

Using a 3D Laser Scanner to Determine the Area of Origin of an Impact Pattern

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Abstract: The ability of a bloodstain pattern analyst (BPA) to analyze bloodstains at a bloodletting crime scene to determine the area of origin (AO) of an impact pattern is dependent upon the collected data. The collection of data can be labor intensive and time consuming. This experiment demonstrated that three-dimensional (3D) laser scanners can greatly assist the BPA with scene examination, provide accurate AO determinations, and decrease time at the crime scene. In this experiment, the accuracy and processing time of the FARO X330 3D laser scanner with FARO SCENE software was compared to traditional manual methods of collecting the data and then downloading the data to the HemoSpat program for analysis. Three typical impact patterns were created for this experiment. There was an acceptable range of accuracy between the results produced by HemoSpat and those produced by FARO. The time to document patterns with HemoSpat ranged from 42 to 59 minutes; FARO documentation times ranged from 15 to 21 minutes. The time to analyze the patterns with HemoSpat ranged from 49 to 69 minutes; FARO consistently took 45 minutes.

Introduction

A bloodstain pattern analyst (BPA) attends bloodletting crime scenes to search for, document, record, analyze, and provide an interpretation of the bloodstain pattern evidence to objectively reconstruct what happened. The examination of bloodstain patterns can be a crucial piece of evidence in a criminal investigation. A bloodstain pattern analyst may be able to provide the courts with an opinion on the events that transpired, the

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mechanism of bloodletting, and the locations of victims and suspects. Bloodstain pattern analysis is the examination of the size, shape, location, and distribution pattern of bloodstains. The BPA provides an interpretation of the physical events that gave rise to their origin [1].

A pattern of particular interest to the BPA is the impact pattern. An impact pattern is a bloodstain pattern resulting from an object striking liquid blood [2]. The examination of an impact pattern at a bloodletting scene can be crucial to determining the events that took place. The impact pattern can indicate where the blood source was located, possible location of the suspect, and the approximate number of impacts. The location of the blood source is referred to as the area of origin (AO) and is defined as the three-dimensional location from which spatter originated [2].

It is important to identify and select suitable spatter stains that can be used in calculating an AO for an impact pattern. Spatter stains are bloodstains resulting from a blood drop dispersed through the air because of an external force being applied to a source of liquid blood [2]. Spatter stains should have a well-defined edge, be symmetrical, and show directionality [3]. These characteristics can be affected by:

- The target surface: rough or textured surfaces can cause the spatter stain to be asymmetrical in appearance, resulting in difficulty determining the long axis.
- Shape of the spatter stain: elliptical shaped spatter stains, with a tail or spines that indicate direction of travel, are beneficial to locating an AO, whereas circular spatter stains are less suitable because of difficulty in locating a long axis.

An area of convergence can be located on a vertical or horizontal surface by drawing a line through the long axis of spatter stains to determine the location of a blood source in two dimensions [2]. Locating an area of convergence can assist with determining the number of possible impact patterns and selecting the suitable spatter stains for each pattern. The area of origin (AO) is calculated by the computer software to a specific location using the x, y, and z coordinates. The size limits for an area of origin may range from a tennis ball up to a soccer ball [3].

In order to produce accurate results, it is important to document, record, and analyze spatter stains associated to the impact pattern. A typical impact pattern has a characteristic “V” shape when it is located on a vertical surface, consisting of

upward moving and radiating spatter stains. An impact pattern located on a horizontal surface consists of radiating spatter stains. Upward moving elliptical spatter stains on a vertical surface contribute to a more accurate determination of an AO than downward moving stains. Downward moving stains have begun their descent from the apex of the parabolic flight path, which results in a calculated AO that will be higher than the actual AO. On a horizontal surface, elliptical shaped spatter stains contribute to a more accurate AO.

The calculation of the area of origin goes back to the World War II era when Dr. Victor Balthazard determined that there was a mathematical relationship between the width and the length of a bloodstain that could be used to calculate the angle of impact [4]. The angle of impact is defined as the acute angle (α) at which a blood drop strikes a target, relative to the plane of the target [2]. The “stringing method” was not developed until the 1970s when Herb MacDonnell introduced a method of manually attaching strings to the stains with the appropriate angle that the blood drop had travelled before it struck the wall. The combination of all of the strings on both sides of the “V” pattern creates an approximate AO where the strings cross. This method is time consuming and can be frustrating for one BPA to accomplish at a scene because of the action of measuring the angle off of the surface with the string and attaching the string to the target surface at the calculated angle [5].

