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Towards a best practice for the use of active non-contact surface scanning to record human skeletal remains from archaeological contexts

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ABSTRACT

Active surface scanners emit light or a laser stripe to record the exterior surface of an object or landscape, providing results in three dimensions. The use of active surface scanners to record anthropological and archaeological contexts has increased within the last few years, creating a number of sub-contexts within these disciplines, and allowing a further development of certain applications, such as quantitative analysis, the use of replicas in education and museums, and the creation of digital databases archived in institutions. However with guidance, this paper aims to assess the advantages and disadvantages of active surface scanning and the potential for research with regards to the recording and analysis of human skeletal remains. The key advantages and uses identified include: quantitative digitisation, geometric morphometric studies, conservation, preservation, documentation, and reconstruction. However, surface scanning also has some limitations, including: cost, technological expertise, the need for a power source, computing requirements, and data size. Overall, the application of active surface scanning technology to archaeological skeletal remains will provide a vital digital archive that will serve to preserve the integrity of this fragile and finite resource for future generations. This is particularly important within the current developer-funded environment in which many skeletal collections, including those yielding unique or unusual pathological or morphological features, are re-buried, with only very limited time for analysis.

Keywords: 3D; Surface Scanning; Human Remains; Digitisation; Anthropology; Archaeology.

1.0 INTRODUCTION

Human skeletal remains are traditionally documented using photographic imaging, written descriptions and / or drawings, alongside the collection of metrical data, as linear measurements of the bones (Olivier & Demoulin, 1976; Buikstra & Ubelaker, 1994). However, actual human remains are three-dimensional and data obtained from traditional photographic imaging lack the third dimension and thus provide a limited perspective (Thali et al., 2003; Errickson et al., 2014). Casting can record surfaces in three dimensions (3D) (Fantini et al., 2008), but some casting methods have been shown to damage bone (Dittmar et al., 2015) and are not advisable on fragile remains. Furthermore, casts commonly used for teaching techniques such as sex or age-estimation, or identification of pathology, are limited in value because they do not expose students to the range of human variation in the expression of these features, and sometimes lack the degree of resolution needed for analysis.

There are a variety of reasons to scan and create a digital archive of human remains. These include: the preservation of information about shape and appearance; to record specific morphological data that are difficult to obtain directly from the remains (e.g. volume); to create a precise digital record in advance of destructive analysis (i.e. DNA or isotopes analysis), and to share the digital collections with other researchers and institutions across the world (Remondino & Rizzi, 2010; Gordon et al., 2013; Gomes et al., 2014).

External surface scanning methodology is used increasingly in archaeology. The umbrella of surface scanning includes both active and passive scanners. Active scanners emit a form of light that is used to record the object, while passive scanners (such as stereoscopic imaging) rely on ambient or external light sources. ‘Active scanning’ is the collective term for both laser and structured light techniques, whose sole purpose is to record the exterior surfaces of an object with light.

The integration of surface scanning into the archaeological context has created the sub-genres of ‘virtual anthropology’ and ‘virtual archaeology’, and is included in ‘digital heritage’ (Benazzi et al., 2010; Weber, 2014). The main aim of surface scanners in these contexts is to digitise, expose, compare, reconstruct, materialise, and share objects (Weber, 2014), providing a new quantitative method for the analysis of artefacts and sites. This paper reviews the advantages of using active surface scanning to record human remains in an archaeological context, assesses the current limitations of the technology and recommends potential research areas for future investigation as a guide for future best practice.

2.0 SURFACE SCANNING

The most commonly used active surface scanners are laser and structured light systems. These techniques are used to record the external surface of an object by providing a 3D topographic data set. Laser scanning systems are passed over the surface of an object in a series of transects creating sets of point clouds (Figure 1). A point cloud is comprised of a group of individual data points, which denote precise 3D geometric locations recorded on the surface of an object. Once collected using various scanning techniques, point clouds can be output as individual data files with x, y, z coordinates (see Section 3.0), allowing an intermittent 3D representation of a scanned object’s surface to be created. Raw point cloud data is typically converted into polygon and triangular mesh formats so as to create a shape with a continuous 3D surface, whereby recorded vertices (points) in a cloud are connected (Figure 1).

To record these points through laser scanning, the principle of triangulation is applied because it is simple and robust with high accuracy (Zeng et al., 1999). On the system there are two known positions, the positioning laser and the detector. The laser is projected onto an object’s surface and reflected back to the detector. Depending on where the light is positioned in the detector it will compute a distance, and this method builds up a series of geometric points. Once the surface has been completely recorded these point clouds are merged together using the overlapping regions as markers.

Structured light scanning systems are comprised of a scanner mounted with a camera that simultaneously adds colour to the point cloud. The structured light scanner projects a plane of light onto a calibration board with shapes of known dimensions (Figure 2). The geometric properties in x, y, z, are documented by the system. From this, the target object replaces the calibration board and the 3D digitisation is completed by analysing the bend of the projected lines when visualised on the surface of the object. Often this can be done using a turntable to rotate the object in front of the camera. This captures data from several different angles. Like the laser scanning technique, the resulting point clouds can be inspected directly or converted into either a triangle mesh model or a surfaced polygon model.

