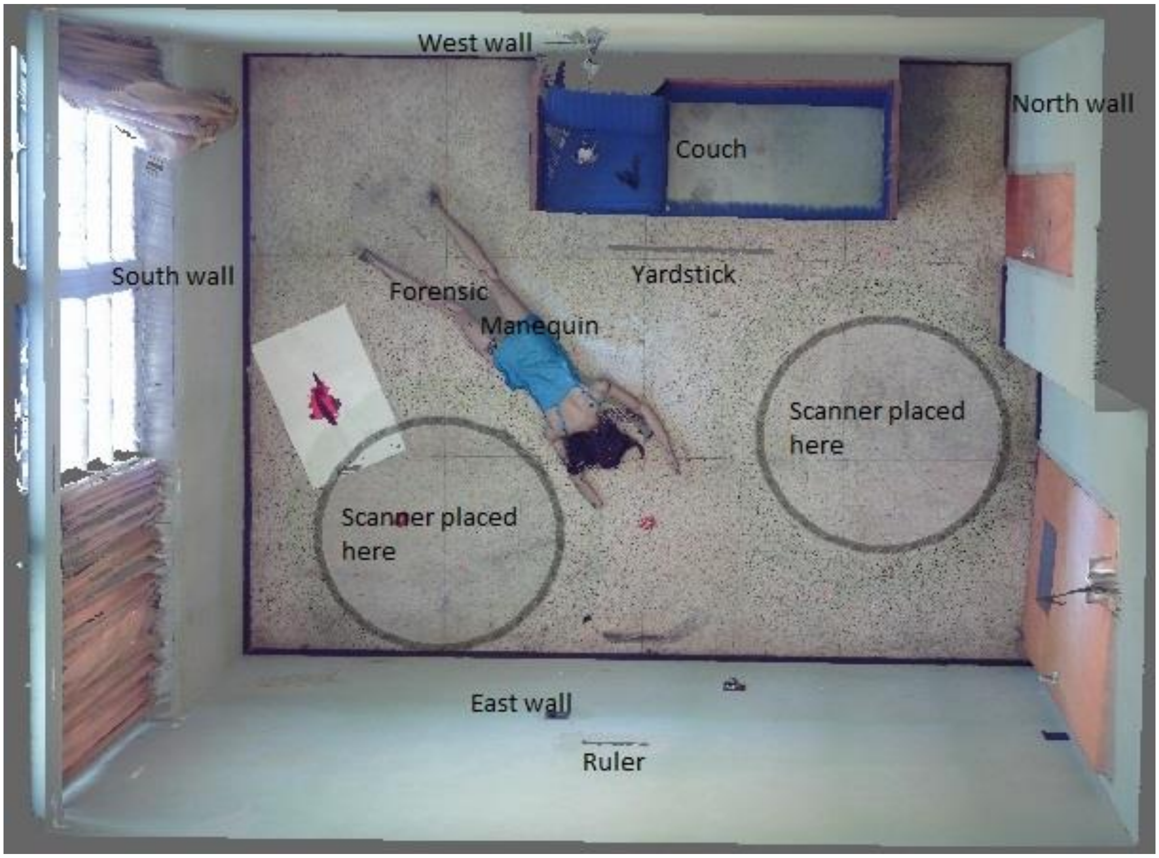


Figure 2: Perspective view of the basic scene.

Scene 2 – Complex Multi-focal Point

This complex multi-focal point scene took place in the entryway to the former hospital, the waiting room, and the receptionist's room (Figure 3). Data from the two connecting hallways and outside the front door was not used, although those areas were partially captured by the scanner. This scene required three scans, one in each of the previously areas mentioned. In the entryway and waiting room, all of the furniture and other furnishings were left against the walls. In the southwest portion of the receptionist's room, a curved wall stood. This wall was two-thirds glass from the ceiling and one-third wall from the floor. An L-shaped desk was located in the center of the room. The wall across the receptionist's room door was captured partially due to the frame of the receptionist's room window.

