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Analysis of Error within Forensic Measurements and Photogrammetry Programs

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ANALYSIS OF ERROR WITHIN FORENSIC MEASUREMENTS AND PHOTOGRAMMETRY PROGRAMS

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Abstract

Digital images and photography have been considered commonplace in forensic science since the late 1990's. Photogrammetry is a tool used in forensic science to measure objects within photographs that contain a scale or programs that are able to measure items in 3D images. Items at crime scenes often need to be measured and forensic scientists may not know what the best option is for their situation. This research will be conducted to show which type of measurement technique is most accurate, calculated against NIST traceable measurements, at various sizes of objects. The measurement techniques that will be tested are standard, commercially available, hand scale measurements, Photoshop, GIMP, IrfanView, and FARO. The hypothesis of the experiment is that FARO will have the lowest percent error for all sizes of objects. It was discovered that Photoshop, GIMP, and IrfanView had the lowest percent errors for small objects (0.43%), while for small objects, FARO had the highest percent error (10.61%). For medium objects, Photoshop again had the lowest percent error (0.44%) but standard measurements had the highest error (1.74%). For large objects, FARO had the lowest percent error (0.28%), and IrfanView had the highest percent error (1.85%). However, most methods had percent errors equal to or less than the acceptable five percent. Some methods were preferred for different sizes of objects, but all programs were useful as long as the limitations were considered.

Keywords: Forensic science, crime scene investigator, measurement, photogrammetry, error, accuracy, uncertainty, FARO, Photoshop, IrfanView, GIMP

Introduction

Crime scene investigators and forensic scientists use photography and measurements frequently in their work. Photographs are taken at nearly all stages of a crime scene investigation and they are also used in evidence comparison after the crime scene has been processed. While photographs and digital imaging are not necessarily new within the forensic science field, digital imaging and processing became commonplace and universally utilized in 1998 (Klasén, Frank, & Peel, 1998). Measurements have been involved in forensic science since its beginnings. While the various methods used during crime scene investigations have changed over the years, the biggest impact on these methods has been from technology itself. Technological systems and processes, as well as digital information, are vast and ever changing (Duren & Hosmer, 2002). Modernizing a field such as forensic science with the use of technology has a multitude of benefits. The National Academy of Sciences produced a report in 2009, questioning the credibility of forensics as a scientific field (NRC, 2009). While this appeared to be devastating and controversial for many professionals in the field, overall the report has helped move forensic science forward towards modernization and accuracy.

When discussing measurements and numbers within science, it is important to consider the concepts of accuracy and error. Uncertainty, accuracy, and error have always been understood conceptually by forensic scientists due to the fact that expert witnesses would be asked to come up with degrees of certainty or accuracy of measurement during expert witness examination in court (Gullberg, 2012). However, one criticism of the National Academy of Sciences report discovered that forensic science research lacked measurements and testing of uncertainty, error, and accuracy. "The assumption of discernible uniqueness that resides at the core of these fields is weakened by evidence of errors in proficiency testing and in actual cases" (Saks & Koehler, 2005). Due to these scientific forces, as well as legal issues, traditional forensic investigation is being pushed towards fundamental change (Saks & Koehler, 2005).

As for scientific error, there are two main categories of variation, "instrumentation and process. …This introduces elements of uncertainty that arise from the procedure and from the person executing it" (Bell, 2016). Mitigating these errors have become a central focus for forensic investigation since the National Academy of Sciences report. "As with all other scientific investigations, laboratory analyses conducted by forensic scientists are subject to measurement error" (NRC, 2009). NIST, the National Institute of Standards and Technology, have created extremely precise measuring tools that they label as "NIST Certified". These rulers, calipers, measuring tapes, etc. can be used to reduce the error from instrumentation, also known as systematic error.

Due to the developments made by the field and the information discovered by the NAS report, more changes need to be made within forensic science. There have been many other suggestions that have been made towards forensic science so that the field can reestablish its scientific credibility. In order to take advantage of the power forensic science has as a profession as well as the need for true science, a number of reforms are needed and have been recommended, "Crime laboratories should be accredited, lab procedures should be standardized, and basic research needs to be conducted on many commonly used techniques" (Giannelli 2006).

