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DIGITAL ANTHROPOLOGY FOR EFFECTIVE RETRIEVAL OF THE ANTERIOR FONTANELLE

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ABSTRACT

Laser scan acquisition, reconstruction and size evolution measurement of the anterior fontanelle are presented for the private osteology collection of the chair of anatomy in the Faculty of Medicine at Strasbourg.

Two main results are presented. The first one regards the skull cap fixed error acquisition and reconstruction. The second one concerns the evaluation of the heterogeneity of the fontanelle closure processes.

Keywords: image processing, digital anthropology, morphometry, laser scanner acquisition, 3D object reconstruction.

INTRODUCTION

Digital anthropology provides powerful tools for investigations and "revisiting" existing studies and theories on human evolution and in particular on growth and development processes. The general framework of the current research is the application of the modern medical imaging techniques to the geometric morphometrics. In a more precise way, we are interested in retrieval of geometric computer models of anatomical shapes for some collection of specimens and the simulation of the geometric morphometric analysis through digital image processing.

In a traditional way Adams (2004), morphometrics uses a full arsenal of multivariate statistical tools to describe patterns of shape variation. First, sets of morphological variables including distances, distance ratios, and/or angles gathered to sample the shape of the object are identified. Next, multivariate statistical analysis typically including principal components analysis, factor analysis, canonical variates analysis and etc., is performed in order to determine shape differences and variations. Finally, the focus is put on geometric interpretation of the extracted patterns. The basic drawback of this approach is that pertinent geometric information about the biological structure of interest could be neglected. For instance, the same set of distance measures could be obtained from different shapes because the location of where the distances are made relative to one another is not included in the data. Moreover, graphical representations of the shape

is usually impossible to generate as long as the relative spatial geometric relationships are not preserved (sets of linear distances is often insufficient to capture the geometry of the original shape). Recently, a new track, called geometric morphometrics, Slice (2005), emerged. Object shape is defined in terms of functional and geometric shape features using homologous sets of outlines and landmarks. Using 3D contact laser digitizers scanners and/or Computer Tomography scanners, digital images of specimens are produced including precise outline and landmark positions. This makes possible registration and multivariate analysis of curves and regions on the input objects and thus supporting the 3D reconstruction and the visualization of the shape and size variation. Our long-term aim is to further take advantage of modern techniques in range image acquisition, segmentation and reconstruction Rusinkiewicz *et al.* (2002). Indeed, till now all the morphometric measurements are applied on the registered outline and landmark positions. No morphometric analysis is performed on the reconstructed image of the initial object shape as a whole. For this purpose, the entire pipeline from the data acquisition to the image reconstruction and the shape and size variation calculation should be refashioned. A new research field, we call **digital morphometrics**, could emerge and make possible to perform morphological studies as analysis on different types of supports such as collections of specimens, real or synthetic objects or computer geometric models, for different types of shape features as distances, angles, outlines, landmarks, surface or volume features, according to different types of metrics as euclidean

metrics Hildebrandt *et al.* (2005), geodesics metrics Surazhsky *et al.* (2005) or multivariate statistical metrics Slice (2005).

An immediate application of this approach will be experienced in the current research for the paleoanthropology investigation of the anterior fontanelle. Four intermediate stages are identified:

- Object feature definition defining the anterior fontanelle.

In this phase, depending on the geometric properties of the anterior fontanelle the morphometric relevant data are specified following familiar to physical anthropologist expertise. The purpose is to establish the best object orientation for the subsequent data range acquisition and registration of the chosen morphometric outlines and landmarks.

- Data acquisition and anterior fontanelle reconstruction.

The acquisition of the object boundary is done using surface laser scanner Synave *et al.* (2008a). The registration produces a computer geometric model of the anterior fontanelle in the form of triangular mesh model.

- Digital morphometric analysis.

At this point, the digital morphometrics analysis starts up with interactive landmark editing. Outlines are brought forward for inspection in order to readjust their positions. Morphometric data measurements are performed according to a chosen protocol using chosen metrics and applied on chosen shape features of the computer geometric model. Multivariate statistical shape analysis is performed using geodesic discrete distance measurements in the reconstructed range images Synave *et al.* (2008b). The underlying basic idea is to assess geodesic shortest path (in contrast to linear distance Euclidean shortest path) and using a discrete Gauss curvature evaluator Surazhsky *et al.* (2005).