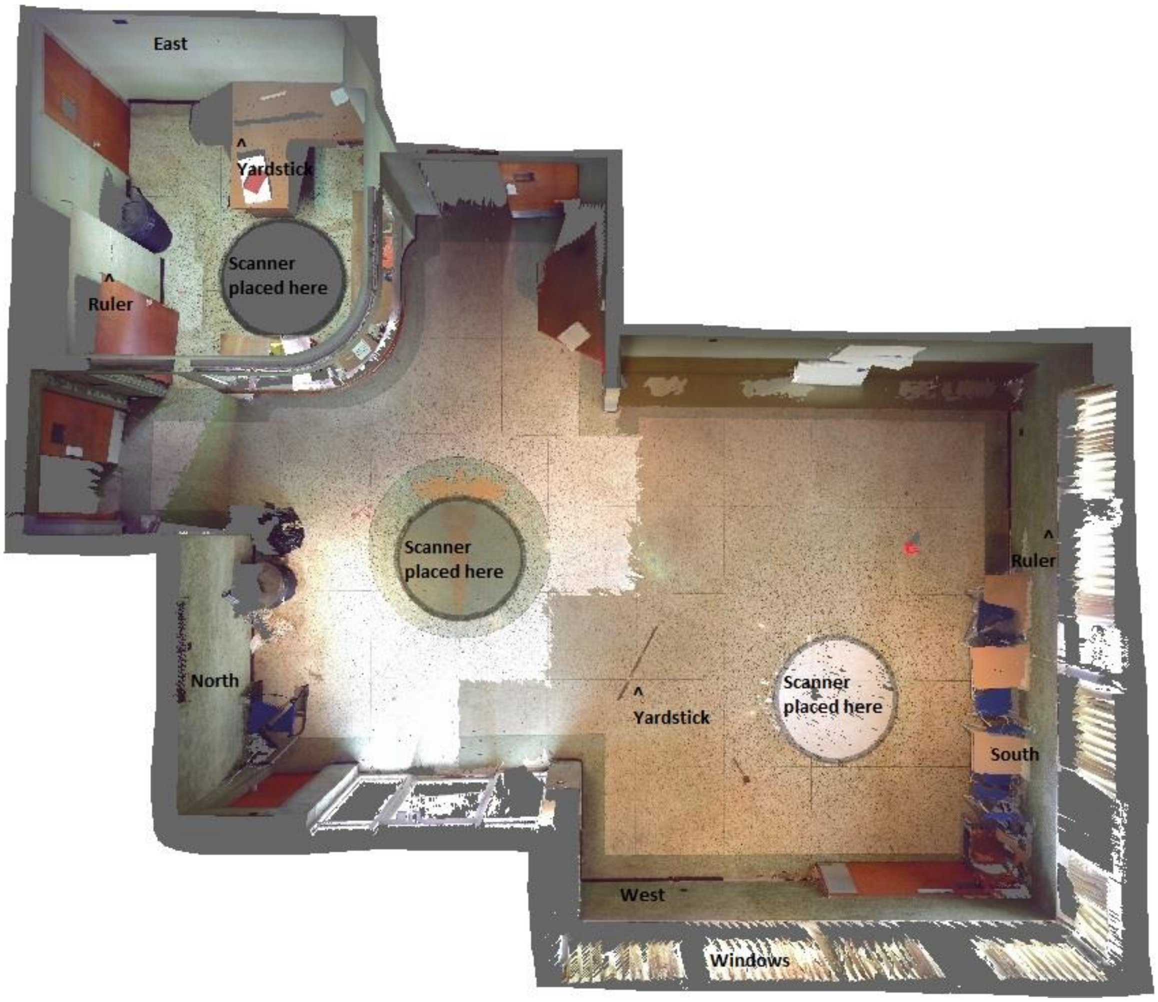


Figure 3: Perspective view of the complex scene.

Sample

In order to validate the accuracy of the scan and models, target stickers were placed in the scene to act as measurement points. The number of stickers represents the sample size. The sample size for each scene differed due to the physical size of each scene. The basic scene contained 15 target stickers that provided 82 measurements.

These contained measurements of wall to wall, wall to floor, wall to ceiling, and floor to ceiling. Two more measurements were obtained from the NIST certified stainless steel ruler and yardstick, making the total 84 measurements. The complex scene contained 38 target stickers that provided 230 measurements. These were also from wall to wall, wall to floor, wall to ceiling, and floor to ceiling. Four more measurements, two each from the ruler and yardstick, were obtained resulting in a total of 234 measurements.

Materials

The University of Central Oklahoma's Forensic Science Institute provided all the materials used during this research study except the target stickers. The fluorescent orange target stickers were purchased locally for minimal cost. The University of Central Oklahoma's Forensic Science Institute provided the FARO Focus 3D 130m, its accessories, the two software programs, the laptop used in conjunction with the two software programs, the SD card for storing the data, and the Bosch laser measuring device.

Measurement Instruments

Six different measurement instruments were used in this research study. This includes the laser measurer, the laser scanner, the two software programs, and the NIST certified ruler and yardstick. A Bosch GLM 50 digital laser rangefinder was used for obtaining the manual measurements. The Bosch GLM 50 obtains measurements for distances from 2in to 165ft using a laser wavelength of 635nm. The typical measuring accuracy of the laser measurer is +/- 1/16in (See Appendix A for technical data). The error rate of +/- 1/16in complies with the standards set forth by NIST.

The FARO Focus 3D 130 was used to obtain the range data for use with the two software programs. The FARO Focus 3D obtains data for distances from 0.6m to 120m indoors/outdoors using a laser wavelength of 905nm. The range error for this laser scanner is +/- 2mm (See Appendix A for technical data). SCENE is the software that comes with the FARO Focus 3D for obtaining measurements and building 3D models. SceneVision 3D is another software program marketed for use with the FARO Focus 3D for obtaining measurements and building 3D models. The University of Central Oklahoma's Forensic Science Institute purchased the FARO Focus 3D laser scanner with SCENE and also acquired SceneVision 3D at the same time.