In addition to changes in forensic measurements and uncertainty, changes are occurring in other related areas of forensic science. As mentioned earlier, photogrammetry can be performed in order to take measurements. It is defined as the science or art of obtaining reliable measurements utilizing photographs and scales (Robinson, 2016). In addition to taking measurements from images, "Photogrammetry encompasses methods of image measurement and interpretation in order to derive the shape and location of an object from one or more photographs of that object. In principle, photogrammetric methods can be applied in any situation where the object to be measured can be photographically recorded" (Luhmann, Robson, Kyle, & Boehm, 2013).

The overall use of photogrammetry in STEM fields has increased dramatically over the years (Wong, 1975). However, there is currently little evidence that photogrammetry and other image analysis information technology have been as widely implemented by forensic groups (Bramble, Compton & Klasén, 2001). This could be due to multiple factors. For one, computers can be difficult for some individuals and learning to measure items in a photograph using a computer program is more complicated that measuring an item by hand. Additionally, some computer programs that are used for photogrammetry purposes can be expensive, and not every department has the funds to support the distribution of these programs.

There are multiple different programs and techniques used to perform photogrammetry. More simplified computer imaging programs such as GIMP, IrfanView, or Photoshop are all relatively straightforward to use and install on any computer. The functions for photogrammetry of these programs can be learned easily and measurements of objects can be taken using a scale within the image. However, there are other tools that forensic scientists can use for photogrammetry that are more involved. For example, Photomodeler or 3D Zephyr, which can use multiple images or a video in order to create a three-dimensional image that can be measured using the software on the computer. In addition, there is a device called FARO, a three-dimensional laser scanner that can be used to create a diagram of a room which allows for virtual measurements of that area.

The amount of photographs and photogrammetry used within forensic science is becoming more prominent because of how useful they are within the field. The increase of viewpoints throughout criminal and forensic investigations and the increasing demand for research within forensic science appear to present a demand for an analysis on this topic (Milliet, Delémont, & Margot, 2014). In addition, the need for accurate data with calculated error and uncertainty rates is increasing within forensic science.

There has been some previous research within the forensic science field regarding error rates, uncertainty, and photogrammetry. One study, conducted at the University of Nebraska – Lincoln on Photogrammetry and Forensic Science, aimed to “identify and analyze the error rate for small, medium, and large sized objects, then identify an overall error rate when using photogrammetry” (Lynch & Barksdale, 2013). The study found that due to the low error rate of only 3%, photogrammetry was a reliable means of obtaining measurements (Lynch & Barksdale, 2013). Another study that was conducted through UNL was based upon *Accuracy of Forensic Measurements using Statistical Testing*. The study used measurements from a tape measure, NIST calipers, and photogrammetry, and concluded that there was no statistical significance between the error rates of photogrammetry and NIST and hand measurements and NIST (Douglas, 2018).

This study aims to conduct an experiment on error analysis to determine the accuracy of various forensic photogrammetry measurement techniques. Hand measurements, as well as multiple different photogrammetry programs and tools will be tested with various sized objects and compared to NIST scale values. The data obtained will be analyzed in order to determine the percent error of these photogrammetry techniques. The difficulty of the learning curve and installation of the photogrammetry programs as well as their costs will be taken into consideration as well. The hypothesis of the experiment is that the FARO scanner will have the lowest percent error for all sizes of objects. In addition to this hypothesis, we expect that simple photogrammetry programs will be sufficiently accurate and not nearly as expensive and will therefore be the best option for forensic scientists.

Materials & Methods

Evidence & Sizes

To begin the experiment, three general sizes of objects were chosen for measurement: small, medium, and large. The range of sizes were selected to represent what a CSI might encounter at a crime scene or what they perform photogrammetry on. Three items were selected of each size group to ensure sufficient trials. These differing evidence sizes allow for a range in values so that we will be able to determine if a certain method of measurement or photogrammetry favors a specific size of object, also preventing error from a skewed analysis.

