3D Image Capture for the Analysis of Bite Mark Injuries

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This work describes the investigation of a new 3D capture method for acquisition and subsequent forensic analysis of bite mark injuries on human skin. When documenting the bite marks with standard 2D cameras, errors in photographic technique can occur if best practice is not strictly adhered to. Subsequent forensic analysis of the mark is problematic when a 3D structure is recorded in 2D space. Although strict guidelines from the British Association of Forensic Odontology (BAFO) exist, these are time consuming to follow and due to their complexity, may produce errors. A 3D capture and processing system might avoid the problems resulting from the 2D recording process, thus simplifying the guidelines and reducing errors.

A series of experiments are described here that demonstrate the potential of a 3D system to produce suitable results. The experiments tested precision and accuracy of the traditional 2D and 3D methods. The results of the experiments demonstrate that distortion and errors created by 2D image capture can negatively affect the digital measurement process. A practical 3D image capture device minimizes the degree of angular distortion, and therefore has the potential to create more robust forensic evidence for use in courts.

> *"It is one of those contradictions of life that although measurement always carries uncertainty, the uncertainty of measurement is rarely discussed when measurements are quoted"* Mlodinow 2009

Introduction

Biting another individual is considered a deliberate act. Bite marks are inflicted during violent altercations, such as rape, child abuse and defensive and offensive combat situations. The biter may be attacking someone or defending himself or herself. The bruise left by an individual's dentition can be an important piece of evidence presented in court. Such evidence may be used to link the alleged biter to the victim.

In simple terms bite mark analysis can be regarded as looking for similarities in two patterns, the pattern of the bruise and the pattern of the biting surface of the teeth.

Much of the photographic evidence gathered by police and medical photographers in the U.K. lacks consistency in quality. This quality is measured by whether or not the photographs represent the bite mark faithfully. The evidential value of the actual bite mark and that of the photographic representation of the bite mark should not be confused with one other. The evidential value of the actual bite mark is expressed by the bruises and or lacerations made by the teeth. Due to the poor registration of human skin and the variation of force used along with the position of the victim's anatomy at the time of biting, variations result in the marks that are made. In some injuries the forensic odontologist will be able to identify the individual tooth marks, which is key to the pattern analysis performed and of high forensic significance. In other injuries there is only a faint bruise, due to the force applied or the time elapsed. A faint bruise is of little forensic significance. A photograph of high evidential value will fit certain criteria and follow a strict protocol. Arguably the most important aspect in the collection of the photographic evidence is the position of the camera when taking the photograph; any error introduced by the photographer can compromise the evidence. This paper investigates the various aspects of bite mark analysis and how 3D imaging can improve the quality and usefulness of photographic evidence.

Method

The research began with a review of the problems of bite mark analysis followed by a review of the current state of 3D image capture applied to bite mark analysis. The authors then conducted a performance analysis of 2D and 3D capture devices.

Review: The Problem of Bite Mark Definition

All the forensic identification sciences involve some form of measurement. This usually includes the determination of which object or person can be linked to a specific injury or mark. When measuring bruises the whole idea of knowing the true size or value is a difficult issue to deal with. A gold standard would be