Certified stainless steel rulers and yardsticks were utilized for the known measurements in both the basic scene and the complex scene. The stainless steel 12" ruler and 36" yardstick are 1in wide and 0.030in thick with engraved, black filled graduation and graphics. Each comes with a serial number and a certification sheet from the manufacturer. The University of Oklahoma's Forensic Science Institute purchased these in November 2014.

Data Collection/Procedures

Step 1: Set-up of scenes

Two mock crime scenes were staged for this study. One scene was a basic, single focal point scene which would require two scans (See Figure 2). The other scene was a complex, multi-focal point scene which would require three scans. Scans in the complex scene included two in the main room and one in the adjoining receptionist's room separated by the partial wall and glass (See Figure 3). Targeting stickers were placed on the walls, floors, and ceiling for the purpose of creating measurement points within these structures. The basic scene had five points on the ceiling (A-E), five points on the walls (F-J), and five points on the floor (K-O). The complex scene had 15 points on the walls, 13 points on the floors, and 10 points on the ceilings. The points on the walls were labeled as K-O, U, V, Y, Z, CC, DD, GG, and JJ-LL. The points on the floors were labeled as P-T, W, X, AA, BB, EE, FF, HH, and II. A-J represented the points on the ceiling. The NIST certified ruler and a yardstick were placed within each scene to verify the accuracy of the scan and served as known measurements within each scene. The ruler and yardstick were each placed once in the basic scene and twice in the complex scene.

Step 2: Set-up Focus 3D, scan, breakdown Focus 3D

The laser scanner on a tripod was positioned within the scene for scanning. Once in place, each scene was scanned twice for the basic scene and three times for the complex scene using the FARO Focus 3D laser scanner. Once the scanner is activated, the FARO Focus 3D rotates clockwise by 180˚. When scanning with color, the scanner will turn 360˚ to capture photographs. Green safety glasses are provided with the scanner to wear if the user is less than a safe distance from the laser. A standard SD card stored the data from each scan. Each scan took approximately 4-5 minutes.

Step 3: Manual measurements obtained

Traditional scene measurements were obtained manually using the Bosch GLM 50 laser measuring device. Laser measuring devices are becoming standard among law enforcement agencies and provide reliable measurements on flat surfaces (walls, ceilings, floors) and for points in between. Using the targets placed before scanning, measurements were obtained from wall to wall, wall to floor, wall to ceiling, and floor to ceiling for each scene. The 3D modeling began after completion of all these steps.

Step 4: Data loading and addition of color through SCENE

Data generated from the Focus 3D was loaded onto a computer from the standard SD card for model building using the software programs. The computer used was a Dell Precision M 6400 with an Intel® Core™2 Duo CPU and 4GB of RAM. The operating system was Windows 7 Enterprise. Before the data was manipulated in SceneVision 3D, it was manipulated through SCENE first. SCENE was used to add color to the scans. The data was imported from the SD card into SCENE. The scans were loaded and color applied using SCENE. After color was added, the data was then imported into SceneVision 3D. This process took approximately 5-10 minutes for the basic scene and 10-15 minutes for the complex scene.

Step 5: Sorting and merging of data within SCENE and SceneVision 3D

Once the colored scanned data is uploaded to SceneVision 3D and SCENE, the next step was to align range data. To align scans in SceneVision 3D, two scans with the same features are positioned side by side and common points within both scans are chosen. In SceneVision 3D, there are two model options: a smart model (high quality, made in hours) and a quick model (low quality, made in minutes). For this research, a smart model was created for the best quality. All scans were then combined to form a single model. Deleting extraneous data, eliminating or reducing overlapping data, and filling holes in flat surfaces are editing functions performed during this phase. These steps give the model a clearer and cleaner overall look when finished. Annotations, such as measurements, are made in SceneVision 3D during this phase of the building process as well. Visible measure lines were the only annotations created.

In SCENE, registration of the data must occur. A point cloud is created and then the model must be put into 3D view. To obtain measurements, the coordinate of each target sticker was found for creating a measurement point. Once measurement points are created in SCENE, then the ability to measure from point to point is possible. Upon completion of the models, the measurements within the models were compared with the measurements taken manually. Data analysis was then performed using a paired *t*-test to compare the two means from the two sample sets.

Data Analysis

Data analysis in this case was performed with the assistance of University of Central Oklahoma Math and Statistics Department's Dr. Tracy Morris. IBM's SPSS Statistics software program was used to run the statistical analysis. To estimate the measurement error (in inches), the manual measurements were subtracted from both the SCENE and SceneVision 3D measurements for both scenes. A paired *t*-test was performed for each scene to determine any significant mean differences in the measurement error for SCENE and SceneVision 3D programs. The paired *t*-test also provided the upper and lower 95% confidence intervals. The paired *t*-test was chosen because the means of two samples with normal distribution were being compared to each other. The data from both scenes was compared with the NIST guidelines of a measurement needing to be within +/- .25 inches for admissibility in court.

CHAPTER FOUR
Results

Introduction

This chapter discusses the quantitative analysis in two forms, descriptive statistics and inferential statistics. For the descriptive statistics, for each software program in each scene the frequency of the differences, the mean, and the standard deviation were described. For the inferential statistics, the results of the paired-samples *t*-test used for comparing the mean differences of the measurement error from the software programs in each scene was also described. As stated in the previous chapter, a paired samples *t*-test was chosen because the means of the samples for each room had normal distributions and they were being compared to each other.