Camera & Photography

In order to ensure consistency, one camera was used: A Fujifilm IS-1 9.0 Megapixel, with a 28-300 super macro lens and a Fujifilm IS-1 UV IR blocking 58mm DR655 Kenko lens. When photographing small and medium sized objects with scales, a CS-1070 copy/photography stand was used to ensure the pictures were taken from a standard height and angle when possible. For larger sized items, the stand was not able to be used for pictures that were taken, but a camera tripod was used instead to ensure stability and a sharper image. Images were taken indoors to reduce lighting issues and three pictures were taken of each object, changing the f-stop slightly each time to ensure an adequate photo was taken with the correct lighting.

Measurement & Photogrammetry

The standard commercial measurement tools that were used included various scales that would be considered common equipment for a CSI that are commercially available. For small items, a 6” plastic scale was used (*Arrowhead Forensic Products,* Standard Photo Scale Kit piece, Item #: A-6600SK). For medium items, a 48” x 22” T-shaped yardstick was used (*Johnson* aluminum, JTS48 Item #: 21227). A long 100’ rolling tape measure was used for large sized items (*Lufkin* 100L Hi-Viz Long Steel Tape, Item # 037103451002). These types of scales or tape measures represented cheaper, commercially available equipment that a department will commonly provide to a CSI or police officer for investigations.

GIMP, Photoshop, and IrfanView were the computer programs used to take photogrammetry measurements from the photographs of the objects in this experiment. The same scale that was used in the standard hand measurements was included in each photograph so images could be resized one-to-one (1:1). In order to resize 1:1, the number of pixels per millimeter on the scale in the image would be determined with the measure tool, and then it is possible to resize the image to reflect this amount. After resizing the photo, the measurement tool in each software program allowed for measurement of the objects in the images.

For FARO, all of the items were placed in a small room, and at a similar level and distance away from the FARO scanner. The room was sufficiently lit, and nobody entered or left the room while the scans were running. The FARO scanner was run 5 times total, once in the middle of the room and once in each of the four corners in order to obtain a complete and respectable diagram. Within the FARO “scene” software, the scans were processed and clustered together to create a 3D representation of the room, and a clipping box was applied and moved so that the inside of the room and the items within it were visible. The “scene measurement” application was used to measure items within the 3D image of the room. See FARO "scene" user manual for instructions.

NIST Measurement

For our NIST standard measurements, two different NIST traceable objects were used. For the smaller objects, a set of NIST digital calipers was used for measurement (*Control Company*, Certification #: 3415-9395243, Serial #: 99146223, NIST Traceable Reference #: 1000418160, 4/13/18). For the medium and large objects, a long 24" stainless steel model 2022A NIST certified ruler was used (*GEI International*, Certification #: 683-286672, Serial #: C66480, NIST Traceable Reference #: 10052546, 1/10/18). Due to the fact that all NIST devices are certified and guaranteed by the National Institute of Standards and Technology, each measuring device should be as close to accurate as possible and using different NIST devices should not cause a difference in the values between size of objects. These values were used as our "actual" values for comparison of methods.

Results

Before taking measurements, two of the common commerical scales we had available were compared to a NIST standard scale. The zero millimeter marks were lined up and the millimeter lines were compared along the scales. These scales appeared to be very similar to the NIST scale, and we were unable to distinguish much of a difference. Some of the millimeter lines were slightly off when compared to the NIST scale, but only marginally and it was random throughout the scale, as if they had just been printed incorrectly (Figure 1).

Figure 1: Common commercial scales lined up for comparison to NIST scale.

Our photogrammetry images were taken and then resized within all three programs (*Figures 2 & 3*).