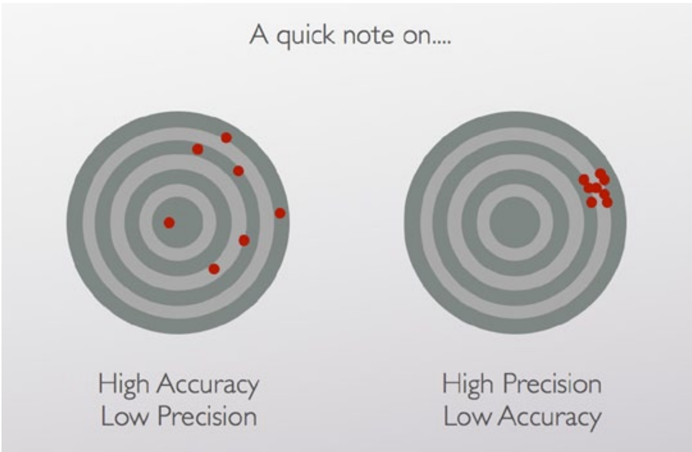

Figure 1. *An Illustration of Accuracy and Precision.*

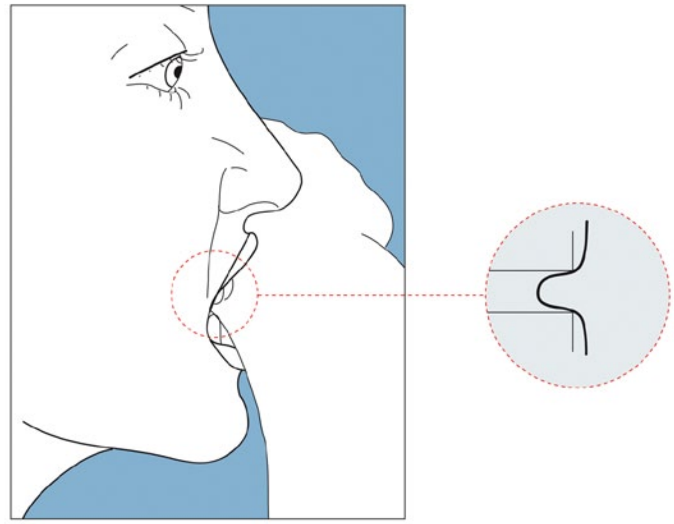

Figure 2. *Dynamic distortion: Interaction of the teeth on skin.*

for a pathologist to cut out the bruise and study the tissue with a microscope; this for obvious reasons would be unacceptable for living subjects. According to the work of Helge von Koch on fractals, (The Koch Curve 2011) certain patterns appear to be made up from repeated and similar patterns of themselves. On closer inspection, the edge of a skin lesion becomes increasingly undulated and ill defined. This problem, especially where bruises are concerned, is compounded by the attempt to determine exactly what needs to be measured and how to measure it. Queries to medical professionals regarding the measuring instrument itself, magnification and the definition the of the lesion's edge often lead to inconsistent answers (Bariciak *et al.* 2003). The dilemma is twofold: the lesion's edge is difficult to acquire accurately and measure precisely, 1) due to a lack of suitable definitions, and 2) due to the lack of a known baseline.

Below are definitions of precision and accuracy as they pertain to this work (see Figure 1).

Accuracy: The closeness of the measurement to actual known value. Although accuracy is vital to the quality of the evidence, in regards to the measurement of a bite mark, the actual known value is difficult to quantify.

Precision: The ability of the device to reproduce the same results under the same conditions. The device's ability to produce consistent results is of the utmost importance. The improvement in the reproducibility of the forensic evidence created by imaging devices is a central point in this work.

An ideal measurement system is both accurate and precise with measurements close to the true value and reproducible.

In addition to the measurement issue of bite marks or bruises, questions arise with respect to how well the biting surface of the teeth imprints on the skin. The age of the resulting bruise and the uniqueness of the distribution of an individual's teeth are as questionable as is the significance of the colour of the bruise (Clement and Blackwell 2010) .

The forensic analysis of bite mark injuries (predominantly carried out by forensic odontologists) and the work of other forensic identification professionals is established practice and has been deemed admissible in courts of law throughout the world. However, with legal precedents such as Daubert vs Merrell Dow (US Supreme Court 1993) and Frye vs United States (Appeals Court, Washington DC 1923), such evidence and subsequent expert testimonies have recently come under scrutiny (Clement and Blackwell 2010), (National Research Council 2009), (Cole 2005). In some cases where too much emphasis was placed on bite mark evidence, the convictions have been overturned on appeal (State v. Krone 1995).

Skin Surface and Photographic Distortions

The forensic analysis of a bite mark is based on three premises:

- The individuality of the suspect's dentition (ideally within a closed population).
- The accuracy in which that dentition transfers the shape of the incisal (biting) surface of the teeth onto the skin as a bruise.
- The assumption that the photograph of both the injury and the dental cast of the suspect's teeth are accurate.