- Reproduction and validation of the results.

The visualization of the numerical model along with the map of geodesics path delimiting the morphometric data in use is generated in order to obtain visual control of the shape feature relocation and the shape and size variation. Further, a result validation step is foreseen based on comparison of the calculated numerical rates with known evaluations of the considered morphometric data.

Each of these items will be developed in the following sections. First the specimen collection

supporting the present study of the anterior fontanelle and the corresponding morphometric characteristics will be considered. Next, the experimental platform and the digital morphometric analysis will be examined. Further, the quantitative results will be provided and finally the entire retrieval pipeline will be discussed.

JUVENILE COLLECTION OF STRASBOURG

The juvenile human skull collection housed in the chair of anatomy in the Faculty of Medicine at Strasbourg is under the responsibility of Professor J.-L. Khan. The specimens were prepared by anatomists between 1872 and 1918. Half of the specimens were born in Strasbourg, 34% in Alsace or bordering regions and the rest came from Germany. Biological data are available: sex is known for most specimens and calendar ages are known with a precision of one month, one week or sometimes one day.

Previous investigations of the osteology collection of Strasbourg could be found in Rampont (1994).

In the current research the studied sample of specimens is presented in Table 1 with respect to specimen sex distribution in the interval from 0 to 3 years. The specimen sex is denoted as *F* for female, *M* for male and *I* for indeterminate. The integer digits correspond to the number of specimens for each sex composition.

Age	Sex		
	F	M	I
< 0 year	0	0	1
0 year ≤ age < 0.5 year	6	5	4
0.5 year ≤ age < 1 year	3	3	1
1 year ≤ age < 1.5 years	2	1	2
1.5 years ≤ age < 2 years	1	1	0
2 years ≤ age < 2.5 years	5	1	0
2.5 years ≤ age < 3 years	1	2	1

Table 1. Studied sample of the Strasbourg juvenile collection

OSTEOLOGY OF ANTERIOR FONTANELLE

SHAPE FEATURE DEFINITION

The frontal bone is ossified from two primary centers, each half of the bone ossifies from a single

center which appears between 6 and 7 weeks of the fetal life and is situated above the supra orbital margin as illustrated in Fig. 1. From each of these centers, ossification extends upward to form the corresponding half of the squama, and backward to form the orbital plate. The spine is ossified from a pair of secondary centers, on either side of the middle line. Similar centers appear in the nasal part and the zygomatic process. For details see in Scheuer and Black (2000). At birth the frontal bone is composed of two pieces, which are separated from each other by the metopic suture. They are also separated from the parietal bones by the diamond-shaped anterior fontanelle. This membranous gap allows the development and the growth of the brain and the skull. From a sample of 138 known-aged children, it has been suggested Coqueugniot (1999) that the oldest child with an anterior fontanelle was around 2.5 years old. Even if the correlation with age is not so high, the closure of the anterior fontanelle was used, along with the feature of the inner ear, to estimate the age of death of the Mojokerto *Homo erectus* infant Coqueugniot *et al.* (2004).

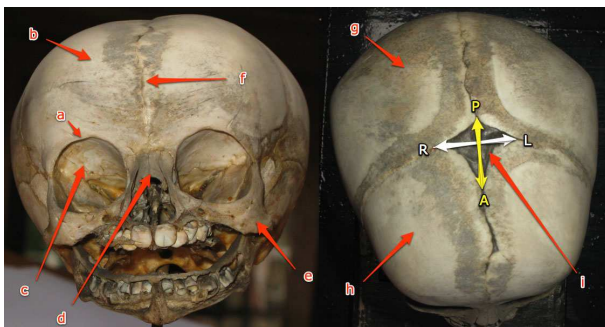


Fig. 1. Specimen "CV0" (a) Supra orbital margin (b) Squama (c) Orbital plate (d) Nasal part (e) Zygomatic processes (f) Metopic suture (g) Parietal bone (h) Frontal bone (i) Anterior fontanelle

In order to evaluate the anterior fontanelle shape the following feature measurements are retained:

– Antero-posterior arc

The antero-posterior arc is the arc between the points A and P respectively the "antero-most" and the "posterior-most" extremities of the membranous gap along the axis delimiting the contact between the right and the left halves of the skull. The illustration is given in Fig. 1. The length of the antero-posterior arc is also measured manually with a millimeter band along the skull surface.