Laser techniques are the most popular active scanning method for digitising human remains. This may be due to the current availability within the horizontal knowledge transfer platform that exists between engineering and archaeology. Some more commonly used devices include the NextEngine, FARO arm, and the Minolta. A literature search for structured light scanning shows that this technique is relatively under-used with only a limited number of returns. However, these active scanners possess a number of advantages and are now becoming more commonly used for heritage documentation in archaeology.

3.0 DATA OUTPUT

As mentioned in Section 2 raw point cloud data is often converted into additional mesh formats to facilitate inspection and analyses. Point clouds must be meshed together using common coordinates, thus spatially aligning the data into a single file. The result is a geometric structure that represents the scanned object. Post processing is often used to enhance the digitisation. For example, noise is removed and a Non-Uniform Rational B-Spline (NURBS) surface may be created for more complicated objects.

The final polygonal formats can be saved in several file formats (Kuzminsky & Gardiner, 2012). The most commonly used formats are ASCII and ASCII TXT. These are data string formats that describe the 3D scene. These file formats are readable and can be formatted in standard text editing software. Another commonly used format is the polygon file (.PLY). This file format stores all of the information pertaining to the properties of a 3D object. This facilitates viewing and 3D printing (Niven et al., 2009). In addition, the .PLY format can be converted into the following data formats: .OBJ, .FBX, .STL, 3DS, etc.

.OBJ is a file format that supports x, y and z coordinates (Trautner, 2015), and is accepted by most imaging software. This format is a plain-text encoded file standard that stores vertex and colour coordinates. In addition, .OBJ supports NURBS and polygonal mesh surfaces (McGrath et al., 2015; Varinlioglu et al., 2014). McGrath et al. (2015) used this file format to save decimated versions of scanned artefacts. Formats such as FBX and 3DS are file formats that are unique to individual software. FBX is an Autodesk file format. This type of extension is supported by programming software such as Python and C++. Similarly, 3DS is a 3D studio scene binary file format that is used by Autodesk.

Rapid prototyping is the fabrication of 3D physical models (Benazzi et al., 2010). It includes stereolithography, fused deposition, selective laser sintering and 3D printing. STL is the reference standard for rapid prototyping and is used in reverse engineering. This data file holds information on the shape, texture, colour and, depending on the technique used, the thickness of the object to be created (Sanchez et al.,2005; Ventola, 2014).

Different instrumentation has varying degrees of scanning accuracy, data size and resolution. The resolution of acquired data is controlled by the point cloud spacing settings, whereby the more point clouds captured per unit area the higher the resolution. Scans with large point cloud spacing will result in lower resolution scans, with surface detail being flatter or more homogenous (see Barbero & Ureta, 2011). Instrumentation settings and hence data output /quality should therefore be tailored to the specific scanning task.

4.0 Advantages for Documenting Human Remains

The ability to render archaeological artefacts or human skeletal remains in 3D has a number of significant advantages that are outlined below.

4.1 Conservation and preservation

Researchers often need to reassess previously recorded skeletal collections, in order to re-evaluate existing studies or to address new research. However, repeated re-use of skeletal collections is known to be damaging, which negatively impacts conservation (Friess, 2012; Kuzminsky & Gardiner, 2012). As a consequence, museum curators may limit access to collections, particularly those that have undergone 'heavy use'. Likewise, skeletal collections that are used for teaching in university departments also suffer from damage during use, despite care and attention being paid to their analysis and storage (Caffell et al., 2001). However, if students are to acquire the necessary expertise in osteology, they must have access to remains, as photographs and drawings are not an adequate substitute.

Some institutions, such as the Smithsonian Institution, Washington DC, USA, now archive human remains digitally as 3D scans (See: http://humanorigins.si.edu(2016)). These scans are then available to a larger number of researchers than the source material is (especially if the material in question is fragile or fossilised). Digital scanning has been particularly important within the ethical and political context of North America, in which many skeletal collections have been repatriated to Native American tribes under the Native American Graves Repatriation Act (NAGPRA). Such scans are still able to provide researchers with detailed morphological information concerning, for example, nonmetric skeletal variants or pathological lesions (Wilson et al., 2017). Likewise, metric data can still be recorded as accurately from scans as the original bones. Thus, it would greatly minimize the risk of damage to skeletal collections curated by museums, and enhance access for researchers, if collections were to be digitized and made available as a substitute for the actual bones (Errickson, 2017).

In addition, skeletal collections may be housed poorly, or moved frequently, which in turn may increase the amount of bones lost (Caffell et al., 2001). This occurred in Jebel-Moya (Sudan), where more than 3,000 individuals were unearthed between 1911 and 1914, but 40 years later the remains conserved included just 98 skulls, 139 mandibles and some postcranial remains (Irish & Konigsberg, 2007). Similar situations can be found in current archived archaeological populations. A scanned record of all the remains would therefore allow them to be studied even after loss or damage of the material.

