THE UNIVERSITY OF CENTRAL OKLAHOMA
Edmond, Oklahoma
Jackson College of Graduate Studies

3D Laser Scanning Technology:

Calculating the Area of Origin for Bloodstains Using FARO Zone 3D

A THESIS

SUBMITTED TO THE GRADUATE FACULTY

in partial fulfillment of the requirements

for the degree of

MASTER OF SCIENCE IN FORENSIC SCIENCE

by

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Edmond, Oklahoma

2018

3D Laser Scanning Technology:

Calculating the Area of Origin for Bloodstains Using FaroZone 3D

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APPROVED FOR THE DEPARTMENT OF FORENSIC SCIENCE

May 31, 2018

By

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ABSTRACT:

Bloodstain pattern analysis possesses a subjective nature in the calculation of are of origin and has inherently received criticism in the scientific community. Current software used in analyzing area of origin (AO) for medium energy spatter stains does not account for alteration during formation of the stains across different target mediums. This calls into question the validity and reliability of the methods used in evaluating bloodstain patterns.

Previous literature of bloodstain pattern analysis has examined different software and compared the results of AO calculation to one another and to a known point of origin. The majority of this analysis has been conducted by Eugene Liscio in correlation with other associates in the BPA community. The methodology has usually consisted of single planar target surfaces of a homogeneous material. A few studies have used surfaces along different axes and curved surfaces for analysis, again with homogeneous material. The results of previous research has validated the software that was being tested by providing measurements of the calculated AO within an acceptable statistical variability of the known point of origin.

The current thesis research consists of two parts, the first is a validation of the software for a bloodstain on a single planar surface, while the second is for a bloodstain deposited across multiple target mediums of perpendicular planes. The thesis statements for each are as follows:

Validation:

H_0: When a medium energy impact bloodstain pattern is analyzed using Faro Zone 3D to determine area of origin, there will be no significant statistical variance of measurement along the x, y, and z axes compared to the known point of origin.

H_A: When a medium energy impact bloodstain pattern is analyzed using Faro Zone 3D to determine area of origin, there will be a significant statistical variance of measurement along the x, y, and z axes compared to the known point of origin.

Multiple Mediums:

H_0: When using Faro Zone 3D to analyze and determine the area of origin for a single source, medium energy impact spatter pattern, there will be no significant statistical variance of measurement along the x, y, and z axes compared to the known point of origin.

H_A: When using Faro Zone 3D to analyze and determine the area of origin for a single source, medium energy impact spatter pattern, there will be a significant statistical variance of measurement along the x, y, and z axes compared to the known point of origin

The present research methodology is analysis of quantitative data with measurements and statistical analysis being compared to determine validity.

Based on the results for bloodstain pattern one, it is clear that the software lacks validity when analyzing this type of single directionality bloodstain. The less than accurate results are based on the large displacement value for the x-axis. The y and z-axis displacement values are within an acceptable variance based on the 7-cm boundary explained by Dubyk and Liscio (2016), stating that measurement is about the average size of a human skull. The x-axis produced the greatest amount of variability for bloodstain pattern 1 because the area of origin could not be triangulated with analyzed stains on the opposite side of where the spatter originated from along the planar target medium. This triangulation effect is what controls the accuracy of the x-axis coordinate. The y-axis is controlled by the elliptical overlay of each individual stain for which the angle of impact is calculated with the Balthazard Formula. The z- axis is primarily sourced from the stains selected as suitable for analysis and their angle of convergence along a two-dimensional surface.

While the validity of Bloodstain Pattern 1 was less than reassuring, Bloodstain Pattern 2 exemplified much more confident results of validity based on the Dubyk and Liscio defined acceptable variance. However, based on the statistical analysis of a 95% confidence interval for each of the bloodstain patterns, neither AO analysis by FARO Zone 3D met the intervals of validity for all axes. In fact, Bloodstain Pattern 1 did not have any of the axes displacement measurements for the AO sphere fall within the range produced by the confidence interval. Bloodstain Pattern 2 did produce an accurate analysis along the z-axis, but both the x and y-axis measurements were outside the acceptable confidence ranges. Therefore, the analytical research rejects the null hypothesis of validity.

The findings of this research reject validity in the science of bloodstain pattern analysis by limiting the subjective nature of analysis by using software that calculates the area of origin for medium energy spatter stains. The results also show that bloodstains deposited across multiple target mediums are capable of being analyzed as a single source stain and the alteration of stain formation does not impact the AO calculation enough to be statistically significant.

An additional aspect of the FARO Zone 3D software is the ability to reproduce a two-dimensional sketch that is to scale of a scene with the BPA analysis visible, as well as a digital three-dimensional representation of the scene. As instances of BPA are often used in court to assist in interpretation of the facts, visual representation is an important so full understanding during testimony can be achieved.

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CHAPTER I

Introduction

Forensic science is a continuously evolving discipline and often comes under scrutiny. The most common criticisms are seen in court when defense attorneys attempt to raise unwarranted doubt about the science behind forensic techniques and methodologies. However, more formal and critical assessments are seen in the National Academy of Sciences (NAS) report of Forensic Sciences from 2009 and more recently in the President's Council of Advisors of Science and Technology (PCAST) report to the President. These reports suggest that the discipline of forensic science needs to be strengthened with objectively based science to reinforce its validity in the courtroom. While certain divisions of forensic science such as DNA or toxicology are considered objective and utilize peer-reviewed scientific methodologies, others have a certain amount of subjectivity associated with analyses. Bloodstain pattern analysis is one of those disciplines that is labeled as subjective in nature and is constantly being challenged as unfounded, with claims it should not be admissible in court.

Bloodstain pattern analysis (BPA) is defined as the, "examination of the size, shape, location, and distribution patterns of bloodstains to provide an interpretation of the physical events that gave rise to their origins" (Hakim & Liscio, 2015). BPA provides information about the position of person(s) and/or objects used during a bloodshed event, the direction a stain was traveling when deposited and the area (AO). The AO is defined by the Scientific Working Group on Bloodstain Pattern Analysis (SWGSTAIN) as "the three-dimensional location from which spatter originated" (2009).

The AO can be determined by manual methods or digital methods utilizing modern terrestrial scanners and software to reproduce the bloodstains electronically. Both manual and digital methods use calculations derived from the physics of motion the blood droplets encounter during flight in combination with the internal characteristics of the blood itself (Bevel & Gardner, 2012). However, manual methods are, “inherently destructive, altering the crime scene with the attachment of strings,” and/or ink markings along with tape (Lee & Liscio, 2016).

Statement of the Problem

The literature exposes a gap in the discipline of bloodstain pattern analysis, specifically in the procedural methods of calculation of AO. Due to methods used in calculation, exact physics are not fully taken into account when determining the area of origin for a particular bloodstain or cluster of bloodstains. Also, the software currently used does not account for any variance of bloodstain droplet size based on the target medium absorption factor. When a single stain is deposited across different surface materials (target mediums), the stain will become slightly altered. These voids in the discipline provide an opportunity for further research to assist in strengthening the objective, scientific basis so that the information continues to be admissible in court.

