Journal of Forensic Research

Research Article

Open Access

Three-Dimensional Crime Scene and Impression Reconstruction with Photogrammetry

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Received date: April 09, 2019; **Accepted date:** April 24, 2019; **Published date:** May 01, 2019

Abstract

It is commonplace for serious crime offences to be recorded in a three-Dimensional (3D) manner in order to facilitate retrospective analyses of spatial positions of exhibits and objects within a crime scene. The current and most common technique, for capturing these images is *via* 3D terrestrial laser scanners by forensic personnel. These units provide a highly accurate and detailed record of crime scenes but can be prohibitively expensive for many jurisdictions to adopt. Other scale recordings taken during crime scene examination, such as 3D shoe outsole impressions, require time-consuming digital photography capture or casting to be done.

Photogrammetry is a relatively new technique that is finding utility in a number of forensic capacities, mostly due to its ease of use and adoption of equipment already possessed by crime scene examiners, namely high-quality digital cameras. This research looked to evaluate the use of Agisoft® Photoscan software for the 3D recording of small-scale crime scenes, along with the detailed capture of 3D outsole impressions. It was found that photogrammetry did have some utility in the recording of entire scenes, albeit potentially only as a tool for the courtroom and jurors. For 3D shoe outsole impressions created in sand, photogrammetry-derived 3D models resulted in -0.73 percent error. This shows promise, with further validation, as a potential replacement to current photographic capture techniques for these exhibits.

Keywords: Forensic science; Forensic surveying; Photogrammetry; Outsole; Three-dimensional; Crime scene Reconstruction

Introduction

Crime scene teams often include forensic surveying expertise to record geospatial data from within the scene. Historically, this was done by detailed hand sketches that identified points of interest and exhibits and their relative proximity which often assisted court testimony for both witnesses and juries. Most modern crime scene investigation teams now have access to high-tech equipment capable of capturing geospatial records in computer-based three-Dimensional (3D) models.

Surveying of crime scenes by forensic departments is dominated by Terrestrial Laser Scanners (TLS). TLS units produce a quantitative 3D digital representation (e.g. point cloud or range map) of a surface in a given field of view with a certain measurement of uncertainty [1]. They do this by emitting a laser beam which travels away from the device until it strikes a solid object, whereby the laser is reflected back to the scanner. Because light moves at a predictable and known velocity, the time taken from emission to detection, or, time-of-flight, is proportionate to the distance travelled. The laser light is pulsed, allowing for simultaneous, multiple measurements that are recorded for the generation of 3D point cloud of an entire room within minutes. These TLS units collect points at a rapid capture rate and provide high quality, and accurate data [2] with which to base a floor plan or measure spatial distances once a forensic examination is complete. These units can, however, cost in excess of $100,000 AUD, which can be prohibitive to some forensic budgets. This research was conducted to evaluate whether newer, more cost-effective technologies may be able to replace TLS units for scene surveying, or at least provide niche benefits.

One such technique, photogrammetry, requires nothing more than a high-quality digital camera and the accompanying software. Given that forensic departments are already equipped with the appropriate camera hardware, software licencing provides only a minor cost hurdle for this technique. The term photogrammetry broadly describes many types of photographic techniques that capture information, such as satellite, aerial and terrestrial photogrammetry. However, forensic use will almost always utilise Close-Range Photogrammetry (CRP) as a method, due to the distance and range required for police work. CRP is a technique representing and measuring 3D objects using data stored on two-Dimensional (2D) photographs [3]. CRP encapsulates image measurement and interpretation in order to derive the shape and location of an object from one or more photographs of the object. In principle, photogrammetric methods can be applied in any situation where the object to be measured can be photographically recorded [4]. Although there is no hard and fast definition, it may be said that close-range photogrammetry applies to objects ranging from 200 m, to whatever the camera can reliably capture in size. Accuracies also range relative to the object. In manufacturing industries, smaller object sizes may observe tolerances of under 0.1 mm whereas architecture and construction applications can be subject to larger discrepancies in sizing as high as 10 mm [4].