Another manual method for determining an AO is the tangent method that was introduced by Tom Griffin and John Anderson [6]. This method is similar to the “stringing method” except that it uses the tangent function to determine the AO. Stains are selected and lines are drawn through the long axis. From the area of convergence, a point of convergence (center point in the area of convergence) is determined and a measurement is taken from the point of convergence (PC) to the leading edge of each stain. The distance away from the surface is calculated using the tangent function. The angle of impact and the distance from the leading edge of the stain to the PC are used in this calculation. This method is still time consuming, but not as frustrating to execute as the “stringing method” because it requires only calculating the AO, rather than handling strings.

By the early 1990s, computer programs were being developed to assist with the calculation of the AO. BackTrack was a program that was developed by Dr. Alfred Carter of Carleton University in 1992. This program involved two programs: one

program to analyze the stain photographs and create strings and the second program to analyze the strings to create a point of origin (PO). The same principles used by BackTrack were utilized and made more user friendly by Kevin and Andy Maloney of Ottawa in 2006. HemoSpat allowed digital images of individual spatter stains to be imported into the program and had the ellipse automatically “fit” overtop the shape of the elliptical spatter stain. HemoSpat would then calculate a PO.

Three-dimensional (3D) laser scanners have been in existence since the 1960s [7] and have evolved to enabling BPAs to accurately record the bloodstain evidence at the scene and use supporting software to determine the PO back at the office.

There are two basic methods of operation for modern-day terrestrial laser scanners: the pulse-based method and the phase comparison method. 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 by a simple formula of:

$$\text{Distance} = \text{Speed} \times \text{Time} \times \frac{1}{2},$$

where speed is the speed of light (constant) and time is the total time it takes for the pulse to hit the surface of the object being measured and then return to the scanner. A division factor of 2 allows for the distance from scanner to the object to be calculated.

The phase comparison method is similar in that light is emitted, reflected, and then returned to the scanner. However, instead of sending out a single pulse, the scanner sends out a constant set of multiple signals. Once reflected from the surface of the object being measured, the difference in phase (i.e., shift in the peaks and valleys of the signal) is compared to the departing signals from the scanner. The difference between the emitted and returned signals is a direct derivative of the distance.

The FARO SCENE software used with the FARO X130 3D laser scanner has a forensic plug-in that can be purchased as an add-on to their software. This plug-in allows the user to derive an accurate 3D position of individual bloodstains within the pattern, and within the scene. A combination of the laser scanner and photographs is used to record the bloodstains and determine their angle of impact to calculate the point of origin.

Materials and Methods

Three impact patterns were created by two colleagues, who did not reveal the actual PO locations until after the analyses were done. The walls were covered with white plastic sheeting for good contrast with the blood and for easy cleaning afterwards. A hockey puck was placed onto a piece of wood and then a measured amount of porcine blood (approximately 5 mL) was placed on the hockey puck. The blood was then struck with a hammer. The actual location of each impact pattern's AO was recorded for later comparison to the results produced by the HemoSpat and FARO SCENE software.

Impact patterns 2 and 3 were created on flat surfaces. Impact pattern 1 had two offset surfaces:

- 1) The first offset surface was the door and frame, which extended 1.2 cm from the west wall.
- 2) The second offset surface was the northern portion of the west wall, which extended out 12.0 cm.

HemoSpat Methodology

Impact patterns 2 and 3 were created on flat wall surfaces. The impact patterns were documented and recorded using the current traditional method of first taking overall photographs of each pattern. Upward moving elliptical spatter stains were selected from each pattern, and a scale tab was placed at the leading edge of the stain (Figure 1). A plumb line was drawn on the scale tab. The plumb line served as a reference line on the surface to assist HemoSpat to calculate the gamma angle, the angle on the wall between a line drawn through the long axis of the stain and the plumb line. The selected spatter stains were measured for location in the room: the distance from the left side of the surface ("y" axis) and distance from the floor ("z" axis). Each of the spatter stains was then photographed using a Nikon D800 DSLR camera with a Nikon 60 millimeter macro lens to capture a 1:1 or as-close-as-possible digital image of each individual spatter stain.