Any analysis that requires the handling of osteological material will have the potential to damage remains. For example, certain pre-scanning procedures such as clamping to restrict movement of samples and the placing of physical landmarks on the bone to facilitate recording have the potential to cause damage, and therefore care needs to be taken. However, the actual process of surface scanning itself offers a non-destructive, non-contact, technique that improves the long-term preservation prospects of human skeletal collections (Errickson & Thompson, 2017), as after initial 3D recording the need for re-handling of the original physical specimen is reduced. Furthermore, it allows the possibility that researchers could access collections remotely, without having to travel to institutions. The expense incurred through travel, accommodation and subsistence when visiting international collections is prohibitive for many researchers. To help overcome such issues, digitization provides the potential for a worldwide reference collection to be achieved (See Digitised Disease for example: http://www.digitiseddiseases.org (2016)). In addition, Betts et al. (2011) have demonstrated the utility of a virtual database of zooarchaeological remains, which allows data to be disseminated globally.

Surface scanners have also proven invaluable when used on archaeological artefacts (Gomes et al., 2014) and could be transferred to record skeletal remains *in situ*. For example, de Oliveria Santos Junior et al*.* (2012) analysed complex artefacts using 3D reconstructed images. *In situ* artefacts, specifically those affected by weathering, such as those that may disintegrate if excavated, or those that are associated with structures and thus cannot be removed can be scanned and the image preserved in perpetuity. For example, quantitative analysis of changes to 3D surface topography has been used to monitor the deformation of rock art (Barnett et al., 2005; Lerma et al., 2010) and other heritage monuments (http://www.helm.org.uk, 2007; Al-kheder, 2009; Gigli et al., 2009; Bathow et al., 2010). Similar techniques are also used to study and control the degree of soil erosion in archaeological sites (Romanescu et al., 2012a; Romanescu et al., 2012b).

4.2 Teaching and Research

Two-dimensional images cannot be manipulated in the same way as 3D digitisations and may be distorted by perspective, or lighting. Moreover, skeletal casts that are sometimes used as a substitute for the skeleton are often not produced with adequate resolution to enable detailed characteristics and distinctions between populations to be visible (Caffell et al., 2001; Lombardi et al., 2014). In the past, stereoscopic imaging has been used to teach anatomy and physiology (Trelease, 1996), but these images also cannot be rotated and moved in a viewer and therefore are limited in their use. By contrast, digitisations created using non-contact surface scanners can be used and virtually explored in the viewer. In addition, pathological lesions and traumas can be labelled digitally, allowing ease of interpretation and ensuring that they are not overlooked by the user (e.g. see anthronomics: Dactyl: http://www.anthronomics.com (2016)); such images are particularly useful for teaching. For example, while students cannot take physical skeletal remains out of the classroom/laboratory context, a virtual viewer with a large number of skeletal examples can be used at the student's own convenience and enhance their learning experience. In addition, 3D images are ideal, especially when the physical storage capacity of an institution is reached (Attardi & Rogers, 2015).

Many institutions are not willing to share anthropological resources and remains due to the risk of damage or loss in transport (Betts et al., 2011; Mallison, 2011). A digital archive can be easily shared and studied without jeopardizing the collection. Some museums also use scans of remains to supplement explanatory videos and guides to increase the level of education that visitors experience (Mallison, 2011). Hence, the utility of 3D scans in 'outreach' activities is particularly valuable. For example, whilst for ethical reasons, school children would not be allowed to handle 'real' human remains they would be able to manipulate 3D scans of the 'real thing'. Furthermore, 3D replicas of the scans (e.g. crania) can be printed out (see section 4.1.4).

It is now understood that most individuals prefer the visual presentation of a 3D image as opposed to a 2D picture. For example, in the medico-legal context there has been a shift towards the use of 3D images within the courtroom. For example, Ampanozi et al. (2012) demonstrated that district attorneys prefer 3D images for 'understandability' of evidence. The advantage of 3D imaging is that, spatially, they offer an up-to-date visual representation that can be more engaging to the otherwise attention challenged individual.