Only the last of these premises, the collection of photographic evidence, is a process where the operator has control whereas the subsequent analysis is subject mainly to primary and secondary distortions as described by Sheasby and MacDonald (Sheasby and MacDonald 2001). These are briefly summarized below:

Primary Distortion Primary distortion is due to the action of the biting process at the time of impact, which includes two categories, 'dynamic' (Figure 2) (the interaction of the teeth and skin), and 'tissue' (stretching and swelling of the skin).

Secondary Distortion Secondary distortion, may be broken down into three categories: time-related changes, body position, and photographic distortion. Arguably the most important aspect in the collection of the photographic evidence is the position of the camera when taking the

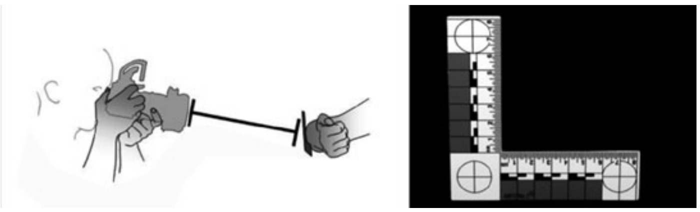

Figure 3. *Incorrect camera to subject placement.*

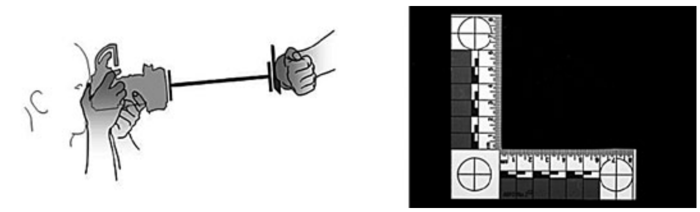

Figure 4. *Correct camera to subject placement.*

photograph in relation to the bite mark. The camera's film plane (CMOS or CCD sensor) must be perpendicular to the bite mark (Figures 3 & 4) as any distortion (angular distortion) may change the appearance of the shape and dimensions of the bite mark (Sheasby and MacDonald 2001), (Evans, Jones and Plassmann 2010). Using conventional 2D single lens reflex (SLR) cameras, the photographer is presented with many issues when attempting to capture evidence that is free of photographic distortion. Angular distortion is caused by operator error and is deceptively difficult to control, especially when dealing with children.

Bruises are often inflicted onto a curved part of the body (Freeman *et al.* 2005), which requires the photographer to take multiple images around the injury and in doing so, reducing the 3D structure of the human body into a 2D space (conventional digital camera). This can cause problems for the accurate representation of depth and the correct placement of scale. To improve the supportive evidence provided by medical and forensic photographers, the photographic distortion needs to be significantly reduced. Some short-term fixes have been proposed, such as a device fitted to an SLR to keep the camera at 90 degrees to the scale and injury (Smith 2011). However, for a viable long–term solution it has been proposed that 3D image capture, be it stereo photography or laser scanning, is more precise, accurate and robust than other forms of recording bite mark injury and that it should therefore be explored as an alternative method (Thali *et al.* 2003), (Blackwell *et al.* 2005), (Martin-de-Las-Heras *et al.* 2007). The authors will therefore discuss 3D capture devices that have been subjected to research in the field of bite mark analysis and the authors' own look at a novel 3D capture device.

Review of existing 3D systems

In recent years, many 3D capture devices have become available on the market ranging from time–of–flight laser scanners used for surveying whole crime scenes (Buck *et al.* 2010). to consumer products such as Nintendo's 3DS (Nintendo 2011). However there are few devices that are suited for the capture of bruises for forensic analysis.

3D scanning devices use two distinctive techniques, passive and active. Passive methods include most stereo-photogrammetric devices. The passive method gathers the data from the reflected light already present in the scene. The active method uses lasers or alternatively either structured or unstructured light. (Structured light systems project a grid onto the subject being scanned, which can improve the gathering of the data needed for 3D reconstruction.)