Descriptive Statistics

To analyze the results for each scene, descriptive statistics were calculated for the differences between the measurements from SCENE or SceneVision 3D and the manual measurements. Descriptive statistics is an analysis of data that describes or summarizes data in a way that patterns might emerge from the data. The sample size for the basic scene was 84 measurements. The ruler measured 12.284 in and the yardstick was 36.372 in. In the basic scene, the ruler in SCENE measured 12.516 in and for SceneVision it was 12.6 in. The yardstick measured 36.48 in for SCENE and 36.396 in for SceneVision 3D. In the complex scene, the ruler measured 12.276 in and 12.444 in for SCENE and 12.396 in for SceneVision 3D. The yardstick was 37.236 in and 36.444 in for SCENE and 37.404 in and 36.204 in for SceneVision 3D. The SCENE-Manual measurement differences mean was -0.192 inches and the standard deviation was 0.461 (Figure 4).

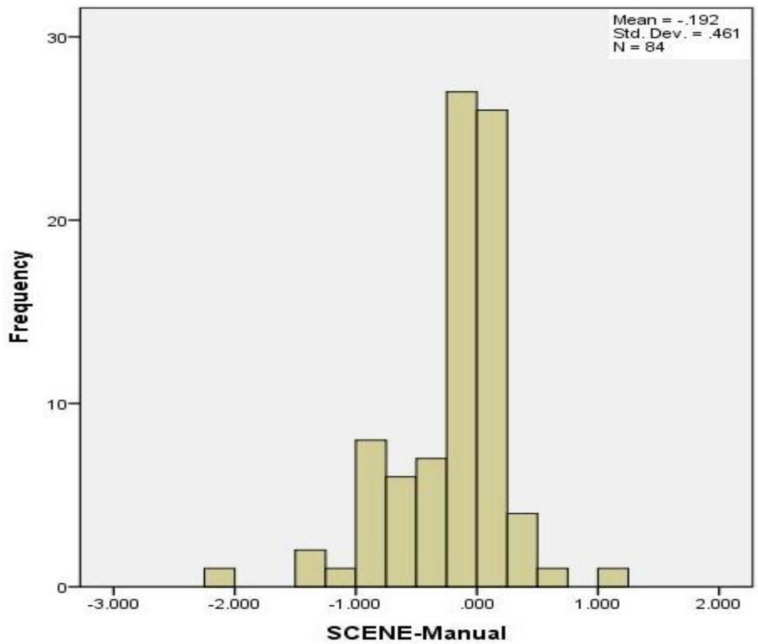


Figure 4. Frequency histogram for SCENE-Manual (in inches) for basic scene.

For the SceneVision 3D-Manual measurement differences mean was -0.243 inches and the standard deviation was 0.454 (Figure 5).

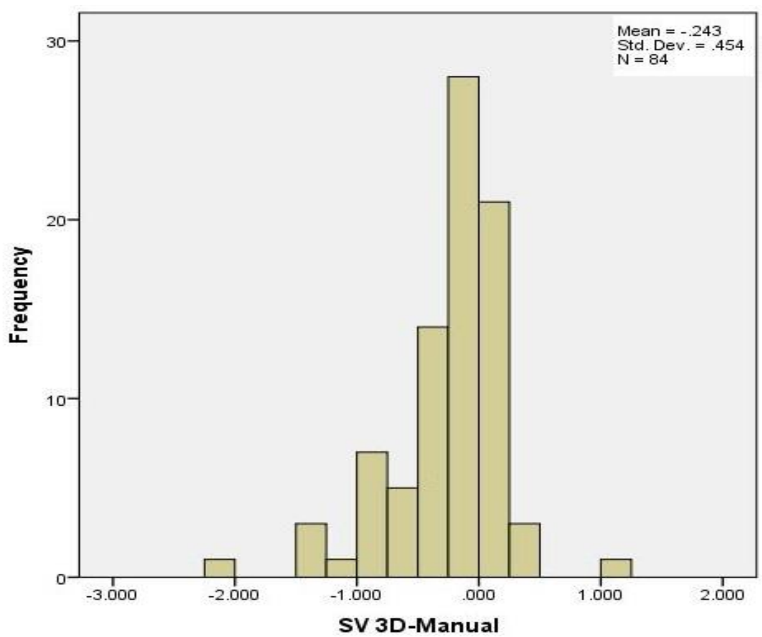


Figure 5. Frequency histogram of SceneVision 3D-Manual (in inches).

The same analysis was conducted for the complex scene. The SCENE-Manual measurement difference mean was -0.154in (SD = 0.0948) where N = 234 (Figure 6).