Photogrammetry is relatively low cost, requiring only a camera and the photogrammetry software for analysis. Collectively, both tools can be acquired for under $10,000 AUD, which should not prove to be overly cost-prohibitive to any major jurisdiction. When considering that any forensic or policing operation will already be in possession of appropriate quality cameras, CRP is perhaps the cheapest method of capturing an object or area in 3D. Photogrammetry may also be a cost saving measure as it can be conducted on historic or amateur images of a scene, requiring only processing time [4,5]. While attempts have been made at utilising retrospective photogrammetry for archaeological studies [6,7], there has yet to be any published findings reporting on its utility for forensic analyses.

Photogrammetry is the measurement of a space in 3D using central-projection as its fundamental mathematical model. The shape and position of an object are determined by multiple points, such as a sharp corner or a distinct visual marker that can be recognised between images. The intersection of bundles of rays are (Figure 1) are used to compute object geometry from multiple images [8,9]. The distance between these points is calculated and the spatial perspective of each image can be determined. From this, a 3D model can be constructed, and every detail of each image can be applied. A larger collection of images and subsequently more recognisable points allow for more a more detailed model. Conversely, fewer images, or large bare and featureless areas may mean that parts of a detailed 3D structure cannot be represented.

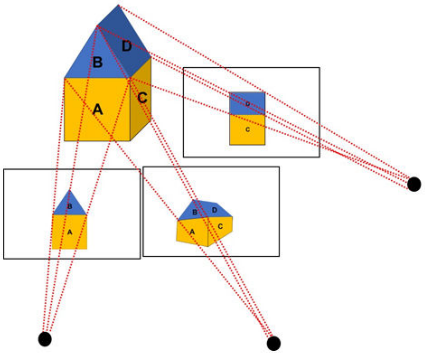

Figure 1: Three images may be used in order to compute approximate shape geometry by photogrammetry software (Source: Luhmann et al. [4]).

Further to general crime scene reconstruction, 3D capture of footwear outsole impressions stands to benefit from the use of photogrammetry. In Australia, the current method for analysing a 3D outsole impression in a forensic investigation is to compile multiple photographs into a single image using post-capture manipulation software such as Adobe® Photoshop®. Correct *in-situ* recording of outsole impressions on a 3D surface are time consuming and often the first forensic task in a major crime response. Further forensic analyses may be delayed in order for physical evidence teams to clear access routes into a scene through the recording of outsole impressions. The reason this can be so time consuming is due of the meticulous processes that must be followed in order to capture an image suitable for comparison. Images must be taken perpendicular to the substrate in order to ensure that they are not distorted by perspective. To highlight peaks and valleys in the impression, a flash is deployed at various points to illuminate different parts of the same impression based on the raised ridges caused by the impression. Once the impression is photographed with light cast from at least four cardinal points, the forensic examiner may consider the evidence captured. This conversion of a 3D impression into 2D image causes loss of information and detail [4]. While casting of such impressions is favoured in some jurisdictions, the dry, sandy nature of many Australian soils precludes its routine use.

The introduction of a technique which simplifies the image capture stage and enables impression evidence to be recorded quickly, would expedite the progression of other forensic processes at a scene. This would also hold an advantage over the current 2D compilation method as the subject is no longer being compressed into a single image which would reduce the amount of information loss while still being free from perspective distortion effects.

The purpose of this study was to evaluate the use of photogrammetry in developing a 3D image of a crime scene room and additional exhibits they may be used for comparison sciences.