At the time of writing there are three leading research teams working on the issues relating to the 3D capture and analysis of bite mark injuries.

1. Thali et al. at The Institute of Forensic Medicine Bern
2. Blackwell et al. at The University of Melbourne
3. Martin-de-las-Heres et al. at Granada University

A proponent in the use of 3D capture methods for the forensic analysis of bite mark injuries is Professor M. Thali and his team at the Institute of Forensic Medicine in Bern, Switzerland, who in 2003 published their findings in the journal *Forensic Science International* (Thali *et al.* 2003). This landmark work demonstrated the potential for 3D capture, and the group's initial photogrammetric setup produced interesting results. The team published papers describing their work with the more advanced ATOS and TRITOP devices (Buck *et al.* 2007), (Buck, Naether and Thali 2006), (Germany, Gesellschaft für Optische Messtechnik, *company for optical measuring techniques*. GOM. www.gom.com).

Figure 5. *The ATOS II scanner.*

The ATOS (Figure 5) is classified as a structured light scanner. This type of scanner employs a method of projecting a known pattern of light from a projector housed in the scanner. It uses two digital cameras, also housed in the scanner, to capture images of the object with the patterns projected on it. In order to capture 3D information (or a scene), multiple patterns and/or multiple sensors can be used. The stereo cameras are placed at a fixed and known distance; this enables triangulation of the coordinates. With the captured data a 3D polygon mesh can be generated as a three dimensional computer model. (Figure 6) This is then viewed on screen as a flat computer graphic image. If a colour render is required then the TRITOP is needed in addition. This instrument uses photogrammetry and reference markers to create a 3D colour render, which is then registered onto the polygon mesh, created by the ATOS device, using dedicated software.

A popular method for capturing 3D data in medical and forensic applications involves using a laser scanner that employs

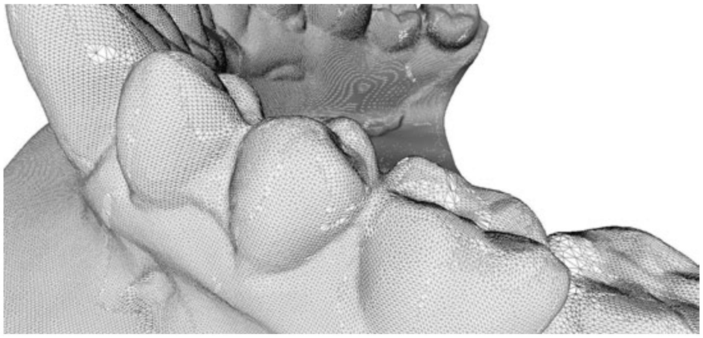

Figure 6. *Polygon mesh of the author's teeth, produced by a laser scanner. A flat computer graphic image.*

Figure 7. *Vivid 910. Approximately 50cm in height.*

a triangulation method. The "Vivid" range of scanners by Konica Minolta is one such scanner. The Vivid V1900 was used for a number of years by clinical research teams investigating facial changes (Vivid VI900), (Kau and Richmond 2008). Its successor, the Vivid 910 (Figure 7), has been used for clinical and forensic applications such as examination of the changes in cleft palate patients (Kitagawa *et al.* 2004) and in bite mark identification analysis (Flora, Tuceryan and Blitzer 2009). Further applications of the Vivid 910 have been reported in recording whole crime scenes (Cavagnini *et al.* 2008). The Vivid 910 was also used as a 3D digitizer for the authors' own experiments involving a dental cast.

Like the Vivid 910, other laser scanners use the stereoscopic principle to generate the 3D model. The scanner directs the light onto the object's surface. The object reflects (scatters) the light back. This light is then collected by a video camera. From this data all the relevant points are located at a known distance from each other. For example, the distance from the scanner to the object and the distance from the laser to the camera are known. Using trigonometry, the 3D (XYZ) coordinates are then triangulated to create, as previously mentioned, a 3D mesh / model of the object.