4.3 Quantitative analysis

Simon et al. (2009) discussed the six additional tools that surface scanning allows in comparison to traditional anthropometric techniques. These include the analysis of: volume, radius, surface area, perimeter lengths, point-to-point evaluation, and vertices. The classical analysis of human remains comprises detailed descriptions and morphometric study. However, in traditional morphometry, documentation is restricted to linear distance measurements, ratios and angles, which present major limitations when working with complex structures (Adams et al., 2004). Geometric morphometrics (GMM) is a branch of statistical shape analysis that merges tools from different areas such as geometry, computer graphics and biometrics (Bookstein, 1997; Zelditch et al., 2004). GMM allows the analysis of groups of homologous landmarks and semilandmarks defined by Cartesian axes in two or three dimensions, preserving the geometric conformation of these points (Baab et al., 2012). 3D data acquisition can be achieved by landmarking the homologous points directly on the remains, using tools such as a MicroScribe, or by landmarking the scanned surface of the object. However, the MicroScribe is a contact technique that jeopardises the integrity of the human remains. Landmarking the scanned surface facilitates the use of different types of landmarks and semilandmarks, and the study of more complex structures, such as teeth. A comparison of the results obtained by digitizing the landmarks with a MicroScribe and those obtained using a surface scanner showed that the surface scanner was better on landmark-based geometric criteria, but not as effective when landmarks were based on anatomical criteria (Sholts et al., 2011). Thus, it is necessary to determine what type of equipment is necessary prior to data collection, according to the morphometric analysis that will be performed.

3D Surface acquisition has been shown to be a robust method for (re)constructing human remains. One example would include dimorphic features and anatomical surfaces of the skeleton (Tognola et al., 2003). This is essential because determining a biological profile of an individual may be important for personal identification in forensic and archaeological contexts. Sholts et al. (2010) used laser scanning to look at differences in cranial variation and surface area to help construct biological profiles. Reconstruction techniques, such as craniofacial reconstruction, have also been carried out with the assistance of 3D models for museum and teaching purposes. For example, the face of the 17th century Korean mummy *Gyeongsun Choi* was reconstructed using a 3D head model obtained by computed tomography (Lee et al., 2014).

Shearer et al. (2012) demonstrated that when surface scanning is used alongside traditional methods, the quality of the documentation is much greater than using traditional methods only and the data is much easier to disseminate. Moreover, there are some dimensions that are straightforwardly recorded from scans, but are difficult to obtain from the remains, as such involving areas and curvatures.

4.4 Taphonomy

Non-contact surface scanning also has good potential applications in recording and quantifying bone taphonomy. Traditional approaches to recording physical bone tissue modification are often limited to macro- and microscopic observations of change and the collection of metric data. Such methods also commonly use qualitative point based scoring systems to assess surface alterations (see for example Behrensmeyer (1978)). Scanning, however, can allow an object's surface to be captured at sub-millimetre accuracy (Barnett *et al*. 2005), and this precise recording of parameters facilitates quantitative analysis of material change. Various non-contact 3D surface scanning methods including microscopic analysis, such as 3D-microprofilometry, are now used in the examination of surface modifications on bone (Kaiser & Katterwe, 2001; Thali et al., 2003; Sansoni 2009; Griffith & Thompson, 2017).

Deformation of objects/artefacts can be captured in a number of ways using non-contact surface scanning. Firstly, sequential scans of the same specimen can be taken over time to monitor material change, such as in actualistic taphonomic process studies (see Barnett et al. (2005) for an example of recording deformation to rock art, and Griffith & Thompson (2017) for an example of recording abrasion on bone surfaces). Incremental scanning enables comparison of the point clouds or polygonal models, which have been altered by taphonomic agents over time. Comparisons are achieved by aligning two or more clouds or meshes in a common coordinate system using homogeneous landmarks, or a common target marker placed on/around the object. For example, in the case of erosion studies, the distance between point clouds from successive scans can be compared, giving a quantitative measure of surface material loss or displacement over time (Barnett et al., 2005; Griffith & Thompson, 2017). Recorded displacements can be plotted using coloured scalar fields in open source and commercially available software, such as CloudCompare (http://www.cloudcompare.org, 2016), allowing heat maps of the geometric distances between scans to be generated, which facilitates spatial differentiation of the occurrence of material change across an artefact's surface. Displacements between scanned objects can be calculated using several methods, including cloud-to-mesh distance, direct cloud-to-cloud comparison with closest point technique, and multi-scale model-to-model cloud comparison (Lague et al., 2013) (see Troisi et al. (2015), pp. 221 and Griffith & Thompson (2017) for examples of how material loss is captured on the surface of a small complex objects. In addition, if a scan is watertight (the mesh or surface data does not contain any holes) volumetric data for bone can be calculated and compared (Gjerdrum & Kuzminsky, 2010; Sholts et al., 2010; Kuzminsky & Gardiner, 2012; Shearera et al., 2012). Furthermore, Griffith & Thompson (2017) show that point could comparison data can also be used to measure volumetric changes on bone surfaces. It should be noted that surface scanning does not record any internal structural properties of bone; therefore a simple closed surface volume is being acquired using these approach (Griffith & Thompson, 2017). CT scanning is a superior method in this respect as it can calculate true volume by accounting for changes in porosity, density and missing mass (Lam et al., 2003). However, surface scanning does provide an alternative way of visually assessing material change, and the potential to quantify these changes.

