

DATA ACQUISITION POSSIBILITIES FOR FACE RECONSTRUCTION PURPOSE

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ABSTRACT:

A new multidisciplinary project extending over a number of years was initiated in Hungary to combine knowledgebases of different disciplines like anthropology, medical, mechanical, archaeological sciences etc. to computerize the face reconstruction.. A research group (*BME Cooperation Research Center for Biomechanics*) was formed representing several organizations that are cooperating during the project period. In this paper we will show the first results of our work: the examination of the possible data gathering methods from special aspects. First the data collecting method has to be able to produce geometric 3D data of the cranium of damaged/mummified subjects. Second, the software development requires huge dataset of 3D face and skull models, which could be produced from living persons, so the method have to be capable to mass data collection. Since any modification of the process during the gathering period can result inhomogeneous database, the accuracy and the feasibility of the measuring methods is highly important.

1. INTRODUCTION

Facial reconstruction is the process of reproducing the geometry of faces of unidentified persons from skeletal remains. Recently the most widespread face reconstruction methods are used by highly qualified and experienced anthropologists and based on artistic tools supported by scientific methods. (Kustár, 2004) The first step is anthropological investigation, by which the anthropologist estimates the age and sex of the person, observes individual characteristics, possible illnesses and injuries, and carry out morphometric measurements on the cranium.

The reconstruction usually starts with making a gypsum copy of the skull. The thickness of soft tissues at the most important anthropological landmarks is estimated based on the roughness of the bone surface and/or on statistical data. The mimic muscles are made of plastilin or clay, the eyes are of marbles and the nose is formed from paraffin or wax. (Figure. 1.)



Figure 1. . Basic steps of face reconstruction (Kustár, 2004)

In the last decades more and more researchers turned to computer technology to make the reconstruction process easier and more reliable. Virtual 3D models of a face can be modified, measured or compared easily, but the available face reconstruction softwares are still in their infancy. These softwares are modifications of common 3D modelling softwares but there are very limited or no facial data and anthropological relationship implemented in them – they are “virtual clay sets”, and for correct operation they still need the specialists’ knowledgebase and experience. The BME Cooperation Research Centre for Biomechanics aims to create a face reconstruction software based on statistical samples (3D face and skull models of 4000 living person) and guided by defined mathematical correlations between the skull and the face geometry.

2. ANALYSIS OF DATA GATHERING TECHNIQUES

The possible data collection technologies for face reconstruction (and for the software development for the same purpose) are: Computer Tomography, X-ray, different types of 3D scanners and photogrammetry. Combinations of the mentioned technologies are able to produce 3D models from dry and ‘living’ skulls, cadavers and living heads, mummies etc.

2.1 X-ray

Traditional X-ray is a possible technology for obtaining data for face reconstruction. To evaluate X-ray images reference points in the object space with known position are needed, and such points are mapped on the images in an identifiable and measurable manner. We designed an X-ray test field containing X-ray opaque point-type markers embedded in a material invisible for the X-ray.

Our previous research (Borbás, 2003; Fekete, 2008) suggested that the two-component, transparent resin, which is in semi-polymerized state during its production, is suitable medium for the markers (in the current case, small, steel balls with diameters between 0.1-0.5 mm). These markers will stay at their positions after the end of the polymerization of the resin and are suitable to become the points of the test network during the following tests. The thickness of the plates can be regulated and set to constant by the quantity of the resin used during the production. Figure 2 shows a larger plate (3) with markers (4) prepared for test on a smaller casting tray (1) and a precision water level(2), which ensures the equal thickness of the resin over the whole extent of the plate.

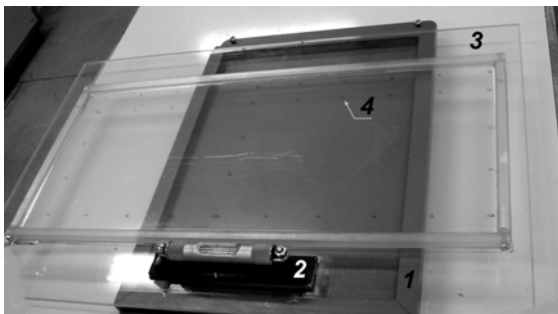


Figure 2. X-ray test-field

X-ray images were taken at the Radiology Clinic of the Semmelweis University. Slanted images were taken of the test field from four directions. Network design regulations for multi-stage convergent photogrammetric networks were taken into consideration for the shooting arrangement. (Fraser, 1996; Fekete, 2006). For X-ray the shooting distance does not play such an important role as in traditional photogrammetry. The test field used for shooting is shown in Figure 3.