In work published in 2005, 2007 and 2010, research teams from the University of Melbourne (Blackwell *et al.* 2005) and Granada University (Martin-de-Las-Heras et al 2009), (Martin-de-Las-Heras and Tafur 2009) used laser scanners for their investigations. To date both teams have studied the weaknesses of bite mark analysis with the use of laser scanners as a precise way of testing their hypotheses. The Granada University team used a Picza 3-D Scanner model PIX-3 (www.rolanddg.com). The team at the University of Melbourne used the ModelMaker H403 (www.metris.com). Neither of these two devices could be considered portable and have short scanning times and are thus not appropriate for use in real case scenarios, however, both teams published work that looked at the robustness of bite mark analysis rather than doing a study on the feasibility of the practical application of the technology.

Experiments on the Performance of available 2D and 3D devices

In our own research, three important areas were investigated: precision, accuracy, and the practicality of using 3D devices for the collection of bite mark evidence. With this in mind, the authors initiated the development of the MAVIS stereoscopic camera, which was already being used to gather data for wound management (Plassmann and Peters 2002) (Figure 8). The performance of the stereoscopic MAVIS camera was compared with a laser scanner (Vivid 910) and a 2D SLR camera (Nikon D700). The devices were assessed for their precision and the results published (Sheasby and MacDonald 2001). The results demonstrated that measurements captured from the MAVIS and Vivid devices are more precise, with lower error rates in intra- and inter- operator tests.

In a further experiment, the devices were tested for their accuracy. This test involved gathering data from a set of steel measurement blocks created by the National Physical Laboratory (NPL), Teddington, UK, which have a known value. Three NPL square blocks with varying size and depth (concave) circles were used. A red cross was placed in the middle of the block, and then the distance from the cross to the edge of the circle was calculated

Figure 8. *MAVIS Stereoscopic camera. An adapted stereo lens for the Nikon D700.*

with the depth of the circle included. This was done to gather a measurement of the true known value in three dimensions.

The three NPL blocks were scanned and photographed five times by each instrument. The images were then measured. These measurements (from the imaging devices) were then compared to the known value of the block. A t-test was employed to calculate the probability (p) that two values stem from the same underlying population. Hence, the smaller the probability is, the greater the difference between the known measurements of the NPL block and the resulting measurements from the scanners and camera. The less accurate the scanner or camera the smaller the (p) is. The p value generated by the T-Test can therefore be used to work out which instrument is closest in its accuracy to the known value. The larger the p value is, the more accurate the instrument was at scanning the NPL blocks.

The results from the accuracy experiment demonstrated the accuracy of the Vivid and MAVIS scanners in relation to the measurements of the known value. The difference between the MAVIS, the Vivid 910 and the measurements to the known value was statistically insignificant. The results from the 2D camera demonstrate that the reduction of the 3D object into a 2D space creates inaccurate measurements that are statistically significant if a curved surface is recorded. Figure 9 illustrates the results.

The resulting data from the accuracy and precision experiments appear impressive, however such results can be misleading. The MAVIS camera and the Vivid laser scanner are accurate, exhibiting an error rate within a statistically insignificant margin. This holds true concerning the NPL blocks, although both the