The digital images of the bloodstains were downloaded into the HemoSpat program and analyzed by the program to determine an AO for the pattern recorded. The room dimensions, including length, width, and height, were input into the software program. The individual stains were selected one at a time and an ellipse was drawn around each stain by the program. The image was calibrated using the scale tab increments. The vertical plumb line was also marked using a plumb line feature. Once the information was input, the program generated an AO for the spatter stains.

FARO Methodology

The FARO methodology begins with an inspection of the bloodstains. Groups of stains are desirable because they can be photographed as a “cluster” and do not require that every bloodstain be photographed individually or with a scale. Any number of stains or clusters may be utilized; however, it is up to the analyst to choose which stains or groups of stains are the most desirable. Larger and more elliptical stains that are spread wider apart aid in the triangulation calculation of the area of impact. Odd stains in the cluster should be avoided. One advantage of this method over traditional methods is that photographs do not need to be taken perpendicular to the bloodstain surface. This is extremely convenient because there can be cases where bloodstains appear in tight spaces and where the camera cannot physically be positioned perpendicular to the surface of the bloodstain.

The method used by the FARO plug-in is novel in that it converts a photograph into a “virtual scan” by converting each pixel of the photograph into a three-dimensional point. Initially, this photograph (or virtual scan) has no orientation and starts with an arbitrary scale. Therefore, in order to place the photograph at the correct scale and orientation on a surface, reference points from the laser scan data must be used as a control. Any points may be used that are common between the laser scan and the photograph; however, the use of small targets that help to provide a precise and easily identifiable point by using high-contrast markers (e.g., black and white checkerboard targets) is useful and practical in many situations where natural features are void (e.g., a plain white wall with a bloodstain may not contain features that are easily identifiable). In this study, a commercially available set of 3/4” circular stickers was used; each sticker had a simple black and white checkered pattern as shown in the image (Figure 2). The camera should be placed to frame the cluster of bloodstains in the view finder and then five to eight reference markers should be placed such that they are spread throughout the photograph.

After the bloodstain areas have been photographed, the laser scanner can then be used to document the scene. Although many scans may be taken of the entire scene, only one is required to run the area of origin analysis. In particular, it is important to achieve a relatively high scan resolution where the bloodstain is located. Resolution is often referred to in terms of point spacing on the scanner and, for bloodstain pattern analysis, a spacing of less than 1mm is desirable. Color may also be added to the laser scan data if desired but is not necessary.

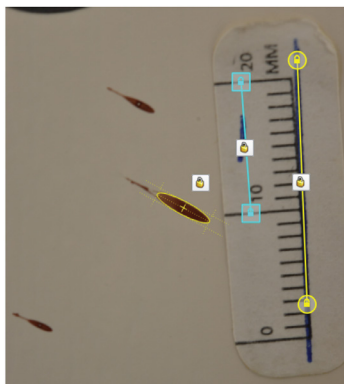


Figure 1
Stain 1 from impact 1 in HemoSpat.



Figure 2
Photograph used in the analysis with reference markers well distributed around a cluster of bloodstains.

Once all the data has been captured, the data is imported into the FARO SCENE software with the bloodstain plug-in and the process of aligning the scans is done first, followed by the marking of the bloodstain ellipses. This marking process is done manually on the computer using a mouse to click on the leading edge of the stain and then moving to the back of the stain along its major axis. The width is adjusted and once the outline of the bloodstain had been made, the operator clicks on the back of the stain to confirm the selection. Once the appropriate bloodstains have been selected, the software can create origins based on either all of the imported bloodstain photographs or a subset of photographs. The result of the analysis will show up immediately in the 3D View and can be visualized in the crime scene.

The time to document and analyze the impact patterns was recorded to determine whether there was a time-saving benefit in using the FARO scanner method over the traditional method using HemoSpat.

Results

As seen in Table 1, there are differences between the two methods when the actual xyz measurements are compared to the xyz coordinates calculated by HemoSpat and FARO. In an experiment conducted by Carter et al. [8], they found 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.