Scanning has advantages over more traditional measures of material change such as weight loss strategies or Archimedes' principle of volume displacement, as it offers greater accuracy (please refer to Barbero & Ureta (2011) for a comprehensive study on accuracy). Surface scanning can also provide high-resolution, quantitative characterisation of surface features on bone. For example, Kaiser & Katterwe (2001) were able to identify insect modification on fossil bone using 3D-microprofilometry. The study of these types of diagnostic marks has important applications in reconstructing past environmental conditions (Kaiser & Katterwe, 2001). D'Errico & Backwell (2009) and Bello et al. (2011) show that 3D quantification can prove useful in establishing the function of bone tools based on surface wear patterns and roughness analysis, advancing our understanding of past ergonomics. While D'Errico & Backwell (2009) and Bello et al. (2011) utilised high-resolution optical interferometry and infinite focus microscopyto digitise 3D surface topographies, as opposed to laser scanning, their studies demonstrate the utility the precise recording of 3D metrical parameters for interpretation; most notably quantitative data allows surface modifications to be statically compared and discriminated. Approaches such as these have good potential application in discerning different anthropogenic and natural environmental alterations to the surface of bone and teeth (Bello et al., 2011; Boschin & Crezzini, 2012).

Finally, the data that scanning produces can be digitally archived, disseminated and incorporated into multiple working datasets (Schurmans et al., 2002; Sumner and Riddle 2009; Weber & Bookstein 2011) (see section 4.1.2). While the application of scanning in bone taphonomy studies is still in the early stages of development, recording surface changes through quantitative means, and disseminating this data, may allow the aetiologies of different taphonomic modifications on bone surfaces to be discerned with more confidence than is possible through subjective, gross morphological assessments: taphonomic processes studies are routed in the principals of relating an effect to a cause, and establishing the predictability/frequency of such relationships, hence allowing predictions about past processes to be deduced from modified remains. A quantitative approach, achievable through the analysis of 3D surface scanning data, facilitates more precise correlations between taphonomic effect, cause and duration. Therefore, these measures may help to limit diagnostic ambiguity by standardizing the classification of features on bone that are indicative of specific taphonomic processes.

4.5 3D printing

Using the digital data from 3D surface scans, 3D printing can be used to generate correct life size replicas of human anatomical structures (Figure 3) (Ebert et al., 2011; Drake & Pawlina,2014). These scale models allow rare specimens to be accessed worldwide, filling gaps in teaching collections. The technique also safeguards rare and fragile examples by reducing the handling of the bones and their inevitable fragmentation (Fantini et al., 2008). Printing copies of the remains will ensure they are safely housed while their copies are exhibited to the public. This approach was adopted in the 2014 with the Skeleton Science Exhibition at the Thackray Museum, Leeds, UK. Such exhibits are more practical and economical in terms of public presentation and can be used to demonstrate pathology and trauma to those who do not have medical training and are not adept in interpreting characteristics using the actual remains (Allard et al., 2005; Wozniak et al., 2012).

Apart from the obvious advantages of having printed copies of human bones for education and exhibition, 3D printing also offers the possibility of enhancing the original by printing mirror images of bones when one side of the skeleton is not available, or in instances where bones are severely damaged (Mallison, 2011). This technique has also been used to reconstruct individuals where bony regions have been lost. For example, Fantini et al., (2008) used 3D printing to restore a damaged medieval skull. 3D printed human remains may also provide a solution for museums that do not wish to display actual human remains for ethical, cultural or religious reasons. This practice is comparable to medical applications in which a 3D print can be used as an accurate and effective substitute if cadavers are not accessible due to their limited availability and/ or ethical constraints (McMenamin et al., 2014).

While visual models can help disseminate information to others (such as the public/ laymen), no 3D printed model can ever fully replace an actual bone (Allard et al., 2005). Reduced contact with actual skeletal collections has a negative influence on learning. For example, 3D printing of surface scanned remains does not imitate bone density (Cohen & Reyes 2015). However, this is a trade-off, as the use of 3D prints allows us to limit the impact on more valuable skeletal collections.

5.0 The Considerations When Documenting Human Remains

5.1 Noise and Limitations

The scanning process can sometimes create noise (extraneous point clouds) in the data set due to ambient light or obstruction of the light sensor, and often this unwanted data must be removed manually (Kuzminsky & Gardiner, 2012). The result of the scanning and the amount of noise created depend on the nature of remains being scanned, because the varying optical properties of different material surfaces can cause systematic offsets in scanning accuracy. As an example, scanning teeth will usually be more difficult and will involve more post-processing work than scanning bones. This happens because the outer layer of teeth, the enamel, reflects the light at a greater than normal intensity, making it harder to create XYZ coordinates, especially when using laser scanners. To avoid this reflection and improve the results, some scanners emit a shorter wavelength blue light instead of white (Friess, 2012). However, since this type of scanner is more expensive, a common solution is to scan dental casts rather than teeth (Figure 4) (Friess, 2012). Nevertheless, making a dental cast can cause damage to the enamel layer, and will be more time consuming. Therefore, before scanning teeth it is very important to determine what type of scanner to use and whether making casts would improve the intended results. To reduce reflectivity objects may also be recorded using a specifically tailored scanning arrangement, for example, using multiple triangulation angles or modified high dynamic range acquisition techniques (Bathow & Breuckmann, 2011).