Significance of the Study

This study will work to validate the reliability of area of origin (AO) in bloodstain pattern analysis with a FARO Focus^{3D} Laser Scanner and agreeable software. This will make the analysis of blood stain evidence and the interpretation of sequence of events more accurate. The process of analyzing the blood stain evidence will also be more efficient with respect to time on scene as the collection of data and initial scans can be collected at the crime scene, while all analysis of the data can be processed off-scene. The study of AO determination across different target mediums will also expose limitations to the software calculations. It will also establish if bloodstain patterns from the same source covering multiple mediums, require unknown samples to be taken from like mediums for accurate AO calculation or if multiple samples can be taken from the entire spatter pattern across all mediums to establish a more comprehensive area of origin.

Conducting analysis of bloodstain patterns using 3D scanning software also provides a more visual demonstrative of the physical evidence when testifying in court as an expert. One objective of an expert witness is to explain the type of analysis conducted on physical evidence and to explain how the results relate to the case in question. Being able to show the position of bloodstain patterns in three dimensions will assist the court, specifically the jury, in understanding what the physical evidence means.

Purpose of the Study

The purpose of this research study is to validate the methodology of bloodstain pattern analysis using three-dimensional laser scanning equipment and software used in previous research, as well as introduce the analysis of bloodstains across different target mediums stemming from a single source. A more comprehensive understanding of the capabilities and limitations of this type of analysis using laser scanning technology and software will also be established. This study will work to limit the subjectivity often associated with conventional methods of bloodstain pattern analysis. It will also demonstrate how bloodstain pattern analysis can be shown in two and three-dimensional representations for use in reports and as visuals during testimony in court.

Hypotheses

Validation:

H_0: When a medium energy, single-angular impact bloodstain pattern is analyzed using FARO Zone 3D to determine area of origin, there will be no significant statistical variance of measurement along the x, y, and z axes compared to the known point of origin.

H_A: When a medium energy, dual-angular impact bloodstain pattern is analyzed using FARO Zone 3D to determine area of origin, there will be a significant statistical variance of measurement along the x, y, and z axes compared to the known point of origin.

Multiple Mediums:

H_0: When using FARO Zone 3D to analyze and determine the area of origin for a single source, medium energy impact spatter pattern, there will be no significant statistical variance of measurement along the x, y, and z axes compared to the known point of origin.

H_A: When using FARO Zone 3D to analyze and determine the area of origin for a single source, medium energy impact spatter pattern, there will be a significant statistical variance of measurement along the x, y, and z axes compared to the known point of origin.

Key Terms

Area of Convergence (AOC): The area containing the intersections generated by lines drawn through the long axes of individual stains that indicates in two dimensions the location of the blood source (SWGSTAIN, 2017).

Area of Origin (AO): The three-dimensional location from which spatter originated (SWGSTAIN, 2017).

Angle of Impact: The acute angle (alpha), relative to the plane of a target, at which a blood drop strikes the target (SWGSTAIN, 2017).

Impact Medium: A surface upon which blood has been deposited.

Medium Energy: A bloodstain pattern caused by a medium velocity impact/force to a blood source. A beating typically causes this type of spatter. (IABPA, 2013)

Stringing Method: Process to visually recreate the trajectory of bloodstain pattern droplets.

Standard Deviation (SD): A quantity calculated to indicate the extent of deviation for a group as a whole.

Normal Distribution: A function that represents the distribution of many random variables as a symmetrical bell-shaped graph.

Confidence Interval: A range of values so defined that there is a specified probability that the value of a parameter lies within it.

CHAPTER II

Review of the Literature

Blood Flight-Path Physics and Characteristics

Blood possesses unique properties that affect its physical characteristics during flight. For instance, blood droplets retain a spherical shape during flight due to surface tension (Gravel & Solomon, 2014). According to Bevel and Gardner (2012), this phenomenon is a result of blood being a fluid that contains cellular material, a property which increases its viscosity (resistance to flow). In comparison to water, blood is roughly four times more viscous. The cellular material within the blood creates bonds between the cells which cause the liquid to occupy the smallest space possible; a sphere (Bevel & Gardner, 2012). The blood will retain the shape of a sphere until an external force acts upon it (Gravel & Solomon, 2014). During flight, the spherical blood droplet is acted upon by external forces, specifically gravity and air resistance. Both forces cause the droplet to fly the path of a parabolic arch (Baxter, 2015). Gravel and Solomon (2014) assert that the velocity of the blood droplet is determined by the external force that caused the blood to become airborne, as well as the proportion of gravitational pull and air resistance. If the force of gravity offsets the air resistance, then the droplet will reach terminal velocity. During terminal velocity, the blood droplet ceases oscillation. Oscillation is described as the compression and expansion along the horizontal axis (Gravel & Solomon, 2014). Blood droplets in excess of five millimeters will experience oscillation, but the extent is determined by the combination of external forces. Gravel and Solomon (2014) explain that oscillation will dampen (become less severe), the longer the droplet is in flight or the greater its velocity is. Also, as blood is a cellular liquid, a blood droplet will “run out” when impacting a surface at an angle and not explode. Figure 1 illustrates as the droplet impacts a surface at an angle, an elliptical shape is produced with a tail that points in the direction the droplet was traveling (Bevel & Gardner, 2012). The directionality of the stain is imperative in determining where the stain originated from in space.

Bloodstain Pattern AO Determination

Several methods for determining the AO have been developed. Almost all of these methods are derived from the Balthazard formula,

$$\theta = \sin^{-1}\frac{w}{l}$$

which determines the two-dimensional space where impact occurred or the area of convergence (AOC). This is calculated by multiplying the measured distance between the bloodstain and the AOC with the tangent of the angle of impact (θ) (James, Kish, Sutton, 2005). James et al. (2005) also states that the angle of impact is determined by taking the arcsine of the ratio between the width of the spatter (*w*) and its length (*l*). Dr. Victor Balthazard was able to take his formula one step further with the introduction of manually attaching strings to the base of the bloodstains with appropriate angles of impact, commonly known as “stringing.” The combination of string from both sides of a “V” pattern created by an impact stain provides a three-dimensional model of the approximate AO (Dubyk & Liscio, 2016).

