Roman Portraiture and Biometric Identification

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This project utilised three-dimensional scanning technology in the study of ancient Roman art and archaeology: Roman representations of faces executed in marble.

In the cultural heritage sector, three-dimensional (3D) scanning finds its primary application in documenting and reconstructing objects and structures mostly of simple geometry: bones, pottery, architecture or the imprint of whole archaeological sites (Adolf 2011). In forensic science, the face is interesting from investigative and probative perspectives, including both recognition and identification. Biometric methods of facial recognition have been part of a plethora of computer science-based applications used in the verification of identity (Davy *et al*. 2005, Goodwin, Evison and Schofield 2010).

The aim of this initial project is to provide objective relevant measurements of key facial features from the two ancient Roman portrait statue three-dimensional scans, which will allow the delineation of relationships between individual portraits including formal and stylistics aspects. The work described in this paper proposal is truly multidisciplinary, it touches on many fields including : Classical archaeologies (specifically ancient art history in the period of the Roman Empire 31BC – AD400), Forensic Anthropology (specifically physical anthropology and human osteology, Facial Biometrics (specifically uniquely recognising humans based upon their intrinsic physical traits and features) and Computer Science and Statistics (specifically the analysis of large complex multi-dimensional data sets).

Visualising ideas and concepts. Imaging and images in museums and galleries. Reconstructive archaeology and architecture. Visualisation in museums. historic sites and buildings. Technologies of digitization. 2D, 3D and high definition imaging.

1. PRESERVING CULTURAL HERITAGE

In the cultural heritage sector, three-dimensional (3D) scanning and modelling technology can provide a more efficient and objective alternative to the traditional practices of curatorial engagement used for this evidence such as drawing, photography and model-building; and it thereby yields considerable benefits for current curatorial practice and serves as a route for sustainable custodianship, reproducing objects in a non-invasive, quick and cost-effective way (Beraldin *et al.* 2002, Finat *et al.* 2005, Pavlidis *et al.* 2007). It helps to protect the originals by making copies available for scrutiny and, in cases where individual objects are displaced from the site of their origin, to reunite them within original context, digitally or in hard-copy (Roy and Schofield 1999).

A number of researchers have examined the technologies in use to record cultural heritage digitally – extensive surveys are given in Dekeyser *et al.* (2003) and Patias *et al.* (2006). These note the multidimensional processes mostly chosen, with techniques and equipment highly dependent on the nature of the relevant object to record and the purpose of its recording (Pavlidis *et al.* 2007). Currently laser scanning is the recording technology most prevalent in the cultural heritage sector. However, its widespread application for the creation of models is impeded by two factors:

(a) The high cost of the equipment required, notwithstanding the fact that cheaper systems are now entering the market (El-Hakim *et al.* 2004, Sansoni *et al.* 2009); and

(b) The complexities around handling the technology. In order to produce meaningful results, skilled personnel is required (Sansoni *et al.* 2009) Yet again, future trends may potentially lead to an overall simplification of the acquisition procedures, rendering system usage accessible to semi-skilled operators (Dekeyser *et al.* 2003, Patias *et al.* 2006).

Most of the existing archaeological applications of three-dimensional computer graphics technology has involved the visualisation and reconstruction of large-scale ancient architecture (Guidi *et al.* 2008), including projects such as CyArk (2010), a non-profit organisation which collects, archives an provides open access to digital data mainly acquired by laser scanning of cultural heritage sites across the globe. Other well-known projects in this field include a reconstruction of the Parthenon (Stumpfel *et al.* 2003); a Roman theatre (Finat *et al.* 2005); and a Byzantine crypt (Beraldin *et al.* 2002). Most of the researchers in this field agree that it is difficult to achieve an experience for a virtual viewer that matches confrontation with the original. However, the virtual experience has the potential to open new roads, leading to new forms of representation for the heritage sector, and in archaeological and art-historical analytical practice more generally: representations which will facilitate new forms of visual and intellectual appreciation of sites and objects (Stumpfel *et al.* 2003).