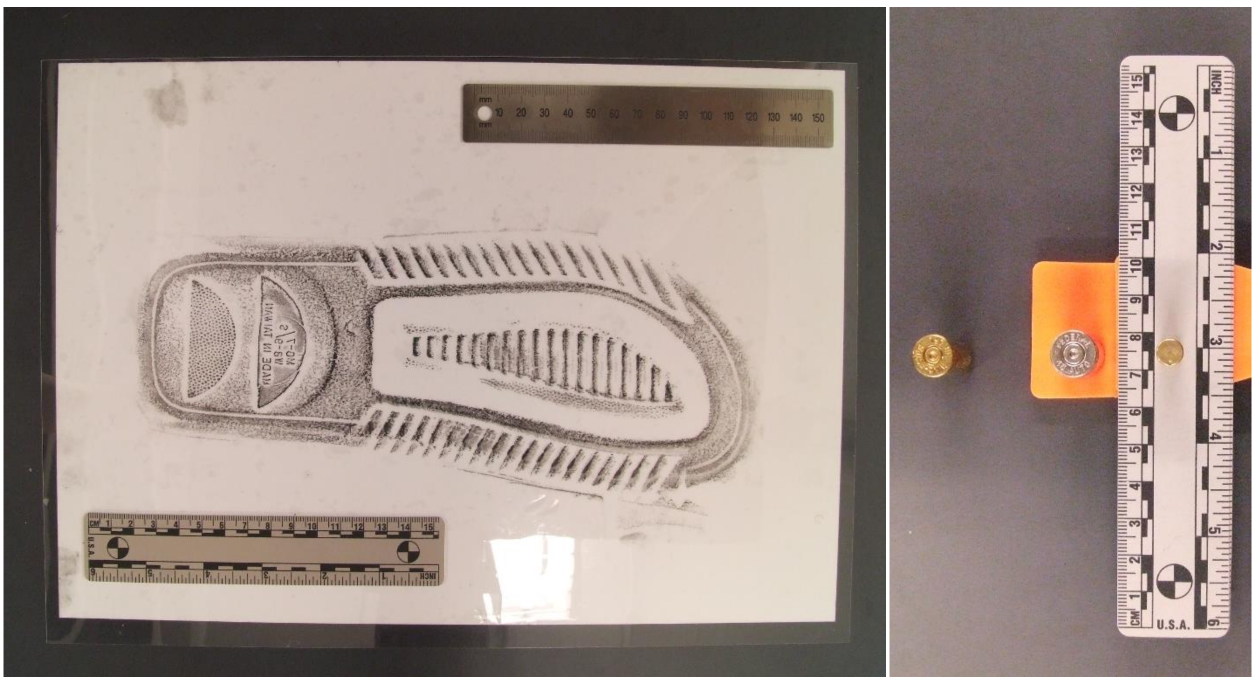

Figure 2 & 3: Examples of images taken for photogrammetry during the project. Figure 2 (left) is the shoe impression, and figure 3 (right) are the three small bullet casings.

The items were placed in the small room and the FARO scans were completed. After the scans were placed into the FARO scene program, the image of the scene was created, and a clipping box was made so that we could see into the room (*Figure 4*). Measurements were taken from all nine of the objects (*Figure 5*).