Materials and Methods

Photogrammetry was conducted using Agisoft® Photoscan software (v1.2.6.2834) to analyse images taken using a Nikon D5500 digital SLR mounted to a tripod. Agisoft software was run on two separate computers; a Microsoft Windows Computer with 16 GB memory and AMD Processor, as well as an Apple Macbook Air (2014). For general scene photography, the camera was set to aperture priority mode with f11 chosen as the aperture size that balanced the availability of natural light with an acceptable depth of field. Focal length was set to 22 mm so as to limit perspective-based distortion. When taking more close-range and technical photographs, the aperture was closed down to f29 for an increased depth of field and a 35 mm focal length was used to enable natural sizing with the Nikon DX image sensor crop factor considered. ISO was set to 100 for all photographs to ensure as little image noise as possible. All photographs were captured in landscape orientation.

A mock crime scene was created in a room within a transportable building, adjoining a sandy shrub area. The room was garnered with the following evidence which varied in size and detail, typical of a crime scene:

- Corpse (mannequin).
- Pooled blood.
- Impact spatter.
- Transfer blood stained outsole impressions.
- Murder weapon (knife) with impact spatter on it.
- Fingerprints (enhanced with black powder for the purposes of the research).
- Drink vessels (can and bottle).
- Cigarette butt.
- A sequence of four 3D outsole impressions in sand (outside the room).

Evidence such as the corpse, bloodstaining and outsole impressions was created with a range of detail to assess the limitations of the technique. The mannequin was dressed in blood soaked and torn clothes to assess whether small bloodstains or individual fibres could be detected in the 3D model. The bloodstains included a large obvious pool on the floor, medium to fine impact spatter on the walls, and fading, sequential shoe outsole impressions in blood. The 2D bloodstain and fingerprint evidence were used to determine if accurate placement within the scene could be achieved, rather than a 3D recreation of the evidence itself.

The 3D items of evidence were assessed individually, and more thoroughly. A sequence of four 3D outsole impressions in yellow builder's sand were created by walking through the sand while wearing a worn sneaker. Some partial and obscured impressions were included.

The scene was initially recorded using routine crime scene investigation photographic procedures, capturing images from various vantage points within the scene to ensure complete capture. Each item was photographically recorded and measured using a manual tape measure for comparison to measurements derived from the 3D model. Within each set of images, a ruler of known distance was placed to allow for scaling during data processing. For the body, interior and exterior scenes, a 1 m measure was used. For the more detailed blood patterns and outsole impressions, a 15 cm rule was included.

While photographing the indoor area of the scene, the photographs were taken from the edges of the room facing inwards and directed from chest height (approximately 1.3 m from ground) across the room, parallel to the floor. Once the room was circled in this fashion, it was circled again with the photographs taken facing downwards at an angle of approximately 30° from the same height, and then again facing upwards at approximately 30°. A total of 49 photographs were taken of the interior scene. The body was photographed as part of the interior model, but also photographed separately using a similar circling technique with downward angle, although from heights of approximately 100 cm and 25 cm from the ground (to allow for shadowing and obstruction created by clothing and body parts). 62 photographs were taken in order to capture the body. When photographing the exterior scene, photographs were taken following the walls of the building, and following around each corner facing towards the building. For this, a total of 13 images were captured. The shoe outsole impressions in the sand were photographed separately using the same circling technique as the body. 43 photographs were taken of the series of four impressions and a further 18 photographs were taken of specifically one of the impressions. The remaining exhibit items; hammer, fingerprint, cigarette butt, can and bottle were all captured in a similar circling manner with 16, 10, 7, 11 and 11 photographs taken respectively.

All images were imported into Photoscan® as individual projects; interior scene, exterior scene, outsole impression series and exhibit items. Photographs were aligned using the highest accuracy setting and default preselecting and point limit settings. Once aligned, a dense cloud was built using the medium quality setting and aggressive depth filtering. Point clouds constructed were comprised of between 950,000 points (the can) and 39,000,000 points (the impression set). These were then used to create the 3D model with the default pixel size allocated by the software.

Within the 3D model of the scene, the photographed scale rule was used to adjust the sizing, in order for measurements within the model to be estimated. The model was then measured directly within Photoscan® software.