Pattern	x			y			z		
	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

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

The variability in the “x” direction is demonstrated in Figure 3. All of the variation falls into an acceptable range given by Bevel and Gardner [3] and Carter et al. [8] The difference from the actual “x” measurement ranged from 1.0 cm to 11.3 cm with HemoSpat, and from -0.6 cm to -6.8 cm with FARO. A positive difference indicates a distance above the actual, whereas a negative difference indicates a distance below the actual.

The variability in the “y” direction is demonstrated in Figure 4. All of the variation falls into an acceptable range given by Bevel and Gardner [3] and Cater et al. [8] The difference from the actual “y” measurement ranged from 0.7 cm to 6.5 cm with HemoSpat, and from 0.4 cm to 6.5 cm with FARO.

The variability in the “z” direction is demonstrated in Figure 5. All of the variation falls into an acceptable range given by Bevel and Gardner [3] and Cater et al. [8] The difference from the actual “z” measurement ranged from 1.5 cm to 7.3 cm with HemoSpat, and from 1.8 cm to 5.7 cm with FARO.

The documentation and analysis times between the two methods produced interesting results. As seen in Table 2, the documentation time with the FARO X330 3D laser scanner was considerably less than the traditional method. The time-saving difference using the FARO X330 3D laser scanner as compared to the traditional method ranged from 25 minutes to 40 minutes per pattern. The times to analyze the spatter stains using FARO SCENE was somewhat less than HemoSpat (15 to 24 minutes).

Pattern	HemoSpat			FARO		
	Documentation	Analysis	Total	Documentation	Analysis	Total
1	55	69	124	15	45	60
2	59	69	128	21	45	66
3	42	60	102	17	45	62

Table 2

Comparing processing times between FARO and HemoSpat (minutes).

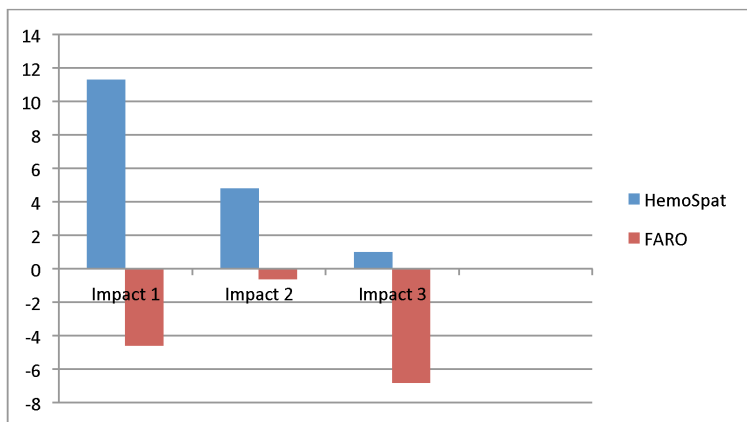


Figure 3

X axis variability between HemoSpat and FARO from the actual, in centimeters.

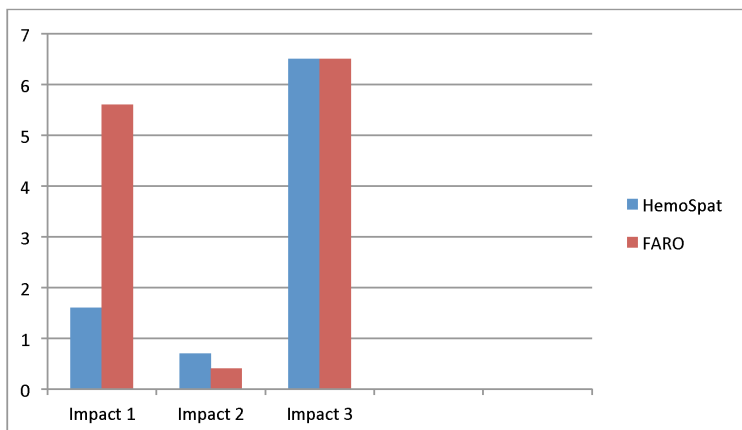


Figure 4

X axis variability between HemoSpat and FARO from the actual, in centimeters.