– Transverse arc

As shown in Fig. 1, the transverse arc corresponds to the arc between the points R and L respectively the rightmost and the leftmost extremities of the membranous gap along the axis delimiting the contact between the parietal and the frontal bones. The length of the transverse arc is measured manually with a millimeter band along the skull surface.

– Antero-posterior chord

The antero-posterior chord is the straight line joining the ends of the antero-posterior arc. The length of the antero-posterior chord is also measured manually with an electronic caliper.

– Transverse chord

The transverse chord is the straight line joining the ends of the transverse arc. The length of the transverse chord is measured manually with an electronic caliper.

MORPHOMETRIC EVALUATION OF THE ANTERIOR FONTANELLE

In the present research, reported results deal with the inter-observer variability of the antero-posterior (AP) and the transverse (RL) chord and arc length evaluation. Standard deviation calculation, abbreviated as *Stdev*, for both chord and arc length measures is illustrated respectively, in Fig. 2 and Fig. 3. The values of *Stdev* in centimeters is given along the vertical axis while along the horizontal axis the specimens are enumerated. The first observation is that chord measures are more precise than the arc ones. Indeed, according to our experience it is very difficult to position the millimeter band on the skullcap surface. Often, the skullcap is damaged, moreover the anterior fontanelle is a gap in the surface and thus the surface curvature evaluation over it is roughly approximated. Second, as one can see, in both chord and arc measures the medio-lateral length along the RL axis is more accurately evaluated than the antero-posterior distance along the AP axis. Finally, the threshold of 3mm of the *Stdev* emerged as a good confidence interval approximation: for chord measures the population under this threshold is 91,2% while for the arc measures 80% of the evaluated features do not exceed this threshold.

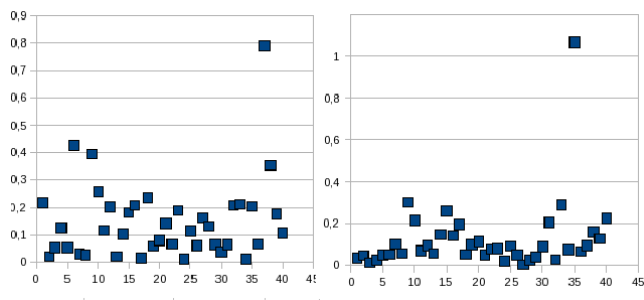


Fig. 2. Standard deviation of inter-observer chord morphometric measures of: AP (left) and RL (right)

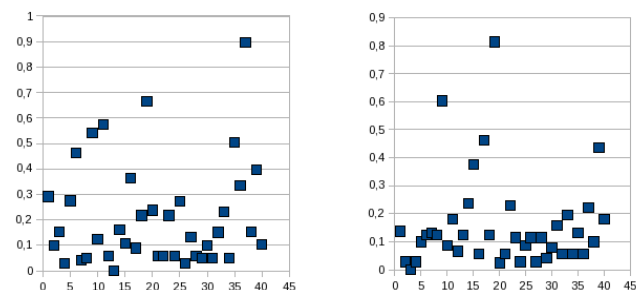


Fig. 3. Standard deviation of inter-observer arc morphometric measures of: AP (left) and RL (right)

DATA ACQUISITION AND RECONSTRUCTION : MATERIAL AND METHODS

EXPERIMENTAL PLATFORM

Our experimental platform is based on a low cost portable 3D laser scanner, the Minolta VIVID300. The basic advantage of this device is the greatly facilitated 3D model acquisition as well as the fact that this scanner is easily transferred in altered circumstances for the study of specimen collections "in situ" in the museums and thus preserving the exhibition original pieces. The drawback of this acquisition device is the limited acquisition resolution that necessitates a more careful post processing of the reconstructed mesh models. This post processing, all the numerical measures and the visualization are performed on an Intel Pentium4, 3GHz, 1Go RAM using our own software package Synave *et al.* (2008a).

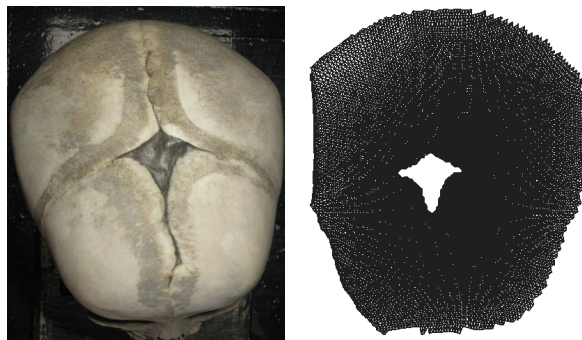


Fig. 4. Specimen "CV0": original (left) and numerical model (right).