A number of attempts have been made to scan important historical objects (Roy and Schofield 1999, Patias *et al.* 2006). A striking example involving statues is the Digital Michelangelo Project (Levoy *et al* 2000), in which a range of Michelangelo's sculptural works has been scanned, including the David. Other similar projects aim to create high resolution scans of Danatello's Maddalena (Tucci *et al.* 2001); the Minerva of Arrezo (Rocchini *et al.* 2001); the Vittoria Alata (Sansoni and Docchio 2004); and the Statue of Liberty, now a digital heritage site (Leica 2012) and a number of statues have been scanned by the Digital Sculpture Project (2012).

There are several advantages to this methodology of recording statues and artefacts through the means of three-dimensional laser scanning:

- Verification of the state of the artwork in order to facilitate a restoration process with minimal error as well as to monitor changes over time.
- Multiple simulations of possible outcomes that would occur to the artefact from restoration as well as digital reunification of fragments.
- Accurate models may provide measurements for replication of the original artefact.
- The models may be used for public display and publicity in a 'virtual' museum.
- The creation of databases that can be used for comparative studies of historical art.

To date, there has been limited work undertaken in the final category above. This project investigates a completely novel application of the three-dimensional laser scanned data: namely the use of forensic science techniques (specifically facial biometrics) to compare individual scanned artefacts.

2. FACIAL BIOMETRICS

As populations around the world increase and transportation becomes more accessible, the social demand for fraud control and the need to authenticate individuals within large databases becomes more necessary. Facial identification is an increasingly important part of forensic anthropology and is currently one of the fastest developing biometric technologies. This is partly driven by the ubiquitous use of Closed-Circuit Television (CCTV) as a security device and as evidence of criminal activity. However, facial identification is also the most controversial of all biometrics (Jarvis, 2004).

A facial biometric system is a tool for identifying patterns of an individual's face that may verify their identity from physical attributes. Over the years, as technology has developed, three-dimensional scanning has become of more interest in regards to facial biometrics. Facial landmarks can be place on the curvatures of the scanned three-dimensional model of a face and measured from point to point. (Moreno *et al.* 2003)

2.1 Facial Biometric Techniques

There are three main methods of facial identification: morphological comparison of facial features, superimposition and anthropometrical analysis (Goodwin, Evison and Schofield 2010).

- The morphological comparison technique applies a classification of facial regions (e.g. eyes, eyebrows, nose, lips and ears). Research in this area includes work by Iscan (1993) and Vanezis *et al.* (1996).
- Superimposition techniques generally assess two facial images (photographs, video or a combination of the two). Early superimposition techniques required that facial images are taken from exactly the same orientation (Vanezis and Brierley 1996 and Maples and Austin Smith 1992). More recent superimposition techniques, developed by Yoshino *et al.* (2000, 2001) do not adhere to this restriction.
- Facial anthropometric analysis usually consists of quantitative measurement of facial images, based upon anthropometric landmarks located on the face. A standard 47 surface anthropometric landmarks of the face that can be identified on direct clinical examination have been defined previously by Farkas (1994).

Innovations in three-dimensional modeling software and research into novel algorithms for

measurement from two-dimensional images have led to extensions of these techniques being developed, including (Evison *et al.* 2010):

- Photomodeler® software has been used as an identification technique of faces from CCTV images by Lynnerup *et al.* (2003).
- Meunier and Yin (2000) analysed the accuracy and precision of a two-dimensional image-based anthropometric measurement system.
- Work by Naftel *et al.* (2002) focused on the development of an automated process to analyse facial morphological changes, using a stereo-photogrammetric imaging system.
- Yoshino *et al.* (2005) developed a retrieval system for a three-dimensional facial image database.

2.2 Facial Biometric Algorithms

Because shape is such an important element of accurate three-dimensional scans, the understanding and analysis of shape is necessary as the basis of any analysis of similarity. Both the concept of shape and measurements of the landmarks on a face are necessary for the method of aligning two objects for analysis. By shape, it is meant that "All the geometrical information that remains when location, scale and rotational effects are filtered out from an object". A Euclidean similarity transform (Ross 2004) removes the unnecessary information of the object while retaining certain geometric properties, such as the angles and parallel lines of the shape itself. This is called.