A limiting factor is that scanning does not collect all the properties of remains (e.g., weight, density, internal properties) (Mallison, 2011). There can also be difficulties with bones that have an irregular morphology, as happens with the skull, the scapula or the os coxae, since the number of ridges, crests, foveas and foramina mean that additional scans are needed, and this usually produces more noise during the alignment. Something similar happens with femora, whose size also entails additional scans, which is time consuming and increases noise levels. However, some scanners, such as the NextEngine, have additional technical and software capabilities that allow the digitisation of larger objects which in turn makes scanning easier and reduces time.

Finally, if the digital file is compressed the results may lose accuracy. This may lead to errors within this dataset and should be taken into account when studying these files. Therefore the researcher must check the requirements and resolution of the scans prior to recording (Mallison, 2011).

5.2 Experience and Ethical Considerations

Scanning an object can be very time-consuming. The time required will usually depend on the accuracy of the result needed and the size of the object, although older scanners are generally slower than more modern ones (Mallison, 2011). Some scanners reduce the time spent by working in a semi-automated way, so the researcher can undertake other tasks while scanning, but the time required to process the results can be equally time-consuming. Laser scanners tend to be slower than structured light scanners, although they are more accurate (Friess, 2012).

It is shown within the only currently written guides for good practice for scanning human remains that experience with using the 3D surface scanners can decrease the noise created in the dataset (http://archaeologydataservice.ac.uk, 2009). These guides serve as a foundation that should be built on and when 3D imaging human remains must be consulted for guidance so that the data sets achieved are optimum. Therefore, training is essential before scanning is undertaken. This task alone can be time consuming.

Although it is currently perceived that accurately scanning human remains is advantageous, there are a number of ethical considerations to take into account. For example, should an accurate 3D representation of a skeleton be made publically available? After all, it is a copy of the actual human remains. In addition, should we 3D print them to generate copies? For example, with regards to NAGPRA if all human remains need to be returned to their representative affiliations should the 3D printed models be returned too? Similarly, is this the same for other repatriation practices? The authors recommend that these issues must be addressed to ensure best practice on data dissemination can be achieved.

5.3 Resolution and Accessibility

The results obtained from surface scanning will vary depending on the scanner chosen, the environment, the condition of he remains to be scanned, and any time constraints. There are several properties to take into consideration prior to data acquisition: accuracy, portability, cost, time for acquisition and flexibility (Remondino & Rizzi, 2010). Ideally the scanner chosen will provide the highest accuracy, portability and flexibility, with the lowest cost and time for acquisition.

Working with human remains usually requires scanning *in situ*. In these cases, structured light scanners are much more portable than laser scanners, and can cost as little £2,000 (Errickson, 2016). However, the resolution of the structured light scanner is significantly reduced in comparison to high-end laser scanners (See Barbero & Ureta (2011)). Non-portable and more stable scanners also usually provide more accuracy (Friess, 2012). Smaller, 'portable' laser scanning devices such as the NextEngine has been used in the field (*pers comms* Decker (2015)) offering increased resolution, but are more expensive (approximately £5,000) and are less portable than single projector structured light scanners.

Not all institutions have access to the surface scanning technique; however this can be addressed through increased collaboration as necessary. As demonstrated, in some cases it may not be necessary to own a surface scanner if 3D digitisations can be passed between institutions. Therefore, it may only be necessary to own a 3D printer. This article recommends an increased cross collaboration between institutions as once the surface scanner has been purchased, additional costs are minimum.

6.0 Conclusion

3D imaging techniques can permanently document bones for future visualisation and analysis, even after the original bones have disappeared (Niven et al., 2009). However, there is a huge difference between a visual replica of a bone and a replica that is to be scientifically studied (Allard et al., 2005). Consequently 3D images can never replace actual remains.

Surface scanning offers an impressive number of advantages, such as allowing additional quantitative analysis using geometric morphometrics and statistical studies; acting as a valuable teaching resource; promoting conservation, and reconstruction; and generating images that in terms of viewing are easy to comprehend.

Although surface scanning is becoming widely accepted some considerations should be understood before any work is undertaken. It is highly important that a clear understanding of the intended final data set is known so that the data can be recorded to the specific quality intended. This can be achieved by using the Archaeological Data Service's 'Guides to good practice', but further guidelines are needed to keep pace with this rapidly evolving discipline (http://archaeologydataservice.ac.uk, 2009). In addition to these guidelines, the ethical considerations (section 4.2.2) must be addressed to ensure we as researchers continue to respect the dead.

By using a horizontal knowledge transfer platform, accessibility to imaging equipment is increasing, but this also permits guidelines from other disciplines to be utilised and adapted and applied to archaeology to ensure the preservation of human remains, help to share data among scientific institutions, assist museums in their teaching tasks, and push the boundaries of our anthropological and archaeological knowledge.