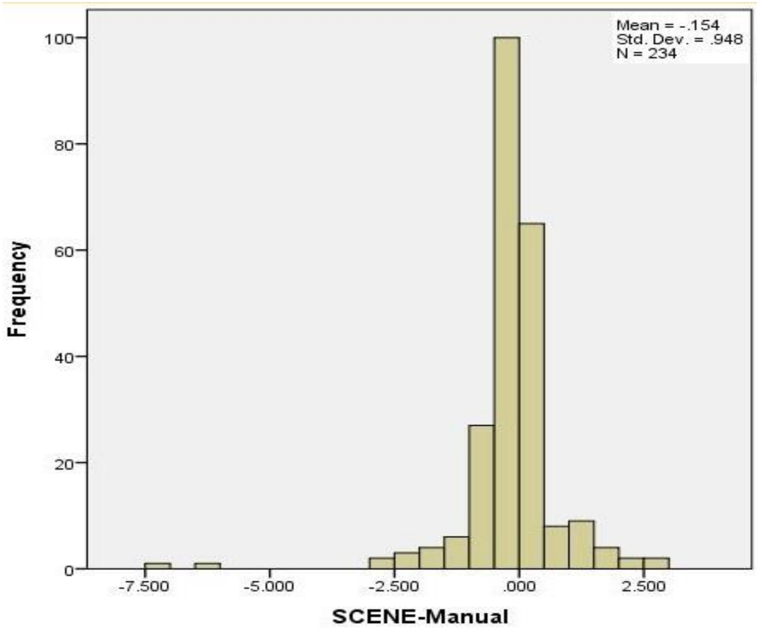


Figure 6: Frequency histogram of SCENE-Manual (in inches).

The SceneVision 3D-Manual measurement differences mean was -0.190 inches and the standard deviation was 0.929 (Figure 7).

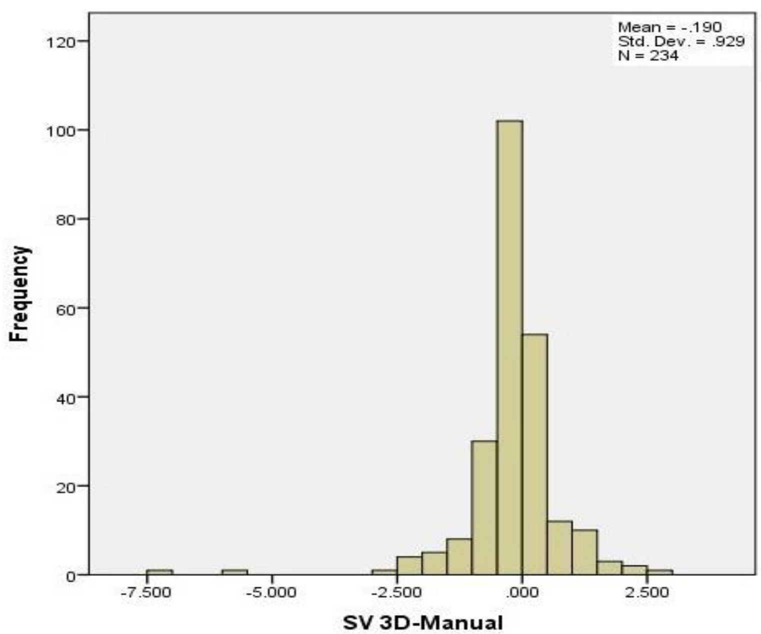


Figure 7. Frequency histogram of SceneVision 3D-Manual (in inches).

Inferential Statistics

For the inferential statistical analysis, a paired-samples *t*-test was performed to determine if there was a significant mean difference between the two software programs measurement error in each scene. This type of statistical analysis is used to make generalizations about populations from which samples were acquired. On average, both the SCENE and SceneVision3D programs seem to slightly underestimate measurements by approximately 0.2 inches, as indicated by the negative means displayed for SCENE-Manual and SceneVision 3D-Manual in Table 2.

Table 2

Summary Statistics and Hypothesis Test Results for the Measurement Error

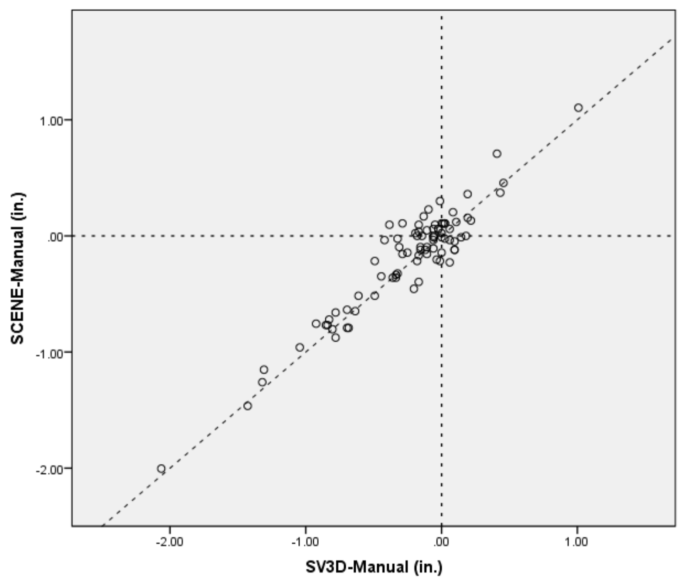
	n	**Mean**	**S.D.**	**95% CI**	***t***	**p-value**
Basic Scene						
SCENE-Manual	84	-0.19	0.46	(-0.29, -0.09)		
SceneVision 3D-Manual	84	-0.24	0.45	(-0.34, -0.14)		
Diff	84	0.05	0.15	(0.017, 0.084)	3.013	0.003
Complex Scene						
SCENE-Manual	234	-0.15	0.95	(-0.28, -0.03)		
SceneVision 3D-Manual	234	-0.19	0.93	(-0.31, -0.07)		
Diff	234	0.04	0.26	(0.003, 0.069)	2.141	0.033