There have been many algorithms which have been used and developed from the research based on these facial identification methods. One of these is Principle Component Analysis (PCA), a technique that diminishes the amount of variables in a large data set and attempts to reduce redundancy within those variables. Redundancy, in this context, implies that there are variables which are correlated with each other because they are measuring the same object. These variables can be reduced in number and fitted into a smaller set of principle components, which are essentially artificial variables, that will explain a significant amount of the variance in the observed variables. (Moon and Phillips 2001)

A Procrustes analysis can then be used for analysing the shape, the method uses "isomorphic scaling, translation, and rotation" in order to fit two or more landmarks on a given shape. It is a mathematical fit of two areas on an object. This has advantages for shape analysis and is also useful for measuring objects of similar alignment, like a face for instance (Ross 2004).

2.3 The IDENT Project

One of the most important recent developments in the field of facial biometrics was the IDENT project which was led by the Federal Bureau of Investigation (FBI). Two of the authors of this paper (Dr. Schofield and Dr. Davy-Jow) were part of a team working on a large ($1.2m) US government grant, the IDENT project (TSWG – T-216E), to undertake work on computer-assisted facial comparison and identification. Over 3000 members of the UK public had their heads scanned using a range of scanning technologies (including laser scanning, photogrammetry and structured light); their features were analysed and the results added to a large database of three-dimensional facial measurements (Goodwin, Schofield and Evison 2010). This project developed novel methods of computer assisted evidential facial comparison that provide a benchmark for the understanding of human facial variation. The work involved extensive statistical analysis of the variation in these three-dimensional facial measurements and the development of novel algorithms for making comparisons between faces. The project results offer courts high quality statistical forensic evidence as to whether a suspect can be excluded or included as an offender via an associated facial match probability (Schofield 2011, Evison and Vorder Bruegge 2010).

It can be seen that effective and accurate solutions to three-dimensional facial analysis could be beneficial to many disciplines, not just forensic facial identification, but it could also be applied, for example, to medical applications (Encisco *et al.* 2003) and, as the authors will demonstrate in this paper, archaeological problems.

3. THE SANCTUARY OF DIANA AT NEMI

Nottingham and Nemi, the two places (one in the Alban Hills south of Rome, the other in the East Midlands of the United Kingdom) became intertwined in history through the workings of Sir John Savile, British Ambassador in Rome and first excavator of the site of the Sanctuary of Diana at Nemi in 1886 (see Figure 1). When Savile dropped his excavations after only two months, in a furious feud with the Italian landowner, he took his finds back to his home in Rufford Abbey, near Nottingham; and upon his death, they were given to the Nottingham City Castle Museums & Galleries, where they remain to this day (Lorenz, Schofield and Noond 2006).

In 2005/6, a team consisting of Dr. Schofield, Dr. Lorenz and Ann Inscker (the curator at the Nottingham museum) started a project related to artefacts from the Sanctuary of Diana at Nemi. Initially the team designed a website (Figure 2)

populated by content which put emphasis on issues around reconstruction, on deriving interpretation from material evidence, on competing interpretive narratives, and on recreating the potential atmosphere of a site such as the Sanctuary of Diana, devoted to worship and sacrifice, health, and the more mundane needs of self-representation (Lorenz, Schofield and Noond 2006, Lorenz 2007, Lorenz and Bligh 2010).

Figure 1: *The Site of Nemi and Artefacts Found There.*

Figure 2: *The Nemi Website and Site Reconstruction.*

This led to three-dimensional computer models of the temple at Nemi being created to interactively visualise different pathways for interpretation by the online museum user (Figure 2). Typically such models are glossy and hermetically sealed representations of the site. Instead, the model maps the uncertainties of reconstruction and multiple interpretations of the individual features of the site. The model confounds the notion that three-dimensional historical reconstructions are absolute, and facilitates user engagement with the fluidity of historical interaction and its modern interpretation (Lorenz, Schofield and Noond 2006).