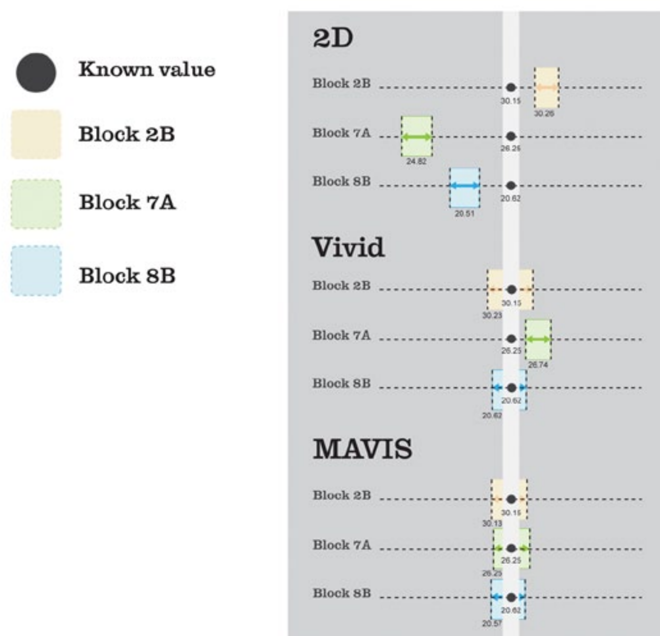

Figure 9. *Results from the accuracy experiment.*

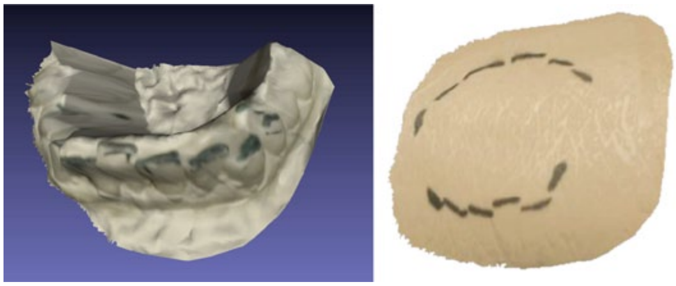

Figure 10. *Images from MAVIS camera. A Flat computer graphic image.*

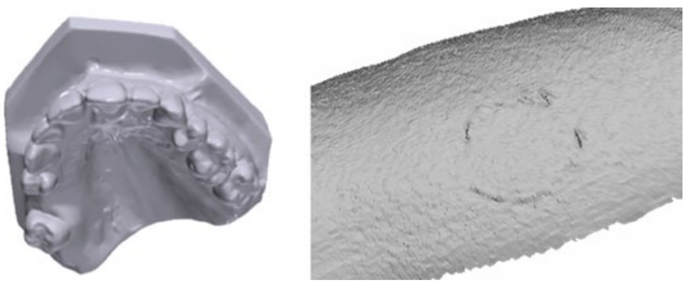

Figure 11. *Images from Vivid Scanner. A Flat computer graphic image.*

MAVIS and Vivid devices demonstrated both strengths and weaknesses. When the Vivid scanner captured the pseudo bite mark and the MAVIS camera captured the dental cast, the results were so poor that the images were not measurable. Conversely the Vivid scanner produced excellent results of the dental cast and the MAVIS produced images of an equally high standard of the pseudo bite mark. The images below demonstrate the results (Figures 10 & 11).

Conclusion

At the time of writing, only the team at the University of Bern who are utilizing the GOM system have been successful in presenting 3D evidence, from stereo photographic capture to computer generated modeling, of bite mark evidence to a court of law. However, two issues arise with the GOM device. Firstly, the price of $230k is prohibitive to most institutions in the UK, especially for forensic purposes. Secondly, the portability of the device is problematic. In many situations bite mark cases involve photography of living subjects, often children. This necessitates that any 3D system should be practical and consistent if it is to replace the current de facto 2D systems. There are some high quality lightweight handheld 3D capture devices (Agosto, E. *et al.* 2008) such as the Handyscan™, which has to be tethered to a computer. However, there is currently a lack of available 3D systems to fulfill this complex task.

It is clear that there is not as yet an ideal single 3D device for bite mark capture and analysis. All 3D devices exhibit strengths and weaknesses. The MAVIS camera demonstrates strengths in its portability and images the quality of a bite mark. Nonetheless further work must be done to improve the quality of data recorded and measurement made from a dental cast.

It is safe to say that there is always room for doubt, and certainty is a fallacy. There is, however, evidence from the authors' experimentation and that of others to demonstrate that the 3D capture of bite mark injuries (and arguably any patterned bruise) is more robust, more precise and more accurate than using our current 2D technology.

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