This was true for both the basic and complex scenes. These means were significantly different from zero as indicated by the 95% confidence intervals displayed in Table 2. All four confidence intervals were less than 0.

It was found that there was a statistically significant difference in the mean amount of measurement error of the SCENE and SceneVision 3D programs for both the basic ($t = 3.013,\ df = 83,\ p = 0.003$) and complex ($t$ =2.141, df =233, p =0.033) scenes.

However, this difference did not appear to be practically significant because this study was not comparing the two software programs. The mean difference in the measurement errors for the basic scene was only 0.05 inches (95% CI: 0.017-0.084) and for the complex scene 0.04 inches (95% CI: 0.003-0.069). In both cases, SCENE was slightly more accurate. Plots of the measurement error for both scenes are displayed in Figure 8.

a. Basic Room



b. Complex Room

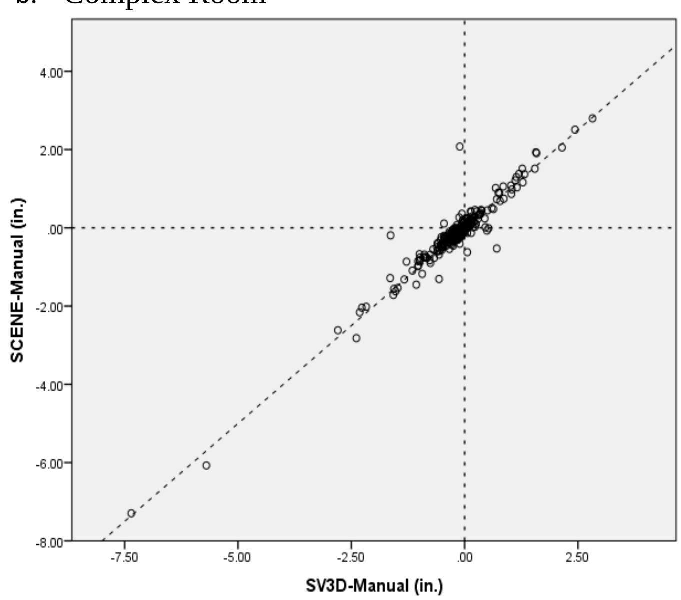


Figure 8. Measurement Errors for the Basic and Complex Rooms.

In Figure 8, the measurement error for the SCENE program was plotted against the measurement error for the SceneVision 3D program. There are three reference lines in each plot. The diagonal line is the line $y = x$. If a point lies on this line then the amount of measurement error for the two programs is the same. The other two reference lines are the lines $y = 0$ and $x = 0$. The further a point is from the intersection of these two lines, the greater the amount of measurement error. In both plots, the points lie roughly along the $y = x$ reference line, indicating that the two methods have approximately the same amount of measurement error.

CHAPTER FIVE
Discussion

Introduction

Laser scanning is becoming an increasing mechanism for obtaining measurements for crime scene processing and crime scene reconstruction. Two of the current software programs available for use in this area are FARO's SCENE and 3rdTech's SceneVision 3D. Even though research studies are available, research validating the measurement accuracy has been sparse. The National Institute for Standards and Technology (NIST) has given a measurement guideline for court admissibility (Crime Scene Investigation: A Guideline for Law Enforcement, 2012). This guideline is +/- 0.25 inches for any type of measurement obtained within a crime scene. The primary purpose of this research study was to validate the measurement accuracy for SCENE and SceneVision 3D for court admissibility. This study sought to determine if the measurements obtained using SCENE and SceneVision 3D are within the guidelines established by NIST.

Discussion

The descriptive statistics were calculated for the differences between the measurements from SCENE or SceneVision 3D and the manual measurements. The SCENE-Manual measurement difference mean was -0.192 inches (SD = 0.461) while the SceneVision 3D-Manual measurement difference mean was -0.243 inches (SD = 0.454) for the basic scene. The SCENE-Manual measurement differences mean was -0.154 inches (SD = 0.948) while the SceneVision 3D-Manual measurement differences mean was -0.190 inches (SD = 0.929) for the complex scene.

For the inferential statistical analysis, a paired-samples *t*-test was performed to determine if there was a significant mean difference between the two software programs measurement error in each scene. On average, both the SCENE and SceneVision3D programs tend to slightly underestimate measurements by approximately 0.2 inches. Table 2 indicates negative means for SCENE-Manual and SceneVision 3D-Manual for both the basic and complex scenes. The 95% confidence intervals indicated these means are significantly different from zero as all four are less than zero.