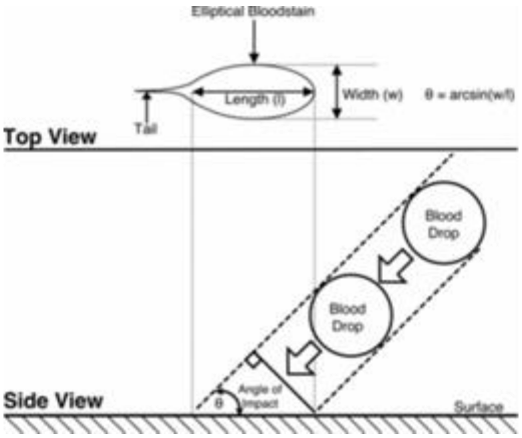


FIG. 1—Ellipse with directional tail generated by a blood drop impacting a surface. The angle of impact (h) is related to the width (w) and length (l) of the ellipse. (Hakim & Liscio, 2015)

In the 1970s, Herb McDonnell brought BPA to the forefront in the United States with similar experimentation and results as Dr. Balthazard and establishing a training course. Another manual method for determining the AO was introduced by Tom Griffin and John Anderson called the “tangent method.” The *tangent method* is similar to the *stringing method*, but instead is calculated using the tangent function of the distance from the leading edge of a stain to a point of convergence within the center of the AO to determine the distance away from the surface. The principles of the Balthazard formula are still used in this method (Griffin, Anderson 1993).

In the early 1990s, the computer software BackTrack was developed to assist in calculating the AO. Developed by Dr. Alfred Carter in 1992 at Carleton University, the software involved two separate, yet equally important, programs working together (Dubyk & Liscio, 2016). The first program analyzes stain photographs and creates strings, while the second program analyzes the strings and calculates the AO (Carter et al. 2006). The same principles of BackTrack were used in the development of HemoSpat by Kevin and Andy Maloney in 2006 (Maloney et al. 2009). HemoSpat is a singular program that analyzes digital images of individual spatter stains by automatically “fitting” a computer generated ellipse overtop the shape of the elliptical spatter stain (Maloney et al. 2009).

Three-Dimensional Scanner Methods of Operation

Modern day terrestrial laser scanners, or 3D laser scanners, use two basic methods of operation: the pulse based method and the phase comparison method (Dubyk & Liscio, 2016). According to Dubyk and Liscio (2016), in the pulse-based method, “a small pulse of light is emitted by the laser scanner. The pulse is reflected off of the surface of an object and part of the pulse is returned to the scanner. The total travel time of the pulse is measured and can be calculated…” The calculation is determined by the formula:

$$Distance = Speed \times Time \times {}^{1}\!/_{2}$$

These time-of-flight scanners typically have standard deviations in the order of millimeters. The accuracy of the calculation is influenced by the accuracy of the angle of the scanner pointing the beam (Boehler & Marbs, 2002). Fröhlich and Mettenleiter (2004) mention that time-of-flight scanners using a pulse based method, “allow unambiguous measurements up to several hundred of meters,” meaning these types of instruments would have increased accuracy in larger outdoor scenes.

The phase comparison method is similar to the pulse based method in that light is emitted, reflected, and returned to the scanner. Where this method differs is that during phase comparison the scanner sends out a constant beam of light at multiple wavelengths. Once the signals are reflected and returned to the scanner, the difference in phase (shift in the peaks and valleys of the signals) is compared to the initial signals emitted from the scanner, resulting in a direct derivative of the distance (Dubyk & Liscio, 2016). According to Boehler and Marbs (2002), since the phase comparison principle requires a return signal, scanners using this method have a reduced range and periodically produce more inaccurate or dropped points. Therefore, the phase comparison method is a technique commonly used for medium ranges that are restricted to one hundred meters or less. Accuracy of measurements within millimeters are possible (Fröhlich & Mettenleiter, 2004).

Experiment Methods

The blood stain pattern analysis literature focuses on research and experimentation that assesses the similarities and differences of software programs and examines the variance of calculations of AO compared to the actual known point of origin (PO) during the production of impact spatter stains. The majority of prior research has examined the accuracy of AO calculation between different software programs, including: BackTrack, HemoSpat, HemoVision, and FARO.

Physical Construction of Environment

Each study in the literature designed an experiment using similar principles, but used different target planes to deposit blood spatter on for analysis, For example, Dubyk and Liscio (2016) and Hakim and Liscio (2015) both constructed a stationary apparatus that consisted of a wooden, hammer-like arm that struck a flat attachment below to create an impact spatter on a singular, vertical plane (Figure 2).

FIG. 2–-Render of impact spatter rig. A 2.84-cm-diameter dowel was fitted to a wooden arm. Upon release the hammer-like arm strikes a modified hockey puck to generate an impact spatter. (Hakim & Liscio, 2015)

An alternative method of experimentation, used by Lee and Liscio (2016), used a similar apparatus to create an impact spatter, but the target(s) were a combination of six different surfaces (Figure 3).

They described the purpose of this was to resemble a multiple planar scene such as a couch up against a wall to see if the accuracy changes due to different angles of impact. Liscio et al. (2015) combined both methods by using the same type of apparatus, but to create multiple impact spatters on a singular planar surface, as well as, multiple planar surfaces with an adjacent obstruction with perpendicular surfaces to the walls (Figure 4).

FIG. 4-Offset surfaces from double-blow pattern. (Liscio et al., 2015)

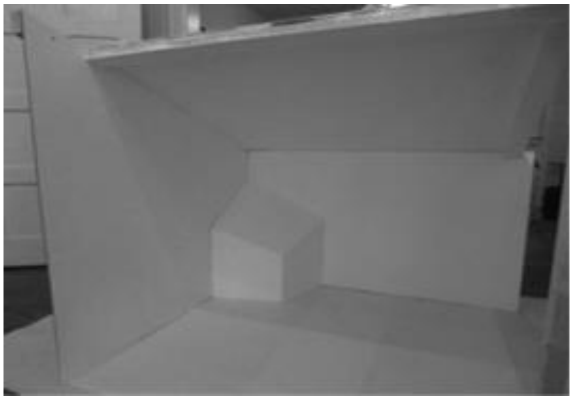


FIG. 3-Six surfaces, made from wooden boards, painted white, onto which blood was spattered. (Lee & Liscio, 2016)

When creating impact spatter, a sample of 5mL of blood was deposited on the flat lower attachment of the stationary apparatus (Dubyk & Liscio, 2016; Hakim & Liscio, 2015; Liscio et al., 2015). Lee and Liscio (2016) used 1.5mL of blood due to the modified size of the target apparatus. The preferred source of blood was sheep's blood containing 1% of a preservative. Dubyk and Liscio (2016) was the only study that used an alternate source of blood - porcine blood.

Another independent variable each study addressed was the target medium or the surface material the impact spatter was deposited on when creating a bloodstain pattern. In two of the studies, the blood spatter was deposited on white painted dry-wall (Dubyk & Liscio, 2016; Lee & Liscio, 2016). Liscio et al. (2015) used gray painted walls with a white colored metal obstruction object that possessed signs of oxidation (rust). Hakim and Liscio (2015) used overlapping sheets of butcher paper to deposit impact spatter on.