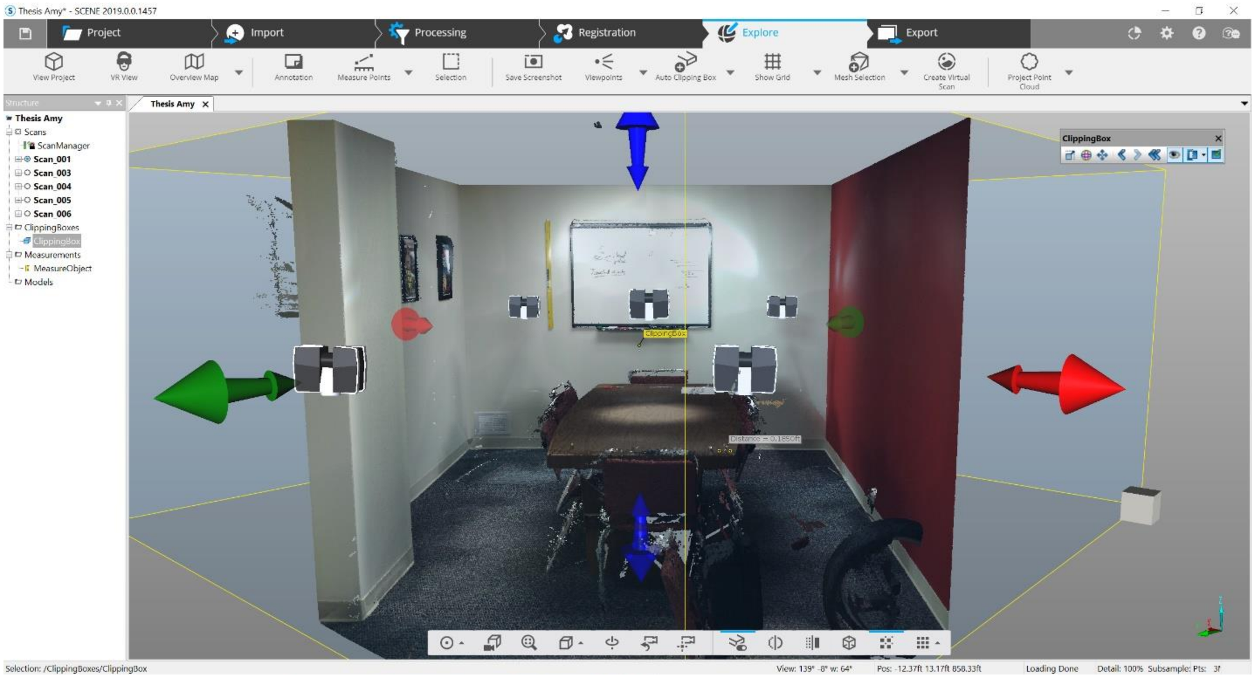

Figure 4: Screenshot of the clipping box view of the room in the FARO scene program.

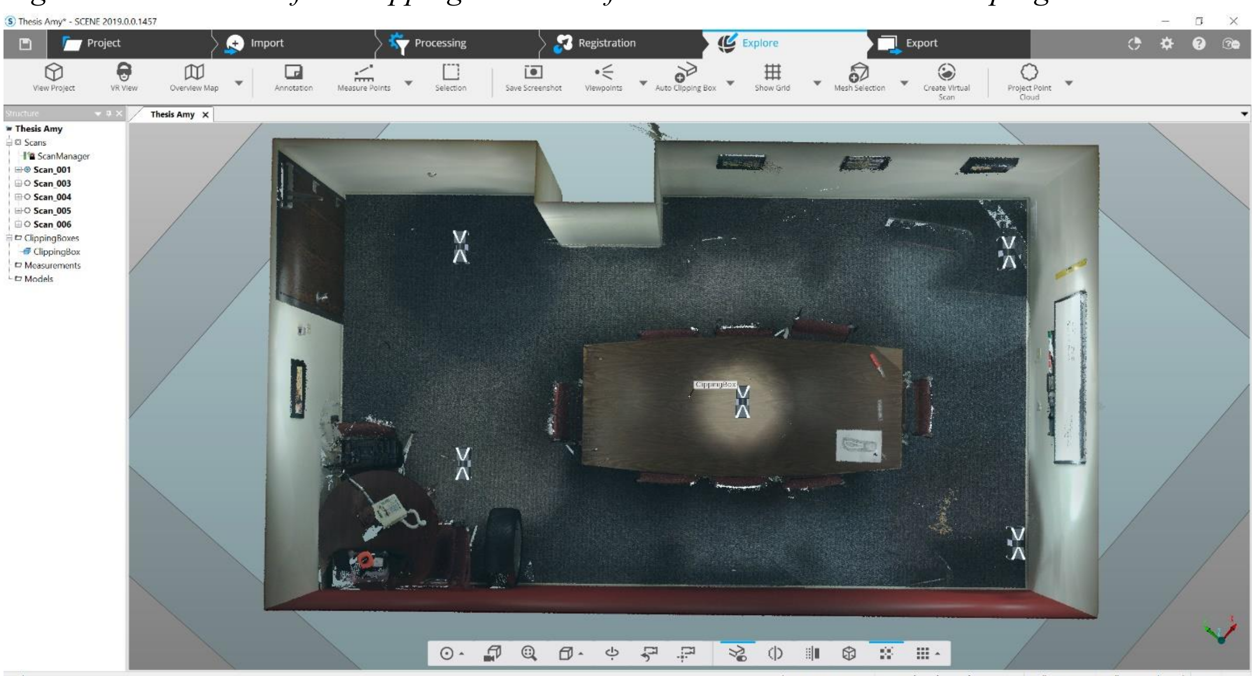

Figure 5: Screenshot of the FARO scene prepared for zooming in and measuring.