Figure 3. X-ray test-field during shoot

To determine the image coordinates of analogue images a ZEISS PK-1 monocomparator was used. The object coordinates were calculated by a software based on Direct Linear Transformation algorithm and developed on our Department (Schrott, 2005).

Processing accuracy analysis is enabled by the fact that the real location of the markers in the resin plates as well as their coordinates determined by photogrammetry were both known. The interpretation of accuracy means how close the final result of calculation is to the "real" figure. Given that we have sufficient number of photogrammetrically perfect object-side points then the square sum of coordinate differences will provide a global picture on the accuracy of the procedure applied. Accuracy was characterised as an average difference of distances namely the square root of the aggregate of variances (σ). The resulted precision attributes with and without gross error filtering are summarized in Table 1. Figures in the table are in mm and mm^2 .

	σ_x^2	σ_y^2	σ_z^2	$\sigma = (\sigma_x^2 + \sigma_y^2 + \sigma_z^2)^{(1/2)}$
Non-filtered	0.0143	0.0145	0.0153	0.21
gross error filtered	0.122	0.0119	0.0121	0.19

Table 1. Accuracy analysis results of X-ray photogrammetry

2.2 Computer Tomography

Computer Tomography (CT) is an enhanced X-ray imaging technique, and it can produce 3D data very fast, that is highly important in case of mass data collection. The question was simple: is the resulting accuracy appropriate for our requirements? We have worked out protocols for both sequential and spiral CT devices to standardize the output of CT imaging. We designed a test to qualify the geometric accuracy of the CT imaging: distances of the same points were measured both on the skull and the resulted 3D model (Figures 4 and 5.). The RMS error remained within the range of 1mm both in the measurements of a skull and a cadaver head. Anthropologist experts evaluated this accuracy as sufficient for face reconstruction purposes.

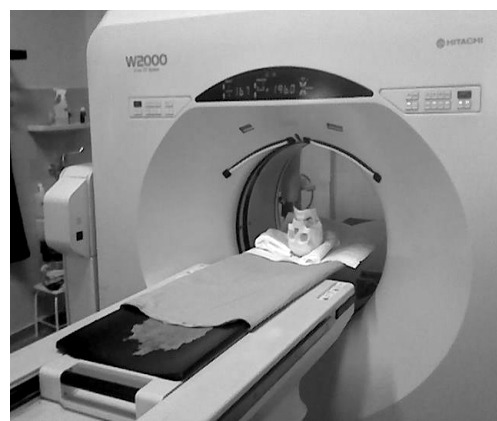


Figure 4. Skull in a CT device



Figure 5. Measuring the skull

Even though the soft tissues absorbs X-rays to a lesser extent, the geometric precision of the 3D model is only slightly lower than in the case of bony structures, therefore theoretically we can gain images of the face by CT. The reason we chose another method was that all of the CT devices we know works on lying persons facing upwards. This position causes the face distorted by gravity which in this case takes effect in different direction as usual. In special occasions (elderly or overweight persons), the difference of the face of a standing or lying person can be so large that the person is virtually unrecognizable.

2.3 3D scanners

Two different type of 3D scanner (a laser scanner and a structured light 3D scanner) have been examined. There are a wide variety of laser scanners available, for our purpose a triangulation-based lased scanner were chosen. Triangulation scanners have a limited range of a few meters, but their accuracy is relatively high, and they are useful for measuring small objects. The principle of this type of scanners based on the phenomenon that the laser beam reflection angle depends on the object distance, therefore the distance can be calculated by measuring the reflection angle (Figure 6.).

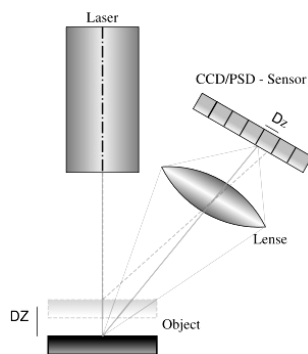


Figure 6. Laser range finder principle (from wikipedia.org)

There are two different methods to use laser range finders as a laser scanner: the range finder has to be actuated at known steps in front of the object, or the same must be done to the object. We have been using the latter: the BME Department of Vehicle Manufacturing and Repairing has a ScanTech laser range finder fitted to a CNC working table. X and Y coordinates were given by the movement of the CNC table, the Z coordinates were measured by the range finder.