Digital Scanning/Photography

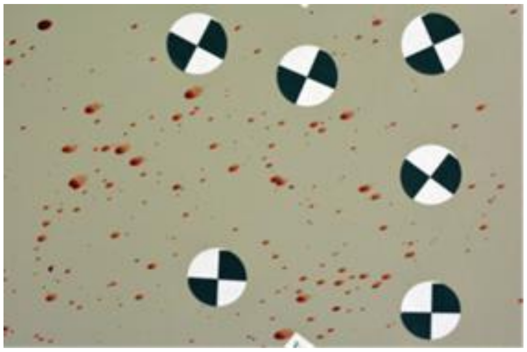


FIG 8--Example of reference markers applied to the bloodstained surface prior to 3D scanning. (Liscio et al., 2015)

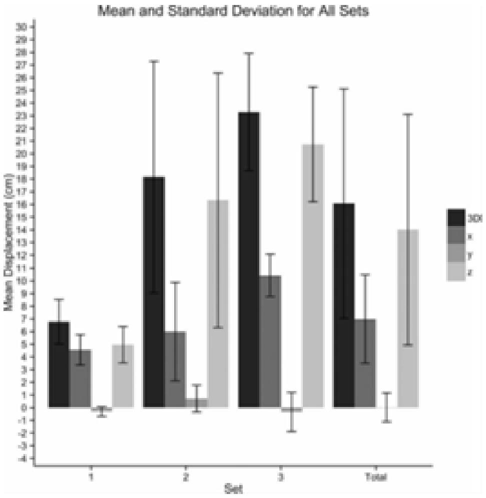
The method(s) of photography and/or scanning depend(s) on the software that is being used for analysis of the bloodstain patterns. For instance, HemoSpat does not require a three-dimensional scan of the scene to analyze the bloodstain pattern. Dubyk and Liscio (2016) used

HemoSpat in conjunction with a Nikon D800 DSLR camera with a Nikon 60 millimeter macro lens in their study and found it provided sufficient data on a 1:1 scale for analysis. As seen in Figure 5, to simplify the process of identifying the location of clusters of bloodstain patterns being used for analysis, checkered stickers can be placed near the stains before photography (Liscio et al., 2015).

Studies that used the FARO software required both a digital scan and a high resolution photograph for analysis of bloodstain patterns. Using both allows the high resolution photograph to be precisely oriented within the virtual scene so a three-dimensional model of the AO calculations can be created (Liscio et al., 2015). Lee and Liscio (2016) demonstrated this in their study by using a Sony Alpha 200 DSLR camera with a 50 millimeter lens along with the FARO Focus^{3D} laser scanner. Liscio et al. (2015) and Hakim and Liscio (2015) also used the FARO Focus^{3D} laser scanner when conducting analysis using the FARO software. Dubyk and Liscio (2016) did not define what type of scanner was used in their study, rather just mentioned that FARO SCENE software was used for analysis.

Summary

In the literature, the experiments recorded the values of the *x*, *y*, and *z* coordinates. The common consensus is that the z-axis values showed the largest deviation from the known PO, while the y-axis values showed the least. Lee and Liscio (2016) showed that individual differences ranged from -1.2 cm to 23.4 cm in the z direction, while the x and y direction differences ranged from -11.5 cm to 1.1 cm and -11.6 cm to 2.2 cm, respectively. Hakim and Liscio (2015) focused on the standard deviations of the data sets. According to them, “standard deviation is a measure of the dispersion of the data set to the mean. A small standard deviation suggests that the data are close to the mean and therefore is an indication of reproducibility.” The z-direction had a large standard deviation with SD = 9.08 cm from their data set, while the y-direction had the most consistent measurement with an overall SD = 1.14 cm (Graph A).



Graph A—Average 3D, x-, y-, and z-displacements for Sets 1, 2, and 3 (n = 5 for each) along with the Total Set (n = 15). The error bars represent the standard deviation. For all sets, y-displacements and standard deviations were the smallest and average z-displacements were the largest. Overall, the y-direction was the most accurate and reproducible, while the z-direction was the least accurate and reproducible. (Hakim & Liscio, 2015)

The only study that provided similar differences across all directions of their data set was Dubyk & Liscio (2016). They claim that based on an experiment conducted by Carter et al. (2006) and their own results, “that the overall average differences between the known and calculated values for all three axes was less than 7 cm, approximately the radius of a human head,” when comparing analysis from FARO to HemoSpat and the actual PO (Table 1).

Comparing the x, y, and z coordinates between the actual, HemoSpat, and FARO.

	x			y			z		
Pattern	Actual	HemoSpat	FARO	Actual	HemoSpat	FARO	Actual	HemoSpat	FARO
1	20.0	31.3	15.4	200.0	201.6	205.6	24.0	26.9	29.7
2	20.0	24.8	19.4	160.0	160.7	160.4	20.0	21.5	21.8
3	43.0	44.0	36.2	170.0	176.5	176.5	12.0	19.3	16.9

Table 1 (Dubyk & Liscio, 2016)

The literature concluded that the *x*, *y*, and *z* values were all within an acceptable range. However, the only study to explain what range they were referring to was Carter et al. (2006). There were many variables that were not accounted for, or could not be accounted for by the software, during analysis of the bloodstains. Hakim and Liscio (2015) mention that the BackTrack, HemoSpat, and FARO Scene software all neglect the influence of gravity and air resistance during calculation and assume a straight line trajectory. The effect of gravity was attempted to be neutralized in all studies by only choosing bloodstain cluster with a positive value along the y-axis, with a baseline set at the same height as the PO. Doing so was theorized to limit the parabolic arch of the blood droplets during flight. The principle of a gravity effects the *z value* dependent on the distance the PO is away from the wall, and caution should be taken when calculating height displacements when that distance is greater than 40 cm (Liscio et al., 2015). Another variable that Dubyk and Liscio (2016) discuss is the number of spatter stains collected along with the quality of each stain within a bloodstain cluster. They explain that bloodstains with a width greater than 1.5 mm and a distinct elliptical shape are most suitable for accurate analysis.

CHAPTER III

Research Methodology

Experimental Construct

Experimentation for the research project was conducted in a vacant apartment unit to provide accurate physical construction of surfaces and materials. A total of two bloodstains were created in separate rooms of the location. The spatter patterns were produced at medium energy, with whole bovine blood consisting of K2 EDTA as an anticoagulant agent at room temperature. Both bloodstain patterns were created using a wooden trap apparatus (similar to FIG. 2 in review of literature). The location of the wooden trap apparatus was measured along the x, y, and z axes to establish precise origin of each bloodstain. The first spatter was created using a 1 mL volume of blood which produced a singular angle pattern horizontally along a single planar surface, perpendicular to the origin. The planar surface was constructed of a textured, drywall material coated with an indoor paint. The second spatter was created using a 3 mL volume of blood, producing a dual angle spatter pattern. The blood spatter was deposited upon externally perpendicular surfaces which consisted of multiple mediums. Said mediums consisted of textured and painted drywall, cabinetry wood, and stainless steel. Location markers were then placed to identify areas of focus that contained blood spatter. On the second spatter pattern, markers were placed to identify spatter on each of the target mediums.