After taking all the measurements and obtaining relevant data, the measurements were placed into excel. The measurements from each method can be seen below, including sizes of objects and what each object was (*Figure 6*).

				Traditional Photogrammetry			3D Scanning
	Methods:	NIST Digital Calipers (sm.) **or** NIST Scale (med. & lg.)	Standard Measurements	Photoshop	GIMP	IrfanView	FARO
Sm. Sized Evidence Items							
	Small Bullet Casing						
	Length (mm)	6.97	7	7	7	7	8
	Medium Bullet Casing						
	Length (mm)	11.03	10	11	11	11	10
	Large Bullet Casing						
	Length (mm)	12.07	11	12	12	12	13
Med. Sized Evidence Items							
	Knife Length						
	Length (mm)	206	209	207	207	206	205
	Shoe Imprint/Pattern Lift Length						
	Length (mm)	269	274	268	270	267	269
	Tire Tread Width						
	Length (mm)	211	215	210	209	209	215
Lg.Sized Evidence Items							
	Whiteboard Width						
	Length (mm)	1191	1210	1178	1175	1174	1195
	Door Height						
	Length (mm)	2170	2183	2130	2129	2115	2175
	Wall Length						
	Length (mm)	3160	3137	3119	3115	3110	3169

Figure 6: Measurements in millimeters taken of three of each small, medium, and large objects for NIST, standard hand measurements, Photoshop, GIMP, IrfanView, and FARO.

The differences between these measurements from the various methods and the NIST value were calculated for each object of all sizes. Using this absolute value difference, divided by the NIST value, the percent error was calculated for each program or measuring device in order to use for comparison (*Figure 7*).

Size of Object	Small Objects			Medium Objects			Large Objects		
Item	Sm. Bullet Casing	Med. Bullet Casing	Lg. Bullet Casing	Knife Length	Shoe Imprint Length	Tire Tread Width	White-board Width	Door Height	Wall Length
NIST Values (mm)	6.97	11.03	12.07	206	269	211	1191	2170	3160
Standard Measurements (mm)	7	10	11	209	274	215	1210	2183	3137
Abs. value of Difference b/w NIST & Standard (mm)	0.03	1.03	1.07	3	5	4	19	13	23
% Error of Standard Measurements	**0.43**	**9.34**	**8.86**	**1.46**	**1.86**	**1.90**	**1.60**	**0.60**	**0.73**
Photoshop Measurements (mm)	7	11	12	207	268	210	1178	2130	3119
Abs. value of Difference b/w NIST & Photoshop (mm)	0.03	0.03	0.07	1	1	1	13	40	41
% Error of Photoshop Measurements	**0.43**	**0.27**	**0.58**	**0.49**	**0.37**	**0.47**	**1.09**	**1.84**	**1.30**
GIMP Measurements (mm)	7	11	12	207	270	209	1175	2129	3115
Abs. value of Difference b/w NIST & GIMP (mm)	0.03	0.03	0.07	1	1	2	16	41	45
% Error of GIMP Measurements	**0.43**	**0.27**	**0.58**	**0.49**	**0.37**	**0.95**	**1.34**	**1.89**	**1.42**
IrfanView Measurements (mm)	7	11	12	206	267	209	1174	2115	3110
Abs. value of Difference b/w NIST & IrfanView (mm)	0.03	0.03	0.07	0	2	2	17	55	50
% Error of IrfanView Measurements	**0.43**	**0.27**	**0.58**	**0.00**	**0.74**	**0.95**	**1.43**	**2.53**	**1.58**
FARO Measurements (mm)	8	10	13	205	269	215	1195	2175	3169
Abs. value of Difference b/w NIST & FARO (mm)	1.03	1.03	0.93	1	0	4	4	5	9
% Error of FARO Measurements	**14.78**	**9.34**	**7.71**	**0.49**	**0.00**	**1.90**	**0.34**	**0.23**	**0.28**

Figure 7: Table of measurement values, their absolute values of the differences between NIST, and the percent error of each of the five types of measurements for all the three sizes of items.