Results

Measurements taken by hand from the scene were compared to measurements obtained by Photoscan® and are detailed in Table 1.

Percent error was calculated for each observed measurement against its corresponding physical measurement. The mean absolute percent error of those measurements was calculated to be -0.73%, with the negative result suggesting that the photogrammetry estimation tended to under estimate. A two tailed T-test was performed, and the measurements observed on the 3D model showed no significant difference to that of the actual measurements (p=0.11), however sample size was low.

Location	Actual (mm)	3D Model (mm)	Difference to Actual (mm)	Error (%)
Room width	2795	2790 (-5)	-5	-0.18
Door frame width	765	764 (-1)	-1	-0.13
Victim height	1860	1820 (-40)	-40	-2.15
Blood pool length	805	799 (-6)	-6	-0.75
Hammer length	344	342 (-2)	-2	-0.58
Cigarette butt length	42	41 (-1)	-1	-2.38
3D outsole impression length	340	344 (+4)	4	1.18
Distance between 3D impression 1 and 2 (i.e. stride length)	355	352 (-3)	-3	-0.85

Table 1: Comparison of measurements taken manually (Actual) with those derived from the 3D model.

Evidence	Actual	Photogrammetry
Interior scene: General	VM	VM
Blood spatter	VM	VNM
Outsole impressions (blood)	VM	VNM
Hammer	VM	VM
Can	VM	NV
Cigarette	VM	VM
Latent (dusted) fingerprints	VM	VNM
Exterior scene: General	VM	NV
3D Outsole impression sequence	VM	VNM
High detail 3D outsole impression	VM	VM
Screwdriver	VM	VNM
Bottle	VM	VM

Table 2: Subjective scores of whether the authors deemed evidence in the 2D photographs and 3D model to be Visible and Measurable (VM), Visual but Not accurately Measurable (VNM), or Not Visible at all (NV).

Each of the evidence types was scored subjectively (Table 2) on whether it was deemed to be visible and measurable from the 3D model. The following classifications were used; Visible and Measurable (VM), Visual but Not accurately Measurable (VNM), or Not Visible at all (NV). The usage of the term "measurable" was relative to the evidence, meaning if the authors believed that valuable evidentiary information could be gathered from it.

3D images of various aspects of the scene were also compared subjectively alongside digital photographs to evaluate whether the 3D models generated would serve as an accurate representation of the scene to a layperson, such as a juror. 3D images (signified as (B)) are presented in Figures 2-12 with their respective digital camera images (signified by (A)). Photoscan .psx files are available as supplementary information.

Figure 2: Photograph (A) and 3D model image (B) of the mock scene room.

Figure 3: Photograph (A) and 3D model image (B) showing blood stained shirt.

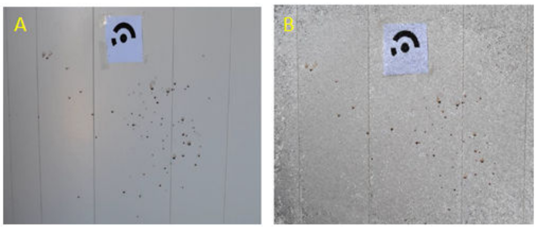

Figure 4: Photograph (A) and 3D model image (B) of the blood spatter on the wall.

Figure 5: Photograph (A) and 3D model image (B) of the drink bottle. Note some error in the 3D.

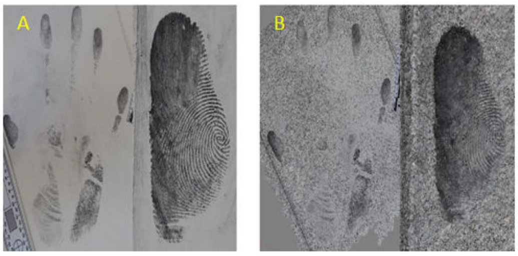

Figure 6: Photograph (A) and 3D model image (B) of the powdered latent print.