To create the virtual model used for analysis of the bloodstain patterns, a FARO Focus ^{3D} Laser Scanner was used. A total of five scans were conducted which encompassed visual representation of each spatter pattern. The virtual model created virtually replicated the area on a 1:1 scale in a three dimensional presentation. The bloodstain patterns require close proximity, high-resolution digital photographs for analysis, this was done using a Nikon D3300 DSLR camera with a Nikon DX VR 55 millimeter macro lens. A total of three photographs were taken of each spatter pattern. Each photo contained the markers so that the pictures can be overlaid on a 1:1 scale within the virtual model.

Software Analysis

Scans produced by the FARO Focus ^{3D} Laser Scanner were imported into FARO SCENE in order to create the three dimensional model. The scans were first imported into the SCENE software and clustered by selecting common planes and points within each of the individual scans. The software would identify the selected points and planes as similar and mesh the scan to create a point cloud with a variance of 1.6 mm between points. Once the scans were oriented and registered to create the point cloud, the project was exported to create a file acceptable for analysis through FARO Zone 3D.

In FARO Zone 3D, the point cloud project was imported and oriented on a z-planar grid to allow for accurate measurement. To initiate analysis of the bloodstain patterns, the high-resolution photographs were positioned on a 1:1 scale by selecting the markers on the photo and matching them within the point cloud. The photographs for the first and second spatter patterns were assigned to separate layers of the project from the point cloud, respectively, so they could be independently manipulated for the spatter pattern analysis. On each high-resolution photograph, 4-5 individual blood stains were selected to analyze to determine trajectory. The software calculates the trajectory using a trigonometric function derived from the Pythagorean Theorem, called the Balthazard Formula:

$$\theta = \sin^{-1}\frac{w}{l}$$

Each selected stain had the length and the width of its ellipse measured in millimeters. The software generated an “edge-detected” ellipse over the selected bloodstain that could be manually adjusted to ensure precise fit over the stain. The ellipse was first aligned with the leading edge of the stain. The overall length and width was then be adjusted to position the ellipse to represent the bloodstain. The data from the ellipse was then entered into the Balthazard Formula by FARO Zone 3D software to generate an angle of impact. That angle produced a flight-path model that extended through three-dimensional space. To ensure an accurate angle of convergence along the two-dimensional planar surface, the flight-path representation was mirrored and aligned with tail of the stain. Once calculations were conducted for all selected stains of each high-resolution photograph, the flight-paths intersected and overlapped, producing the area of convergence (AOC) that is represented by a sphere in the virtual model. The measured values of the AOC are what were compared to the known point of origin.

Statistical Analysis:

A statistical confidence interval was calculated for the data set based on the standard deviation of the area of origin spheres produced by FARO Zone 3D. The confidence interval is represented by the function:

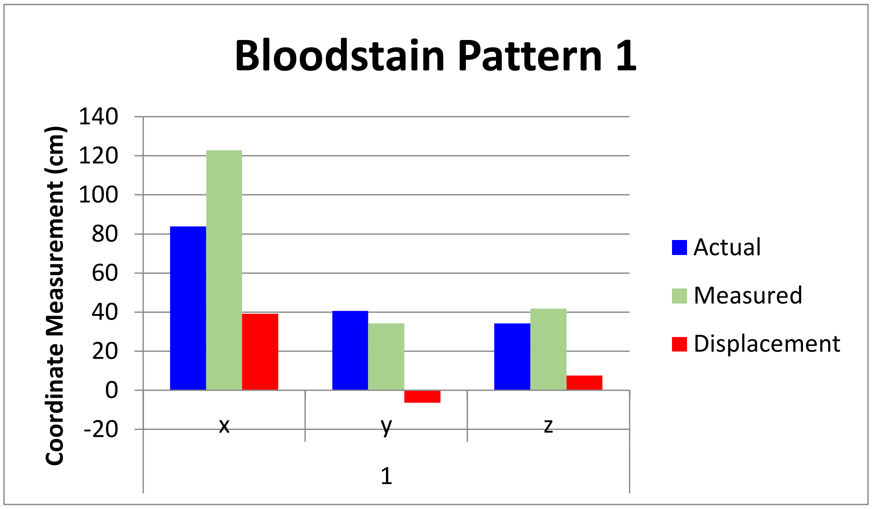
$$\bar{X} \pm t\frac{s}{\sqrt{n}}$$

The variable $\bar{X}$ represents the value of the center of the AO sphere. The *t* value is determined based on the constant provided by a t-table, dependent on the *n* value which is the amount of data point or in this case individual bloodstain droplets. The *s* variable of the equation represents the standard deviation of the AO sphere provided by FARO Zone 3D. A 95% confidence interval was chosen for the analysis as a standard which accounts for 5% error or data falling outside the calculated acceptance.

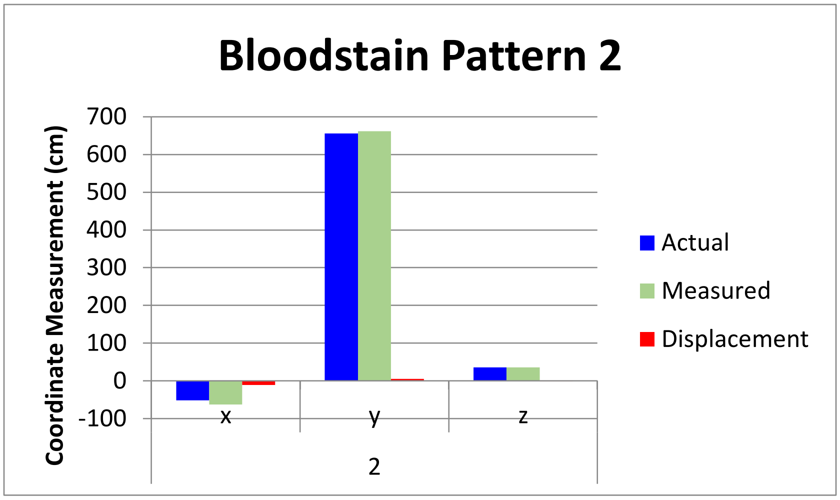
CHAPTER IV

Results

The generation of an area of convergence for the bloodstain patterns created in the research experimentation provided coordinates for the center of the encompassed area that is represented by a sphere. Bloodstain pattern one provided coordinates of 122.89 cm, 34.22 cm, and 41.84 cm for the x, y, and z-axes respectively. These measurements are compared to the measured coordinates of the known point of origin. Those coordinates are 83.82 cm, 40.64 cm, and 34.29 cm in correlation to the above coordinates. The x-axis for Bloodstain Pattern 1 showed a displacement of 39.07 cm, while the y and z-axes revealed a displacement of -6.42 cm and 7.55 cm respectively. The FARO Zone 3D software calculated a standard deviation of 5.88 cm for the AO sphere. The standard deviation represents the average distance of the blood spatter path of flight lines to the center of the AO sphere.