The percent errors were then averaged for each size category of objects for the purposes of easier comparison. (*Figure 8*). Overall, Photoshop, GIMP, and IrfanView had the lowest percent errors for small objects (0.43%), while for small objects, FARO had the highest percent error (10.61%). For medium objects, Photoshop again had the lowest percent error (0.44%) but standard measurements had the highest error (1.74%). For large objects, FARO had the lowest percent error (0.28%), and IrfanView had the highest percent error (1.85%).

Average % Error Calcuations	Standard	Photoshop	GIMP	IrfanView	FARO
Small Objects	6.21%	0.43%	0.43%	0.43%	10.61%
Medium Objects	1.74%	0.44%	0.60%	0.56%	0.79%
Large Objects	0.97%	1.41%	1.55%	1.85%	0.28%

Figure 8: Average percent error for each size of measurement or photogrammetry method when compared to the NIST value.

Discussion

In short, Photoshop appeared to be the best tool to use when measuring objects when considering all sizes of objects because of the low percent error. Despite the hypothesis that FARO would have the lowest overall error rate, Photoshop came out on top. Photoshop is a commercial program that Adobe has perfected for photography purposes for many years. When it came to medium and large objects, FARO and Photoshop were comparable. The highest percent error we saw was from FARO when measuring small objects. This could be due to the way that FARO creates its scans. FARO was never intended for very small-scale items. FARO, as well as other laser scanners, scan an area or room for distinct points and create a digital version from these points that match up – which is not the same as a picture from a camera. Due to the fact that the smaller objects we measured were the most inaccurate, it is possible that there are just so few points on the evidence that the measurements of these items have so few points that the possibility for inaccuracy is much higher. For medium or larger pieces of evidence – for which in our case FARO had a much lower percent error – there are many more points within the object, allowing for more accurate measurements.

The fact that standard measurements generally had percent errors than other methods was something we anticipated. We expected this higher error from these commercially available standard scales due to the fact that each scale can vary slightly when they are not certified. Human error can also be a larger issue with measurement technique, and often scales are not as precise due to the fact that the lines are so small when looking at the millimeter level. It was impressive that GIMP and IrfanView had such low percent errors at all sizes of objects, even with their free downloaded program. One of the issues that was encountered with photogrammetry, was with the larger sized items. When using a scale in a photograph as your reference, it can be very difficult to ensure that the resolution of your image is sufficient enough so that zooming in on the scale does not cause blurriness and inaccuracy when attempting to resize the image at 1:1. In addition, it can be difficult to photograph large objects, especially in small areas, due to the fact that distortion and curving of the object can become an issue.

While an acceptable percent error can depend on the type of work that is being conducted, it is commonly found that a 5% error – as seen in statistics and other research – is the generally accepted level for an acceptable percent error (Jonakait, 1991). Based on this, percent errors for most of the methods that we used to conduct measurements and photogrammetry are all within the acceptable 5% at most sizes, however, some of the percent errors were not within that 5%. Because of this, it is apparent that some methods are preferred based on the sizes of objects that are being measured. FARO should not be used for small objects because of its 10.61% error will small sized objects. While most photogrammetry programs are within the 5%

error rate for all three sizes, larger objects can cause issues related to distortion and sharpness and should be avoided for larger objects if possible.

So, what does this mean for forensic scientists? While FARO has many benefits, such as creating a 3D visual for a jury panel or being able to re-create the crime scene, crime labs should not feel the need to spend $25,000 on a new FARO scanner just for measurement purposes. In addition, FARO scans can take upwards of 6 or 7 minutes per scan, and at an average of five scans per room for a high-quality result, FARO may be more work than it is worth in terms of its measurements and percent error. FARO does have a smaller handheld scanner that can ensure the level of detail for smaller items is increased, which would decrease the error for smaller objects, but that does add on additional cost, training, and time. However, in the case of Photoshop or other photogrammetry programs, the cost of the program may be worthwhile. While Photoshop can seem pricey – at over $200 for the program – it was the most accurate measurement tool discovered in this study. In addition, GIMP had the second lowest percent error, and that program is free to download and use. The one issue to consider would be that there is some minimal training involved in using each program. Overall, the photogrammetry programs were not difficult to learn or operate, but for individuals that struggle with computers, training may be a necessity. Photogrammetry does require decent quality photographs as well as a scale in the photograph, but it not extremely time consuming since images with scales are often taken anyways at a crime scene. Hand measurements are the least time consuming, require the least amount of training, do not cost any more money than purchasing a measuring scale or tape measure, but they had generally higher percent errors than other methods. However, it is necessary to keep in mind that based on the results stated above, it appears that most measurement types are sufficiently accurate for forensic work because they are within the generally accepted percent error.