3.1 The Statues of Fundilia Rufa

The work creating digital representations of the site led to interest in scanning and analysing some of the Roman portrait statues from the Sanctuary of Diana at Nemi.

Recently, Dr. Lorenz has laser scanned two representations of Fundilia Rufa (Figure 3), the herm (sculpture with a head) statue in Nottingham, UK and the full-body statue in the Ny Carlsberg Glyptothek in Copenhagen, Denmark. Both statues were found with a group of other pieces, including herms of non-imperial individuals of Claudian date and the full body statue of the dedicant of the whole, Fundilius Doctus; and they were found in a room in the Sanctuary of Diana at Nemi (Lorenz, Schofield and Noond 2006 and Lorenz 2007).

Figure 3: *Fundilia (left : Nottingham Museum and right : Ny Calsberg Glyptothek, Copenhagen).*

4. METHODOLOGY

This project was undertaken in a number of distinct work stages. Whilst interdependent throughout, the thematic focus of these stages varies, thus requiring both specific expertise from individual team members and collaborative work of the whole team in all stages of the project.

4.1 Preparing Data Sets

The scanning was conducted with a Faro V3 laser scanner, connected to a Faro Quantum 7-joint, 1.8m scan arm (Figure 4), the software used for acquisition and editing was Polyworks V11 (© Innovmetric 2012). The reach of the scanner can be extended by mounting it onto fixed objects or tripods, and by scanning in individual batches from different points, to be 'stitched' together later. Both statues were scanned section by section from various positions (Figure 5).

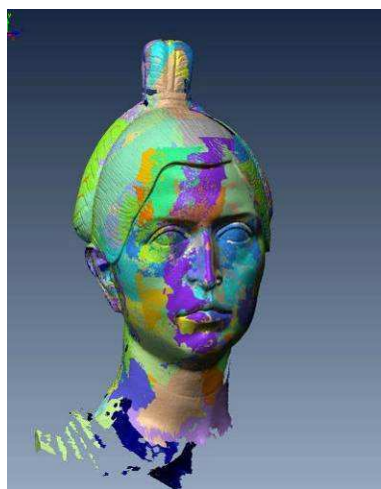***Figure 4:*** *Scanning the Nottingham Fundilia Statue.*

Figure 5: *The Nottingham Fundilia Portrait Scan.*

4.2 Forensic Measurement

This part of the project involved undertaking a range of biometric measurements on the three-dimensional laser scans with consideration given to potential errors and comparisons with other measurement techniques. Each of the heads was landmarked with a complete set of anthropometric landmarks in x-y-z space using 3DS Max software (© Autodesk 2012). During the IDENT project a set of 30 anthropometric landmarks demonstrating the most variation was determined (taken from a larger set of 62 points) for the analysis of patterns of three-dimensional face shape variation (Morecroft *et al.* 2010). These are the landmarks that were used for the analysis of the Roman portraiture. Distance and ratio measurements were taken from all of these landmark sites on each face.

The team is certain that this will be the first time anything of this nature has been attempted on Roman portraiture. The land-marking system can deal with heterogeneous data as defining different versions of one individual face; and the aim is to express the relationship between individual faces in precise mathematical terms (Schofield 2011).

4.3 Statistical Analysis

This stage primarily involved a statistical analysis of experimental data generated during previous work packages. Initially this work has focussed on an intra-group comparison of the measurements taken from the three-dimensional face scans.

Three-dimensional matching and alignment algorithms (running in sagittal and transverse planes) were used to remove differences attributable to translation and rotation, and to reveal any underlying differences in size and shape between the scanned facial models. After registration, a Principal Components (PC) analysis of size and shape was carried out by decomposing the sample covariance matrix (Goodwin, Evison and Schofield 2010). This allowed objective relative ratio comparisons to be performed on the three-dimensional scanned models; in particular focusing on measurement and observer errors within the data (Morecroft *et al.* 2010).

Centroid size was used as a size measure (the square root of the sum of squared Euclidean distances from each landmark to the centroid). A true shape distance was used to measure the distance between shapes where position, rotation, and scale are ignored. Root mean square shape distance was then used to measure shape variability in the sample where location, rotation, and scale will again be ignored. The root mean squared distance is approximately equal to the root mean square distance of individual shapes to the overall mean shape after scaling to unit size and alignment registration (Evison *et al.* 2010 and Schofield 2011).