Bloodstain Pattern 2 measured known point of origin coordinates of -51.56 cm (x-axis), 655.93 cm (y-axis), and 35.56 cm (z-axis). The calculated AO spherical center coordinates were represented as -62.19 cm (x-axis), 661.26 (y-axis), and 35.53 (z-axis). The displacement along the x-axis for Bloodstain Pattern 2 was -10.36 cm, while the y-axis was 5.33 cm, and the z-axis being -.04 cm. The standard deviation for AO sphere of Bloodstain Pattern 2 was calculated by the software of being 4.47 cm.



The coordinate values are measurements from a baseline axis placed within the point cloud on the southwest corner of the bedroom. This baseline corner is along intersection of the planar surface of Bloodstain Pattern 1 and the wall that extends to the closest point of origin for Bloodstain Pattern 2 (appendix 1-B).

The confidence interval at a 95% confidence, produced an interval of ± 3.257 cm from the center of the AO sphere in all directions for Bloodstain Pattern 1 based on the standard deviation of 5.88 cm and an *n* value of 15 individual stain droplets used for analysis. Along the x, y, and z axes the interval created for the known point of impact was (80.563 – 87.077), (37.383 – 43.897), and (31.033 – 37.547) respectively. The same process was used to calculate the 95% confidence interval for Bloodstain Pattern 2 with a standard deviation of 4.47 cm and an increased *n* value of 17. The interval value produced was ± 2.298 cm from the center of the AO sphere along the x, y and z axes. The intervals created were (-53.858 - -49.262), (653.632 – 658.228), and (33.262 – 37.858) for the axes respectively.

CHAPTER V

Discussion

The first aspect of this research was to validate the software in accurately calculating the area of origin for a medium energy bloodstain impact spatter pattern. The first impact spatter pattern upon a single planar surface, consisted of stains that were suitable for analysis in a singular direction. Based on the results for Bloodstain Pattern 1, it is clear that the software lacks validity when analyzing this type of single directionality bloodstain. The less than accurate results are based on the large displacement value for the x-axis. The y and z-axis displacement values are within an acceptable variance based on the 7-cm boundary explained by Dubyk and Liscio (2016), stating that measurement is about the average size of a human skull. The x-axis produced the greatest amount of variability for Bloodstain Pattern 1 because the area of origin could not be triangulated with analyzed stains on the opposite side of where the spatter originated from along the planar target medium. This triangulation effect is what controls the accuracy of the x-axis coordinate. The y-axis is controlled by the elliptical overlay of each individual stain for which the angle of impact is calculated with the Balthazard Formula. The z-axis is primarily sourced from the stains selected as suitable for analysis and their angle of convergence along a two-dimensional surface.

While the validity of Bloodstain Pattern 1 was less than reassuring, Bloodstain Pattern 2 exemplified much more confident results of validity based on the Dubyk and Liscio defined acceptable variance. However, based on the statistical analysis of a 95% confidence interval for each of the bloodstain patterns, neither AO analysis by FARO Zone 3D met the intervals of validity for all axes. In fact, Bloodstain Pattern 1 did not have any of the axes displacement measurements for the AO sphere fall within the range produced by the confidence interval.

Bloodstain Pattern 2 did produce an accurate analysis along the z-axis, but both the x and y-axis measurements were outside the acceptable confidence ranges. Therefore, the analytical research rejects the null hypothesis of validity.

The confidence interval is a function that represents the probability of a data set falling within the provided range. The lower the confidence percentage, the more precise the range becomes. If a 99% confidence interval were selected, the data would be much closer to supporting validity of the software but would the defeat the purpose of accuracy. This software needs to be both accurate and valid to be acceptable in the field of Forensic Science and warrant use in assisting in criminal investigations.

The second aspect of this research is the affect that different target mediums will have on altering stain formation and if FARO Zone 3D can accurately determine the AO across these separate mediums as a single stain. Upon visual examination of the individual stains deposited upon the different target mediums, there was obvious evidence of alteration during stain formation. The stainless steel provided the most elliptical stains with smooth edges and distinct tails. The painted drywall did present slight distortion to many of the stains in respect to the smoothness of the edges forming the ellipse; as well, many of the stains did not possess distinct tails. However, this could also be due to the severe angle of impact and not the target medium. The most difficult medium to select suitable stain for analysis from was the cabinet wood medium. The elliptical shapes were very irregular with partial formation and slightly spined edges. This made overlaying the ellipse difficult due to having to assume the true elliptical shape while omitting the spined edges. This medium proved to be the most subjective during analysis since many of the stains were unsuitable for analysis. One individual stain that was selected for analysis was omitted from the AO sphere due to being an anomaly in regards to the angle of impact calculation. This is directly linked to the ellipse formation of the stain and the inaccuracy of overlaying the shape to determine the angle of convergence and angle of impact. Overall, the null hypothesis was rejected in that a single sourced medium energy bloodstain pattern can be analyzed by FARO Zone 3D as a single stain pattern across different target mediums without any statistically significant variance. I am confident though that the software has the ability to analyze the stain as a single source across different mediums if the standard analysis of bloodstain patterns becomes validated due to the variance being lower for Bloodstain Pattern 2 that the analysis for Bloodstain Pattern 2.

The final phase of purpose of this research was to enhance the visual representation of the analysis of bloodstain patterns for purposes of testimony in a court of law. While FARO Zone 3D is working on being capable of virtual reality representation, any type of animation or augmented reality is not admissible in courts. However, FARO Zone 3D is still capable of illustrating the scene of analysis in three-dimension by taking snapshots of the point cloud project (appendix 1-A and 1-B). The software can also produce a two-dimensional sketch by two methods. The first of which, consists of a ‘bird’s eye’ top view of the point cloud while a clipping box is applied to hide the ceiling of the scene. A snapshot can be taken in this view to produce the 1:1 scale sketch. The second method requires a tracing function, where the analyst uses tools to trace the outline of the scene and any objects that need to be added using templates provided by FARO Zone 3D (appendix 2).

Along with the less than reassuring results in regards to the bloodstain pattern analysis, the FARO Zone 3D software has many other difficulties that need to be improved. The software is not overall user friendly. Starting with the importation of the point cloud, the project did not set on the z-planar grid. The point cloud was at an elevated position and orienting in on the grid was extremely difficult and caused the software to not respond and crash multiple times. Which brings up the next point of reopening the project, when launching the project again a prompt to import the point cloud along with the project analysis appeared. This prompt leads me to believe that the imported point cloud does not become a permanent component of the FARO Zone 3D software analysis. This has the potential to cause problems if the project needs to be loaded and the point cloud is not present on the computer in which it was originally produced. During the actual analysis of the bloodstain patterns, the importation and orientation of the high resolution digital photos was relatively easy and accurate. The increased amount of matching points from previous software versions ensured a more precise fitting. The droplet auto-fit function and editing the elliptical template made for user friendly analysis, but based on the end results there is still a fair amount of subjectivity and possible error in calculations. A major area of concern regarding the bloodstain pattern analysis is the reports generated. An angle is illustrated on the generated reports, but upon closer examination it is not the angle of impact but the angle of flight path orientation. If the flight path is determined based on the Balthazard formula and the produced ellipse of the bloodstain, the orientation angle is irrelevant and the ambiguous data could be misleading.