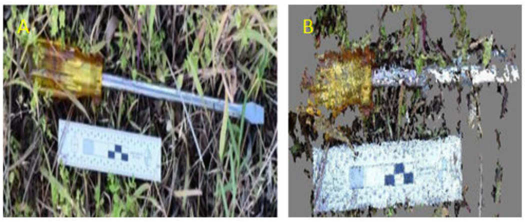

Figure 7: Photograph (A) and 3D model image (B) of the screwdriver in short grass. Note the error in the 3D model due to the inability of the photo scan software to align the grass.

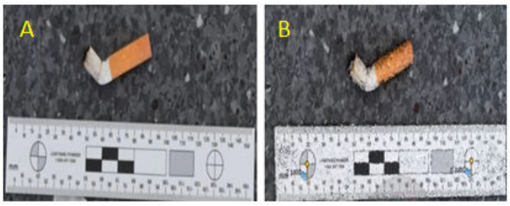

Figure 8: Photograph (A) and 3D model image (B) of the cigarette butt.

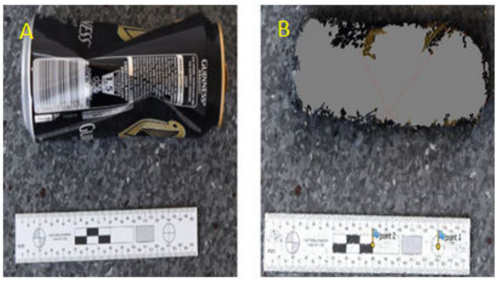

Figure 9: Photograph (A) and 3D model image (B) of the drink can. Note the complete loss of detail in the highly reflective can in the 3D model.

Figure 10: Photograph (A) and 3D model image (B) of the blood stained hammer.

Figure 11: Photograph (A) and 3D model image (B) of the series of shoe outsole impressions in sand.

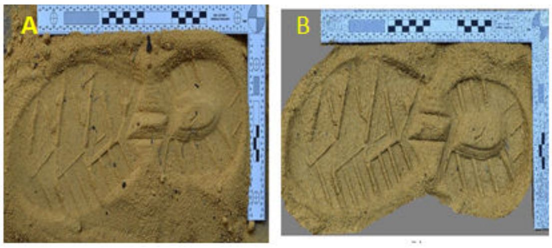

Figure 12: Photograph (A) and 3D model image (B) of a single outsole impression.

Discussion

Photogrammetry showed a capability to deliver a detailed result of smaller objects provided enough quality photographs were taken. While the single outsole impression processed at the highest quality capable by the software (Dense cloud: Ultra High, Model Face Count: High) took considerable processing time (upwards of 24 hours per impression), the resulting detail in the 3D model was remarkable. Individual grains of sand were visible in the model, with differentiation of one millimetre to the physical measured distance. This result was easier to obtain than conventional outsole photography as it does not require any specific lighting methods or tripod alignment to capture. As a matter of interest, a second impression was captured using 16 photos from the Nikon camera set to automatic mode and handheld. The resulting 3D model was also of a reasonable quality and took just over a minute to capture. Further validation of the suitability of such lax approaches to collection need to be conducted but this trial shows some level of potential. It is important to note that the authors suggest that extensive quality controls may not be necessary in order to achieve a high-quality result. Given the high quality of mobile phone cameras available, an extension of this may be that if no forensic personnel can attend a scene and destruction is imminent (by say, weather conditions), a first responder may be directed to capture multiple mobile phone photos, which could then be used to construct a model. Again, further research is required to properly evaluate this suggestion.

A minimum of 16 photos were taken for the photogrammetry process for each of the exhibits in the mock scene. This may not be sufficient to properly capture adequate detail of all evidence. The blood-stained hammer displayed notable spatter, but not to enough detail for a Bloodstain Pattern Analyst (BPA) to examine. An increase in the number of photos captured may render this detail more readily measurable to enable its analysis. Normally, bloodstain interpretation is impossible when the spatter is present on odd or uneven surfaces, however, if a 3D model is considered accurate enough, there may be scope for each individual blood-stain to be assessed on its individual surface for the determination of impact angle. Further research is essential in determining the plausibility of this approach.