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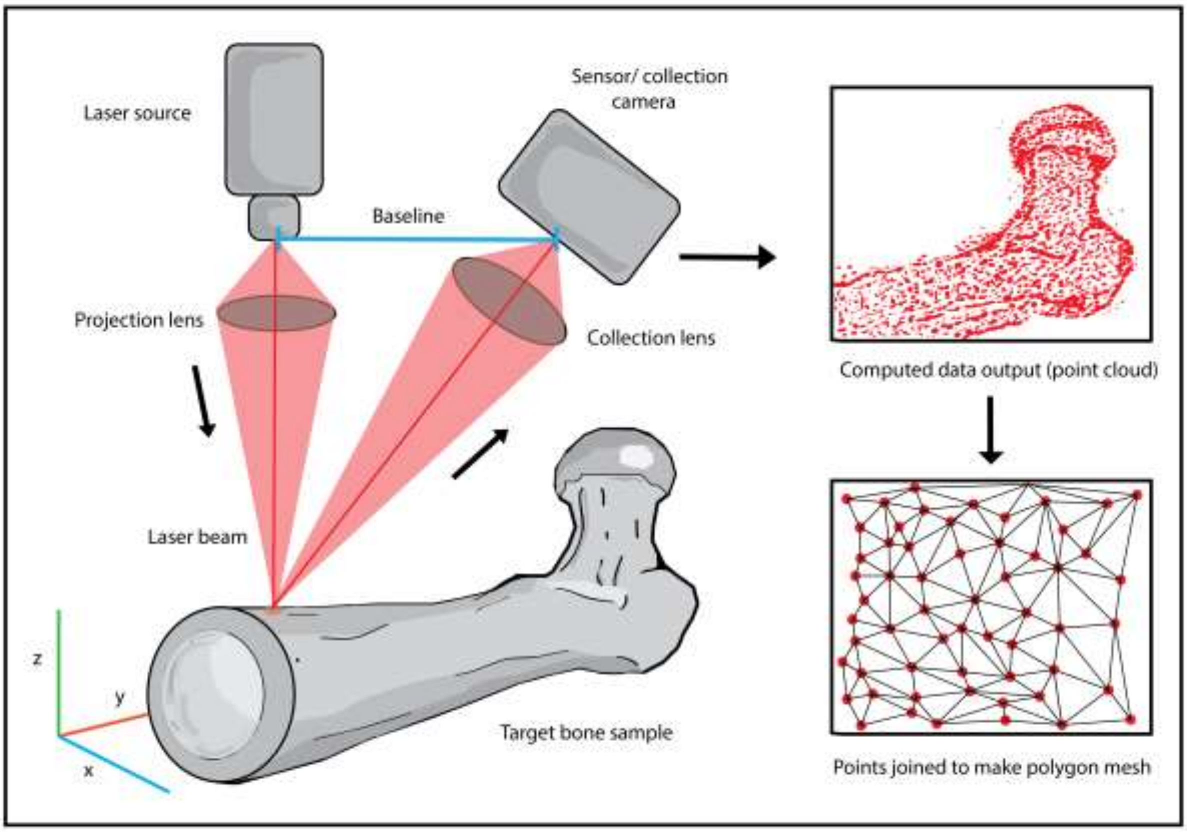