Overall, FARO Zone 3D possess potential of being a progressive tool in Forensic Science application, but must go through extensive revision before achieving that status. The most important of the revisions be that of becoming valid in the analysis of bloodstain patterns. Once validity is ensured, the software overall needs to become more user friendly so that constant specialized training is not needed to produce correct and accurate results.

Limitations

Bloodstain pattern analysis is an evolving discipline in forensic science. As with many developing disciplines, limitations in regard to the methodology and to the correct execution of analysis are encountered. The first limitation in this study relates to the physics of individual blood droplets during flight. Blood droplets travel in a parabolic arch due to the external forces of gravity decelerating the droplet. However, calculations to determine area of origin use trigonometric formulas, specifically those related to the Pythagorean Theorem. These calculations are derived based on the laws of 90-degree right triangles and the straight lines that construct them, not parabolic arches. Calculating the parabolic path of travel is difficult because of the inability to know the severity of the arch that the droplet traveled. Also, there are an immense amount of external variables influencing the blood droplet. Flight path can be altered by environmental conditions such as humidity, temperature, and air resistance as well as variables within the blood droplet such as viscosity, surface tension of the spherical shape of the droplet, and the magnitude of oscillation during flight. The internal temperature of the blood during experimentation is used at room temperature, compared to a spatter pattern sourcing naturally from a human would be at roughly 98.6^{o}. Also, natural blood from a human body does not contain an anticoagulant preservative such as the K2 EDTA that is present in the bovine blood used in experimentation. Other factors that can alter the parabolic flight path of blood is the force deposited upon the blood to induce flight and the velocity in which the blood travels. In bloodstain pattern analysis, the force inflicted upon blood is classified in three energy categories: low energy, medium energy, and high energy. Each of these classifications is based on a range of velocity of the object that impacts the blood, not the velocity in which the blood itself travels through space. To diminish the effect of this limitation on AO calculations, stains are selected only from areas that have a positive y-axis value, meaning spatter patterns that are deposited higher than the AO. This may not be attainable during practical application when the AO is not already know, but needs to be determined.

Once a blood droplet forms a stain on a surface there are limitations that affect the formation of the stain and the selection of stains suitable for analysis. Bloodstains are usually analyzed after a period of time from when the stain was deposited and the blood is typically completely dried prior to analysis. This involves the absorption of the blood droplet by the surface it has been deposited on. With different target mediums, different absorption factors contribute to the overall formation of the individual droplet stains. Absorption factors may cause alterations to the stains resulting in calculations that show variance. As a means to achieve the most accurate results, only stains that possess an acceptable size and form a clear and consistent elliptical shape are deemed as suitable for analysis. Droplet stains that are too small or have irregular edges or shapes will make measurements difficult to attain and may affect the validity of the calculations. There is subjectivity in the selection of quality impact spatter patterns for analysis. Subjectivity also extends to the amount of stains considered necessary for AO determination. Since there is no standard in regard to bloodstain quantities required for AO determinations, the amount of stains selected is subjective in nature and may influence the calculations to a significant degree.

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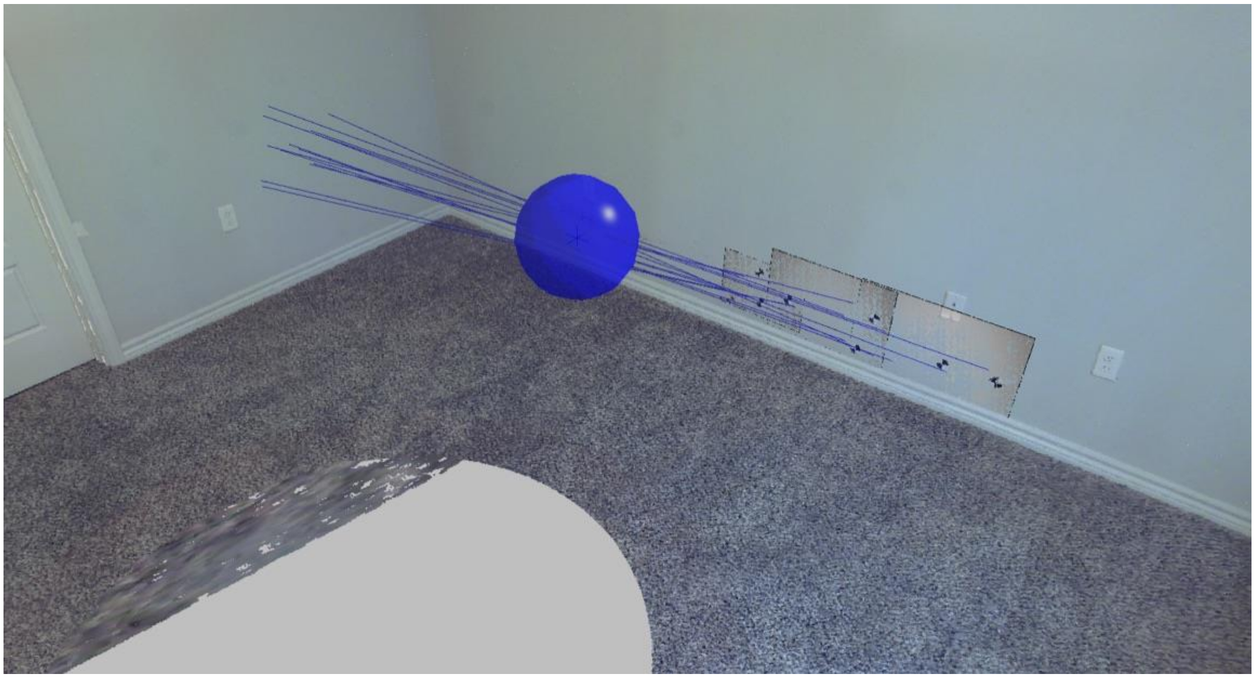
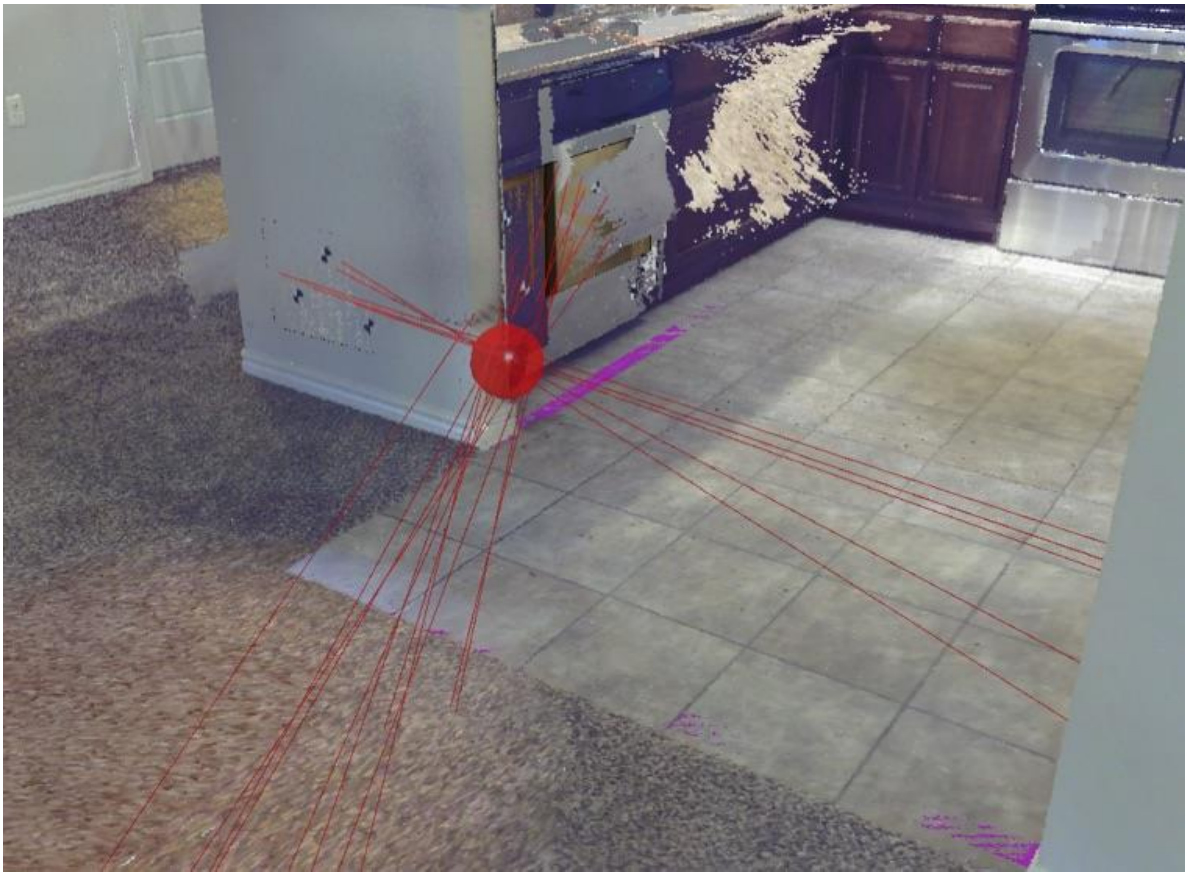
Appendices