To utilise high quality photogrammetry processing, a computer with highly specified RAM, CPU and video card hardware becomes necessary. Standard home or office computers like the ones used in this study could take multiple days to process a model of a single exhibit on the highest detail settings. In attempting to overcome the bottleneck of analysis at the crime scene, it is possible that this limitation may merely move the bottleneck to the laboratory. The Photoscan® software manufacturer provides a guide on the RAM requirements of its processes for users. The most memory-dependent stage of model construction is the building of the 3D model which for 20-50 images, at approximately 12-megapixels, on the ultra-high setting utilises between 32 and 96 GB of RAM. We recommend for forensic use that high and ultra-high settings are adopted and as such machines with a minimum of 32 GB should be used to avoid lengthy processing time.

The need to save time during on-scene capture is perhaps most important in footwear impression examination, where evidence often must be collected before all others, to avoid destruction or contamination by the traffic of police personnel through the scene. If a high-quality 3D model can be captured and rendered in the space of minutes, this could potentially improve the workflow of forensic impression teams. As with the capture of digital photography at crime scenes, the confirmation of successful capture needs to be determined as soon as possible. With digital photography, the user obtains real-time feedback on their image capture quality through picture review. The key to the success of photogrammetry for the collection of outsole impression evidence lies in the ability to confirm (in real time) that the detailed 3D model has successfully been captured. Quick processing of the model is paramount for this outcome.

Reflective surfaces such as the drink can and bottle produced 3D models that were incorrect. The can was placed in a low light environment, but even so its black colouring and highly reflective surface resulted in it being modelled as an empty hole in the floor. A similar problem was encountered with the bottle and its reflective glass surface. This problem occurs due to the software viewing the reflected image as the surface of the object and being unable to construct the distorted result. This problem is also present in TLS units when recording rooms with reflective surfaces such as a mirror.

Photogrammetry as a technique did not require a time-intensive training process, and the Photoscan® software was user friendly, requiring very little time to learn enough to produce a high quality, scaled model. The process of converting the photographs to a 3D model was relatively simple, requiring the knowledge of how to take the photos in a sequence, and required only small changes from default settings within the software. What may limit the practicality of photogrammetry for forensic use is the time it takes to process a high-quality model. For this reason, the authors suggest that photogrammetry may play a valuable tool for select analyses only. As illustrated, the utility of photogrammetry for the capture of 3D outsole impressions could provide an expedited way to process the access and egress points of a crime scene. A potential unease to this may be that there is no immediate feedback to ensure that the capture has been successful, with 3D rendering taking hours to complete even once photographs have been captured. To validate this, a series of parallel analyses need to be undertaken in order to collect a large data set comparing conventional impression comparison techniques with photogrammetry.

Perhaps the most useful role that photogrammetry plays is not in the generation of forensic evidence or expert analysis required to stand the rigour of court testimony, but as a tool to better guide jurors and the court with 3D crime scene walkthroughs. The benefit of having an immersive crime scene experience for jurors may assist attorneys to better demonstrate spatial situations, without the requirement for perfectly scaled models. Additionally, a benefit of having the crime scene digitised is that components such as deceased victims may be respectfully modified in order to accommodate the sensibilities of layperson jurors.

Conclusion

The results of this study show that photogrammetry has demonstrated the capacity to deliver a detailed 3D model of small exhibits, and to a lesser extent, small rooms. Of particular use to forensic teams would be the generation of a high-quality 3D outsole impression, which can be captured on-scene in a time-scale equivalent to that already dedicated to a single impression. There is promising potential for this technology to have the capability of producing a high-quality, measurable 3D model of an outsole impression that can be captured in minutes on scene and referred to at any point in the future in the same 3D environment.

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