The primary aim of these processes was to discover relationships and detect discrepancies between the facial feature measurements taken from scans of the Roman portraits.

5. RESULTS

Thirty facial landmarks were placed on three-dimensional scans of two Roman statues and the coordinates mathematically analysed. The aim was to provide objective relevant measurements of key facial features from the two scans, which will allow the delineation of relationships between the individual portraits including formal and stylistic aspects.

The co-ordinates of the thirty facial landmarks plotted on the three-dimensional scanned models were imported into a statistical software package (MiniTab 16, © Minitab 2012). The statistical distance and spatial mean information relative to the three-dimensional coordinates of the anthropometric landmarks was then examined.

The X coordinate represents the position of the landmark on the transverse (X-Y) plane. The Y coordinate represents the position of the landmark on the coronal (X-Z) plane and the Z coordinate represents the position of the landmark on the sagittal (Y-Z) plane. The coordinates of the two models are represented by the following notations : the Nottingham scan (X1, Y1, Z1) and the Copenhagen scan (X2, Y2, Z2). The following sections will discuss the methods used in this initial study to analyse the statue scans.

5.1 Principal Components Analysis (PCA)

After manipulation using alignment algorithms, further analysis was then provided through a Principle Components Analysis (PCA) of shape and size by decomposing the sample covariance matrix. By sorting the coordinates into categories, PCA will accomplish two essential tasks;

- Determination of the qualities that are the most significant for identifying components and
- Combining components to reduce the number of variables.

The first component's eigenvalue (or variation descriptor) explains 55.7% of the variation between the two scans. This means that the first axis extracted a little more than half of the variation from the entire set (Table 1). These results indicate that X1, Z1 and Z2 are negatively correlated to Y1, Y2, X2. Notably, that X1 and X2 are inversely related. Essentially, any changes along the X1 and X2 axes will move inversely, changes along the Y1 and Y2 will move positively together but inversely with Z1 and Z2, which move positively together.

The second components eigenvalue explains 29.7% of the variation. This component indicates that the X1, Y1 and X2 are negatively correlated to Z1, Z2 and Y2 (Table 1). The most significant component loadings, Y1 (.588) and X1 (.409), indicate that the data on the traverse axis (X-Y) move positively in the same direction along component 1. Also worth mentioning, is that Y1 (.588) and Y2 (-.645) are inversely correlated, or, move in opposite directions.

Table 1: Eigenanalysis of the Covariance Matrix

Eigenvalue	6635.0	3542.9	1422.4	158.5	150.1	12.8
Proportion	0.557	0.297	0.119	0.013	0.013	0.001
Cumulative	0.557	0.854	0.973	0.986	0.999	1.000
Variable	PC1	PC2	PC3	PC4	PC5	PC6
X1	−0.412	0.409	−0.414	−0.590	0.378	0.012
Y1	0.217	0.588	0.291	−0.063	−0.201	0.691
Z1	−0.128	−0.009	0.724	0.006	0.675	−0.059
X2	0.410	0.253	0.290	−0.505	−0.277	−0.593
Y2	0.194	−0.645	0.060	−0.613	0.005	0.408
Z2	−0.749	−0.082	0.363	−0.130	−0.532	−0.015

Because multidimensional data is difficult to understand when viewed through a matrix (unless the viewer has a mathematical understanding of the data being presented), it is often easier to view the data through visual representation. One way to represent three-dimensional data is through the use of a histogram.