Appendix 1-A



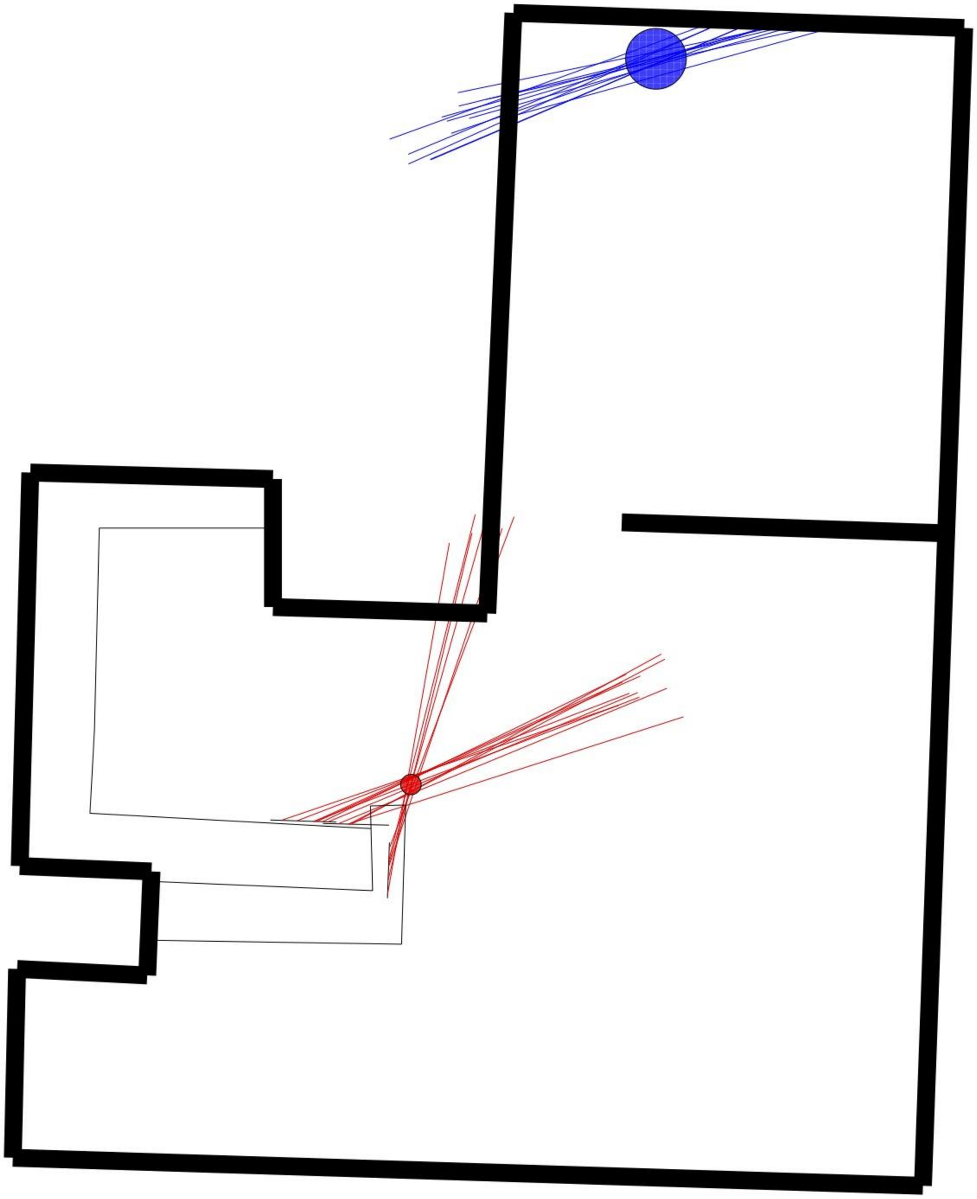
Three-dimensional representation of AO, represented by sphere, for bloodstain pattern 1. Impact spatter deposited upon single planar surface of painted drywall medium.

Appendix 1-B



Three-dimensional representation of AO, represented by sphere, for bloodstain pattern 2. Stains deposited along perpendicular planes. Target mediums consist of painted drywall, cabinetry wood, and stainless steel.

Appendix 2



Two-dimensional traced sketch with flight of path travel for each individual stain of bloodstain patterns 1 and 2 with representation of calculated area of origin, represented by outlined circles.