This study was preliminary, and there is a great deal of future research and limitations that need to be considered. Because of the limited number of trails conducted, the sample size was not large enough for effective statistical analysis. Future studies on this subject would be recommended to include larger sample sizes so that the data and results can be used for scientific proof of error analysis. Measurement uncertainty and analysis can be satisfactorily examined within the forensic science community with further research (Wallace, 2010). The lack of studies within forensic science needs to change, as pointed out by the NAS report in 2009. There has been an increase in demand for rigorous quality control within forensic science due to the lack of standards within the field, as well as the failure to present data-based results and evidence (Schnieder, 2007). This will also assist with expert witness validation within court, “Skeptical defense attorneys who routinely formulate astute Daubert challenges to contest the scientific validity and reliability of every major forensic science discipline are one catalyst to this revolution” (May, 2010).

In addition to these considerations, it would be interesting to see more studies on this topic, possibly looking into the difference between indoor scenes and outdoor scenes and how the light may affect photogrammetry. Another possible area of consideration would be 3D imaging programs being used for photogrammetry purposes. The world today is blessed and cursed by rapid technological advances, and because these programs will be affected by updates and changes, forensic science must overcome this with constant research, “…a steady influx of novel scientific advances makes possible the formulation of consistent and scientifically-based quantitative forensic evidence analyses to overcome the ‘undervalidated and oversold’ problems affecting many areas of forensic science" (Thompson & Tobin, 2006). The last area of research that would be recommended would be statistical calculations and uncertainty budgets. Uncertainty budgets would be useful because they state measurement uncertainty and document the components and calculations of uncertainty estimation (Hogan, 2017). Statistical analysis would also be extremely useful because of its strength within court and the ability to provide definitive standard deviation and confidence intervals.

Conclusion

In summary, measurements are essential to forensic science – standard hand measurements and photogrammetry are often used in the field. Error, accuracy, and uncertainty have been criticized in the forensic science field recently – especially during the 2009 NAS report – and it has been determined that further research needs to be conducted on forensic science techniques. Because of this, changes are constantly occurring in forensic science. Another effect for this push for change are the technological advancements in todays society that affect forensic science. Photography and photogrammetry are no exception to this modernization within the field, as these practices are becoming more routine and often times even required during investigations. This study hypothesized that FARO would have the lowest percent errors for all sizes, but simple photogrammetry programs would be sufficiently accurate and not nearly as expensive and would therefore be the best option for forensic scientists. After the data was collected from the five programs for objects of different sizes, percent error was calculated and discussed. Overall, Photoshop, GIMP, and IrfanView had the lowest percent errors for small objects (0.43%), while for small objects, FARO had the highest percent error (10.61%). For medium objects, Photoshop again had the lowest percent error (0.44%) but standard measurements had the highest error (1.74%). For large objects, FARO had the lowest percent error (0.28%), and IrfanView had the highest percent error (1.85%). In conclusion, our hypothesis was partially correct. What was accurate was the idea that expensive programs are not necessarily worth the price for forensic measurements, but we were incorrect in that FARO was not the most accurate form of measurement all the time – Photogrammetry programs were more accurate for smaller objects. It was determined that certain measurement techniques may be beneficial when used with certain sizes of objects, but most methods of measurement were within the generally accepted 5% error rate. Because of this, all of the methods are acceptable as long as the limitations of each program or technique are considered. While our research was rudimentary, it will pave the way for future research on this subject and allow for error rates and statistical analysis to help forensic scientists testifying as expert witnesses court or solving crimes out in the field.

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