Figure 1: The recording method using a laser scanner

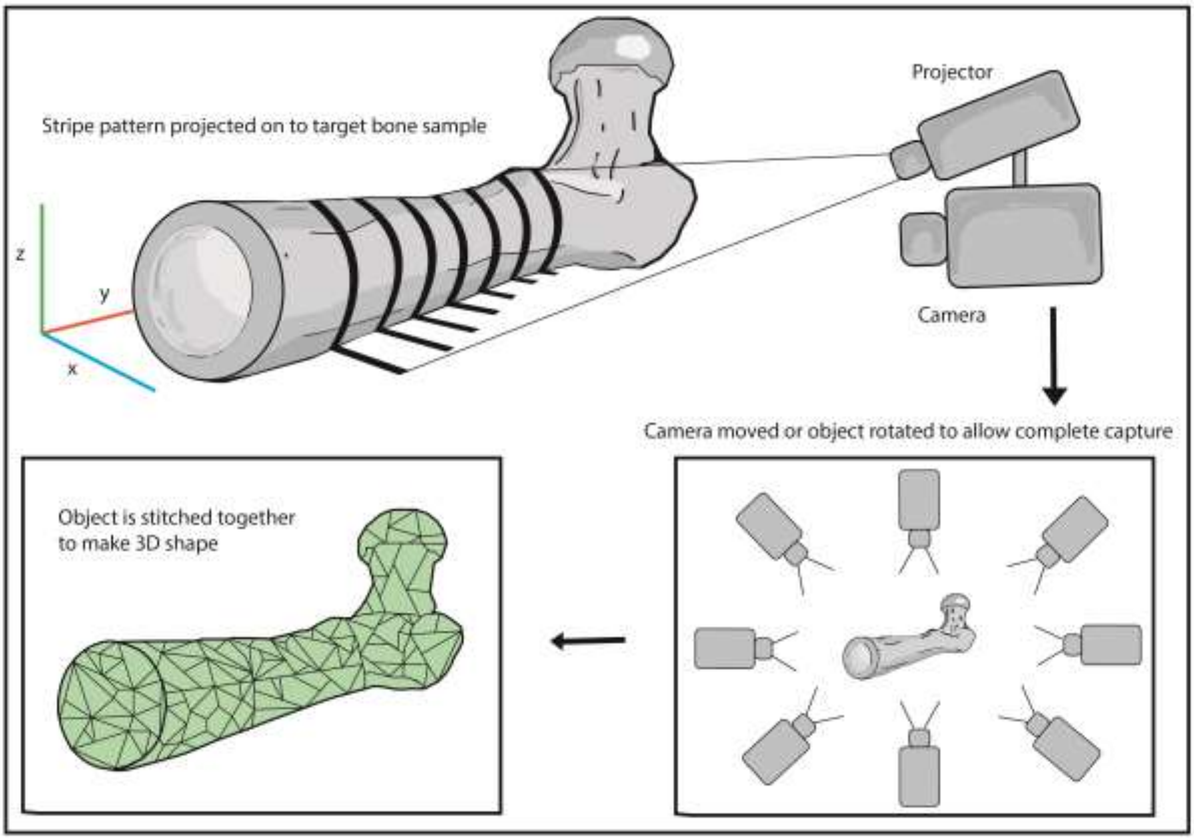

Figure 2: The recording method using a structured light surface scanner

Figure 3: An example of a 3D printed mandible showing specific male features at anatomical locations useful in anthropological assessment

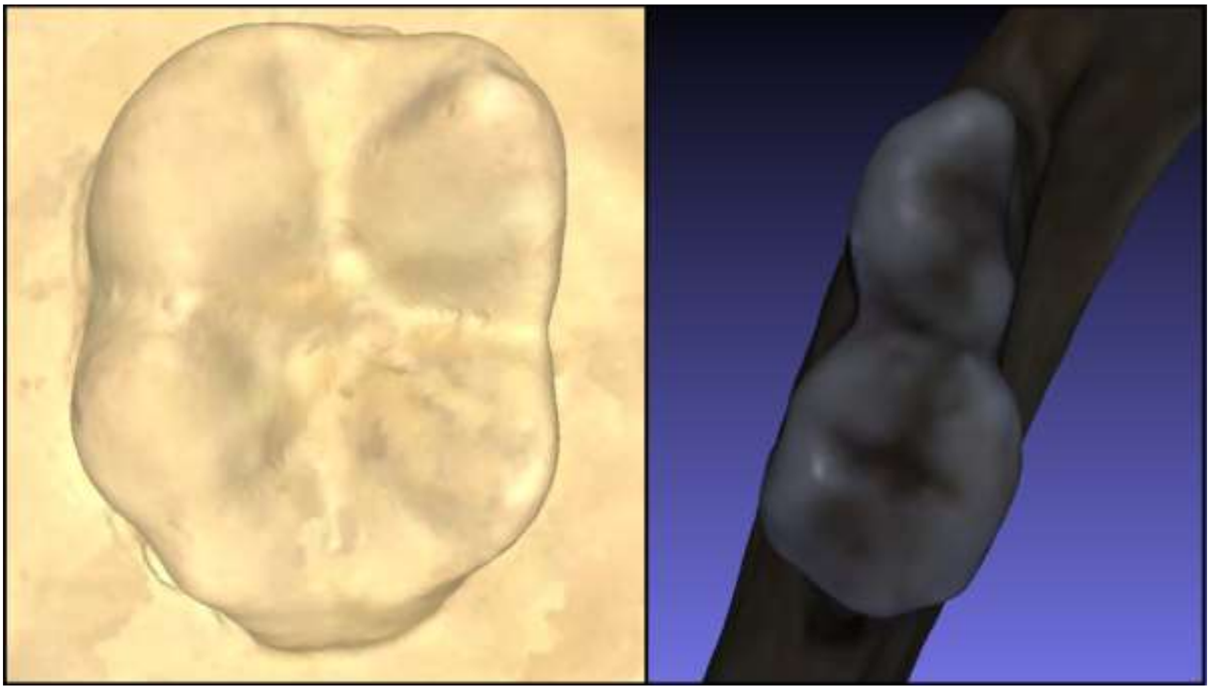

Figure 4: Comparison between a scan of an ASUDAS (Arizona State University Dental Anthropology System) dental cast made with a NextEngine laser scanner and a scan of a tooth made with a PicoScan structured light scanner. Although the result using the tooth is slightly less accurate than that using the cast, the structured light scanner allows faster data collection, and in many cases it may not be viable to make a dental cast