There is a statistically significant difference but not a practically significant one in the mean amount of measurement error of the SCENE and SceneVision 3D programs for both the basic and complex scenes. The mean difference in the measurement errors for the basic scene is only 0.05 inches and for the complex scene 0.04 inches. In both the basic scene and the complex scene, the SCENE program is just slightly more accurate. When plotted against each other, the two methods were found to have approximately the same amount of measurement error.

After the analysis of the results, it was found that, on average, measurements from both FARO's SCENE and 3rdTech's SceneVision 3D are within the NIST guidelines of +/- 0.25 inches for admissibility as evidence in court. It was also found that both programs tend to underestimate by 0.2 inches when obtaining measurements. Fortunately, this underestimation is still within the NIST guidelines. During the analysis, SCENE's measurement differences were found to be just slightly more accurate than SceneVision 3D's by 0.04-0.05 inches when obtaining measurements. Overall, each program obtains measurements that are very close to what the other program produces.

Limitations

This study did not factor in time needed to conduct a scan or to create a 3D model. Each type of program needs varying amounts of training and use to be familiar with the product. Time needed for training may be different for each program due to different complexities within each. This means time needed for training was not a factor in this study. It was found that the laser scanner could not capture evidence on light fixtures unless the light was in the off position. Point H in the complex scene was removed due to this issue. In SceneVision 3D, a crime scene professional can add into a model a photograph of evidence on a light fixture.

The University of Central Oklahoma's Forensic Science Institute purchased NIST certified stainless steel measuring devices, a yardstick and a ruler, for use as the known measurements during this study. Unfortunately, it was found that the steel of the ruler and yardstick was too reflective for the laser scanner to capture them properly. Because of this reflectiveness, the models displayed voids where these measuring devices were, or the hatch marks/numbers were not distinct enough for clear visualization. To use these known measurements, the devices were measured from one physical end to the other. In the model, the void left by the measuring device was measured or, if present, the physical end of a device to the other was measured.

Recommendations for Future Research

As this research study only sought to validate the accuracy of the measurements obtained using one of these programs for use at a crime scene, there are many different aspects that could be researched in the future. Because some of the measurements were skewed due to light sources, this study could be repeated with better placement of some of the measurement points, or under varying lighting conditions.

Another area for possible future research could involve whether using a tripod for the laser measurer would affect the manual measurements more so than it being hand held. The further the distance to measure, the harder it is to keep the laser steady for a measurement. Human error can possibly skew the measurements obtained manually.

There are many aspects of each program that were not considered for this study. SceneVision 3D has a blood stain tool that could be validated for use and admissibility as evidence in court**.** **User-friendliness** and **time needed** are other factors that could be studied. Both programs have learning curves associated with them that could affect both of those two factors. Both programs are vastly different in the process by which a model is constructed and this can affect both **user-friendliness** and **time needed**. Training offered can affect both of these factors as well as experience of the operator.

Conclusion

Based on the findings in this study, on average, measurements obtained using FARO's SCENE and 3rdTech's SceneVision 3D fall within the range required in the guidelines published by NIST for court admissibility. Even though both programs tend to underestimate to a slight degree, the mean of the underestimation is still within NIST's guidelines. Measurements obtained using SCENE or SceneVision 3D should be admissible as evidence in a court case when measurements have evidentiary value.

Human error can come into play heavily when obtaining measurements by manual means. The laser measurers and tape measurers both have drawbacks to them.

Both of the software programs remove some of this error. Even if a measurement is accurate to +/- 0.25 inches, this may not be of importance practically speaking. If there is a grouping of small items, it may not be necessary to know within +/- 0.25 inches where they are in the scene. The guideline NIST has published is just that, a guideline. A judge may decide a measurement is still admissible even if it doesn't fall within the guideline published by NIST.

One advantage of SceneVision 3D is that it has features that allow for bloodstain analysis and for adding in photos of reflective evidence from a calibrated camera. Another advantage is that SceneVision 3D is more visually appealing, and a user can create a simulated walkthrough of the crime scene. A third advantage is that the cost of the software program includes three days of on-site training. The main disadvantage of SceneVision 3D is the time required to delete the duplicate data. Deletion does make the model more visually appealing, but it is the most time consuming of the steps involved in the model building.

A major advantage of SCENE is that it is much easier to use in terms of model building. The time spent creating the model is far less than that needed for SceneVision 3D. One of the disadvantages was the SCENE model was less visually appealing. The polygonal mesh was constantly visible when navigating through the mock crime scene. There did not appear to be a feature that allowed the user to hide the polygonal mesh. The other disadvantage was the user training videos on youtube.com did not always correspond to the features of the current SCENE version. Videos are normally a great option, but in this instance it was not. Newer training videos for the newer version were not readily available. The manual was helpful sometimes to fill the gaps in the video instruction.

Overall, both SCENE and SceneVision 3D can be used to obtain measurements that are, on average, accurate and should be admissible in court as evidence. It is recommended that SCENE or SceneVision 3D be used by someone on a consistent basis for the best quality. A lengthy time between usage of either software program can make the process of model building more time consuming. In any case, it is up to the crime scene professionals and their agencies to decide which program is best for their agency, in what capacity they want to use it, and which works well for them under their local rules of evidence and criminal procedure.