DIGITAL MORPHOMETRIC ANALYSIS

As a result of our acquisition and reconstruction pipeline, numerical models of the anterior fontanelle for the osteological collection are produced. An illustration for the specimen CV0 is given in Fig. 4. On the next stage of the processing AP and LR chords are measured as euclidean distances between vertices of the supported triangular mesh models. Each vertex is situated in chosen skull landmark position. Again, inter-observer measurement variation is evaluated. The standard deviation of the AP and LR length chord measures is given in Fig. 5. The first observation that can be made is that confidence interval is much tighter: the Stdev of 95, 6% of the specimen population is under 1, 6mm. Further, as for the physical morphometric evaluation the RL length measures are more precise. Last, the numerical model allows a more reliable landmark position identification.

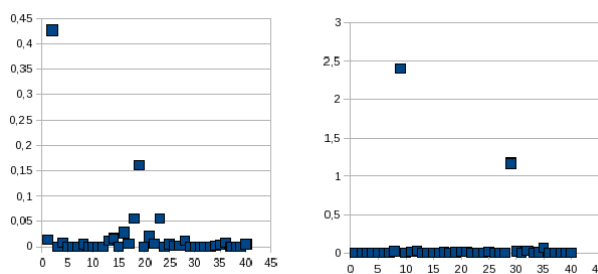


Fig. 5. Standard deviation of inter-observer numerical measures of: AP (left) and RL (right)

REPRODUCTION AND VALIDATION OF THE RESULTS

In order to validate the digital analysis, numerically calculated distances are compared with

their physical counterparts. For the moment, only the similarity of the AP and RL chord measures is exploited. In 78,2% of the specimen population the *StDev* between physical and numerical length measures is under 5mm as it is shown in Fig. 6. In almost all cases with *StDev* out of this range the numerical estimation error is owed to damaged original skull surface that mislead the laser scan acquisition and thus the posterior object reconstruction. This results gives us the opportunity to further exploit the digital analysis using 3D impressions of the initial shapes. According to our experience the minimal thickness of printable offset surfaces corresponding to numerical representations of the osteological surfaces are within the same range i.e. 5mm.

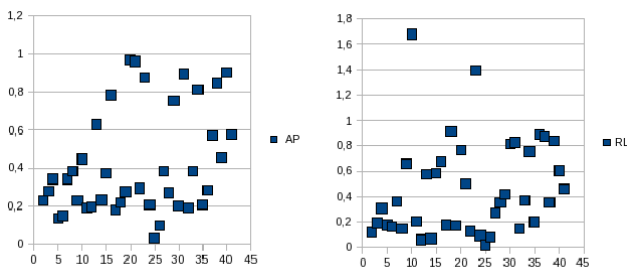


Fig. 6. Standard deviation of inter-observer chord morphometric measures of: AP (left) and RL (right)

CONCLUSION

Feature definition is a primordial factor in object retrieval. Depending on its size, shape and position on the object, the data acquisition process could produce invalid results. Furthermore, the validation of the object reconstruction is determined on the ability to perform reliable morphometric measures. The present study contributes to both digital image processing and digital anthropology. Concerning the image processing, we propose an osteology surface reconstruction within a fixed reconstruction error. Regarding the anthropology domain, we notice that the ossification is not homogeneous in the fontanelle closure processes: the medio-lateral axis seems to be predominant over the antero-posterior one. This last assumption needs further experimentation as well with respect to an enriched osteological database as more accurate digital morphometric evaluation. For the study of the anterior fontanelle we intend to include additional curvilinear measurements of the diamond lateral sides. Moreover we envisage to develop tools for repairing the reconstructed mesh model as the constrained hole filling that maintain

surface curvature. Digital morphometric analysis is in a "premature" stage as long as it is strongly related to the measurement error control all over the acquisition and reconstruction pipeline. 3D object reconstruction becomes an integral part of current computer graphics applications but the development of efficient retrieval methods with certified reconstruction error range remains a challenge.

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