5.2 Histogram

The histogram displayed in Figure 6 illustrates the difference in density of coordinates for both Nottingham and Copenhagen statues. The density curves on the graph indicate a variation in the distribution of the coordinates, which represent a three-dimensional model. The spatial differential of the density plots further indicate that if the statue
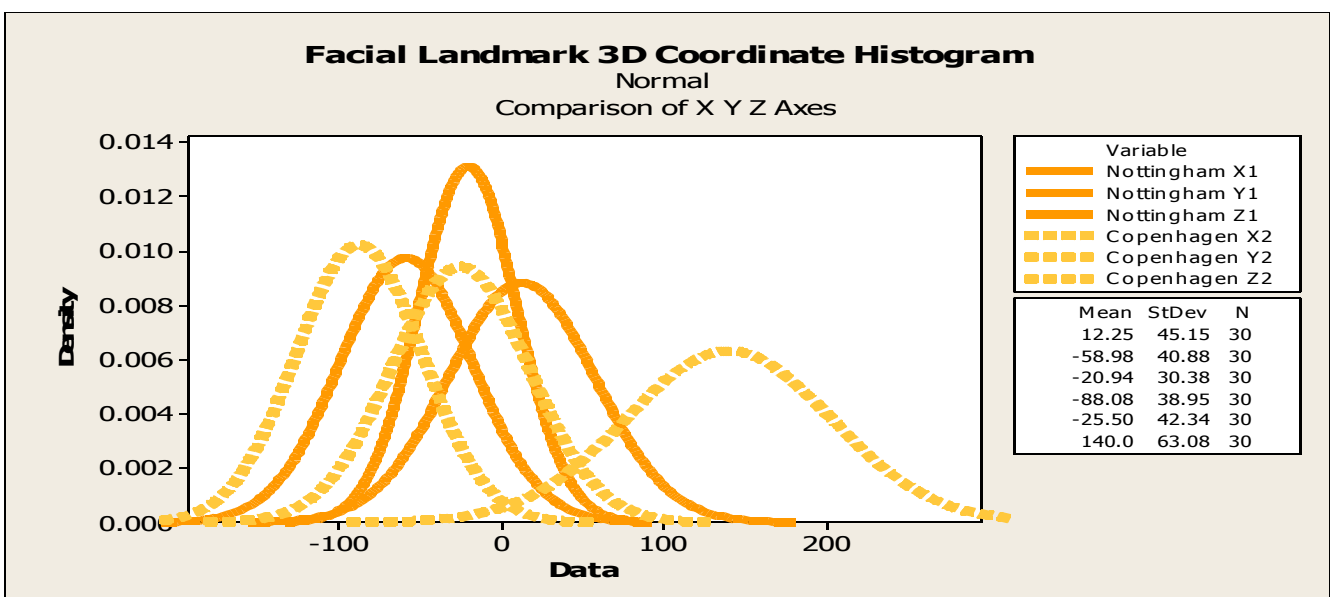

Figure 6. Facial Landmark Coordinate Histogram Comparing Nottingham and Copenhagen Statues.

heads were to be super-imposed, there would be significant discrepancy.

The histogram for these two data sets is useful for micro comparisons of facial landmark coordinate measurements. Alternatively, from a macro perspective, the data is a representation of the coordinate data, not the actual facial features. For instance, there is no visualization that constructs a mapping for the comparison of the noses or chins. This distribution of the frequency, is a representation of the coordinate density of the thirty selected landmarks in three-dimensional space. The layering and separation elements of the histogram allow for visual comparison of the data in the traverse (X-Y), coronal (X-Z) and the sagittal (Y-Z) planes.

The overall outcome of this work is that the variations in ranked measured differences suggest that the area of the eyes are highly similar in terms of relevant proportion and the areas of broader facial landmarks such as the ear or jaw have greater differentials. The tighter and more precise areas that are centred in the middle of the face tend to correlate positively whereas the broader areas have a more negative correlation.

6. CONCLUSIONS

The examination of the two portraits by means of laser-scanning yields certain benefits over traditional stylistic analysis, the mode of enquiry generally used in the study of ancient portrait sculpture: the relationships between the two representations can be mathematically quantified, thereby rendering stylistic analysis more transparent. At the same time, the outcomes seem to support the traditional view of the processes of Roman copying: that is, that artists concentrated specifically on the facial area around eye-brows, the nose and mouth in order to take a copy of a specific representation of an individual, whereas the other areas of the face were copied more freely. The next stage of the project will involve further analysis of the mathematical data and visual feature comparisons between the statues.

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