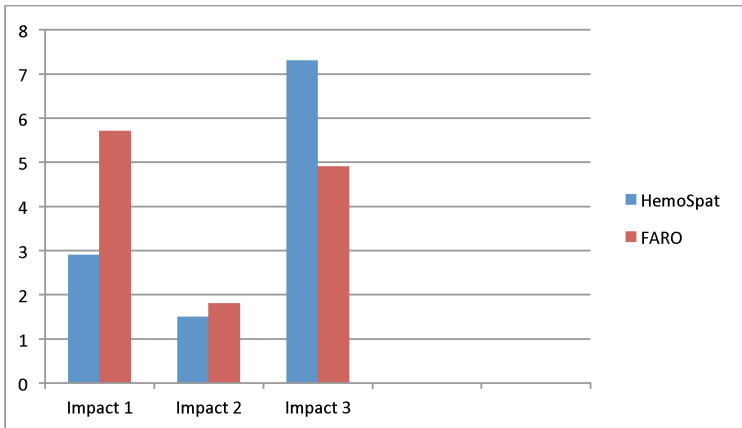


Figure 5

Z axis variability between HemoSpat and FARO from the actual, in centimeters.

Discussion and Conclusion

This experiment examined the accuracy of calculating the area of origin of an impact pattern using HemoSpat and the FARO X330 3D laser scanner with supporting FARO SCENE software with the forensic plug-in. The processing times were also recorded for the two methods. Both the traditional method using HemoSpat and the FARO scanner produced results in an acceptable range of accuracy.

The number of spatter stains selected can influence the accuracy of the AO calculation. In this experiment, 24 total spatter stains were selected from each impact pattern. Twelve spatter stains were selected from each side of the impact pattern. A minimum of 16 total stains is suitable to calculate an AO. Increasing the number of spatter stains selected will provide a more accurate AO calculation.

De Bruin et al. [9] conducted a study to examine methods of improving the accuracy of AO calculations. The study used two software programs, HemoSpat and BackTrack, to calculate AO. Their findings indicated that selection of bloodstains was a factor that affected the AO determination. They found that

the bloodstains with a width greater than 1.5 mm and a distinct elliptical shape were more suitable. They concluded that the selection of bloodstains from more than one surface contributed to more accurate results and advised BPAs to be cautious when blood sources were more than 50 cm away from the front wall.

Reynolds [1] examined the accuracy and precision of computer-fitted theoretical ellipses on bloodstains using BackTrack images and Microsoft Office Excel 2003 auto shapes. The study demonstrated that fitting theoretical ellipses for bloodstain measurement produced accurate results. Reynolds also observed that measurement accuracy improved for stains with a more oblique angle of impact.

In a study by Buck et al. [10], bloodletting scenes were documented using a laser scanner and photogrammetry. The results of this study demonstrated that with the high accuracy and resolution of documented bloodstains on all surfaces, an analysis could be completed. It was also noted that the scene documentation was more efficient.

A study completed by Hakim and Liscio [11] examined the calculating of AO using a laser scanner. Their findings were similar to those of de Bruin et al. [9] It is important to select well-defined elliptical stains from various locations in the impact pattern, in order to generate a more accurate AO. Caution should be used for bloodstains more than 40 cm from the blood source.

The findings of this study demonstrate that the use of 3D laser scanners to document and analyze impact patterns produces results that are comparable with results obtained from the traditional method using the HemoSpat bloodstain software program, according to the range limits given by Bevel and Gardner [3] and Carter et al. [8] A difference was observed in the results between the two methods. Some of this variation can be explained:

1. Different stains were chosen between the two methods.
2. The bloodstains are marked differently between the two methods.
3. There could be small errors in the measurement of the bloodstain location (traditional method with HemoSpat).
4. There are some small errors when fitting the photos to the laser scan data (FARO method).

A time-saving benefit was observed with using a 3D laser scanner to document and analyze the scene when compared to

the process currently used by BPAs. This time-saving benefit can have a significant impact on reducing the time spent processing a scene and labor costs. An additional time consideration with the FARO 3D laser scanner is the set-up time of 10 minutes to prepare the scanner for scanning. The time to analyze the bloodstains with the corresponding software is comparable between both methods.

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