Appendix A:

Technical Data

FARO Focus 3D Technical Data Sheet

FARO Laser Scanner Focus[3D]

www.faro.com/focus

Performance Specifications

GSA Contract Holder

ISO 9001 BUREAU VERITAS Certification

Ranging Unit

Unambiguity interval: 153.49m (503.58ft)
Range Focus[3D] 120[1]: 0.6m - 120m indoor or outdoor with low ambient light and normal incidence to a 90% reflective surface
Range Focus[3D] 20: 0.6m - 20m at normal incidence on >10% matte reflective surface
Measurement speed: 122,000 / 244,000 / 488,000 / 976,000 points/sec
Ranging error[2]: ±2mm at 10m and 25m, each at 90% and 10% reflectivity

Ranging noise[3]	@10m	@10m - noise compressed[4]	@25m	@25m - noise compressed[4]
@ 90% refl.	0.6mm	0.3mm	0.95mm	0.5mm
@ 10% refl.	1.2mm	0.6mm	2.20mm	1.1mm

Color Unit

Resolution: Up to 70 megapixel color
Dynamic color feature: Automatic adaption of brightness

Deflection unit

Vertical field of view (vertica/horizontal): 305° / 360°
Step size (vertical/horizontal): 0.009° (40,960 3D pixels on 360°) / 0.009° (40,960 3D pixels on 360°)
Max. vertical scan speed: 5,820rpm or 97Hz

Laser (Optical transmitter)

Laser power (cw Ø): 20mW (Laser class 3R)
Wavelength: 905nm
Beam divergence: Typical 0.16mrad (0.009°)
Beam diameter at exit: 3.8mm, circular

Data handling and control

Data storage: SD, SDHC™, SDXC™; 32GB card included
Scanner control: Via touch-screen display
New WiFi(WLAN) access: Remote control, Scan Visualization and download are possible on mobile devices with Flash®

Multi-Sensor

Dual axis compensator: Levels each scan with an accuracy of 0.015° and a range of ±5°
Height sensor: Detects the height relative to a fixed point via an electronic barometer and adds it to the scan
Compass: Electronic compass gives the scan an orientation. A calibration feature is included.

1) Depends on ambient light, which can act as a source of noise. Bright ambient light (e.g. sunshine) may shorten the actual range of the scanner to lesser distances. In low ambient light, the range can be more than 120m for normal incidence on high-reflective surfaces.
2) Ranging error is defined as the maximum error in the distance measured by the scanner from its origin point to a point on a planar target.
3) Ranging noise is defined as a standard deviation of values about the best-fit plane.
4) A noise-compression algorithm may be activated to average points in sets of 4 or 16, thereby compressing raw data noise by a factor of 2 or 4.
Subject to change without prior notice.

Patented: US 7,430,068 B2; 7,733,544; 7,847,922 B2

Hardware Specifications

Power supply voltage: 19V (external supply), 14.4V (internal battery)
Power consumption: 40W and 80W respectively (while battery charges)
Battery life: Up to 5 hours
Ambient temperature: 5° - 40°C
Humidity: Non-condensing
Cable connector: Located in scanner mount
Weight: 5.0kg
Size: 240x200x100mm³
Maintenance calibration: Annual
Parallax-free: Yes

SFDC_04MKT_0235.pdf Revised: 10/5/11

Bosch GLM 50 Technical Data Sheet

d Laser, switched on
e Measurement reference level
f Temperature warning
g Battery low indicator
h **"ERROR"** indication

Technical Data

Digital Laser Rangefinder	GLM 50
Article number	3 601 K72 210
Measuring range	2-in - 165-ft (0.05 - 50 m)[A]
Measuring accuracy (typically)	±1/16-in (±1.5 mm)[B]
Lowest indication unit	1mm
Operating temperature	14°F... 122°F (-10°C... +50°C)[C]
Storage temperature	-4°F... 158°F (-20°C... +70°C)
Relative air humidity, max.	90%
Laser class	2
Laser type	635nm, <1mW
Laser beam diameter (at 77°/25°C) approx.	
–at 33-ft (10 m) distance	0.24-in (6 mm)
–at 165-ft (50 m) distance	1.4-in (35 mm)
Automatic switch-off after approx.	
–Laser	20s
–Measuring tool (without measurement)	5min
Batteries	2x1.5V (AAA)
Battery life, approximately	
–Individual measurements	10,000[D]
–Continuous measurement	2.5h[D]
Weight according to EPTA-Procedure 01/2003	0.3 lbs. (0.14 kg)
Dimensions	2" x 4.4" x 1.2" (51mm x 111mm x 30mm)
Degree of protection	IP54 (dust and splash water protected)

A) The working range increases depending on how well the laser light is reflected from the surface of the target (scattered, not reflective) and with increased brightness of the laser point to the ambient light intensity (interior spaces, twilight). In unfavorable conditions (e.g. when measuring outdoors at intense

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