These types of laser scanners produce high density point clouds from short distance, with high accuracy. (Figure 7.)

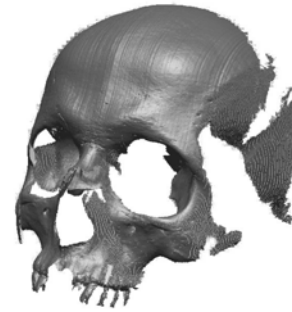


Figure 7. Laser scanned 3D model

A similar accuracy analysis as for the CT images was employed, and resulted almost similar RMS errors (about 0.3 mm) both on the scanned 3D model of a skull and a cadaver head (Figure. 8.)

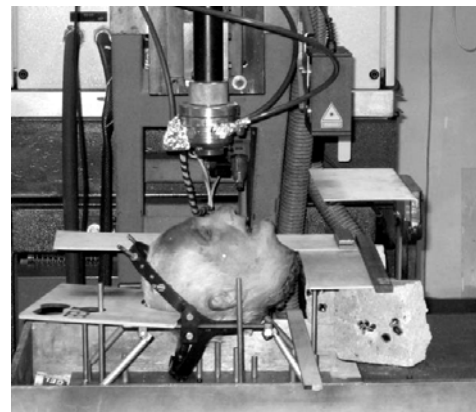


Figure 8. Cadaver head during scan

The only drawback is that the scanning process takes a long time with these instruments. As the scan of the cadaver head has taken 3 hours with our equipment, obviously this scanning method is inappropriate for scanning living people.

A faster and more versatile method to scan a surface is the usage of a structured light 3D scanner. Figure 9. shows the tested scanner (Breuckmann SmartScan).



Figure 9. Structured light 3D scanner

During structured light 3D scanning patterns of parallel light stripes are projected to the surface and a camera (or several cameras) captures the scene. From different viewpoints, the pattern appears geometrically distorted due to the surface shape of the object, and a pattern analysis and triangulation can recover the objects' 3D coordinates.

The accuracy evaluation of this scanner differed from those of previous methods, because the skull and the cadaver head were no longer available for us and a photogrammetric test-field was used instead (Figure 10.). The 3D model produced by the scanner combined from the overlapping point clouds of six scanning sequence, each of them covered a part of the test-field. The model coordinates has to be corrected by a scale factor. The resulted accuracy was characterized by the RMS error, which was 0.54 mm for the merged 3D model. Accuracy was about 20-25% better for each scanning part individually. This accuracy is considerable for our aims, but the multiple scanning procedure is not, because the complete immobility of the living subjects cannot be assured. Recently we also have been testing a scanner built for face scanning (Figure 11), which can generate 3D model in one step (approx. 4 seconds), but its accuracy is not yet calculated.

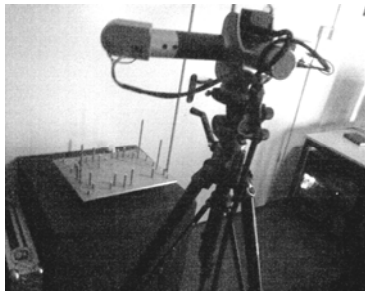


Figure 10. Test measure with the 3D scanner



Figure 11. Face scanner

2.4 Photogrammetry

According to the literature (i.e. Fraser, 1996) and our previous experiences (i.e. Tóth, 2005), we are nevertheless certain that photogrammetry can produce adequate 3D data by using a multi-station convergent photogrammetric network for face reconstruction. The most serious disadvantage of the photogrammetric method is the extreme time- and effort requirements of processing. Further investigation required to determine which part of the process can be automated (image matching, feature extraction etc.). We have been investigating a new image matching method based on colorimetric

measurements, because the common image matching algorithms seems to fail on the human skin as a texture.

There is another way to reduce the amount of required workforce. Obviously, the less manual measurement needs less time and workforce, so we provided an estimate of the needed point density and the useful distribution of the measurement points. The scanning methods mentioned above produces point clouds of 2-300000 points per subject. Most of these points are unnecessary, because these points can be interpolated from their neighborhood accurately enough. Basically high curvature parts of the face require high point density, almost plain parts require low density. A filtering method has been defined to achieve these requirements. (Varga, 2008) The method based on a simple curvature estimation along the contour sections of the face model. Three consecutive points define an arc. when this arc is "straight enough", the middle point was found to be unnecessary. The threshold was chosen in such a way that the RMS error of the distance between the original and the interpolated points had to be less than 1 mm. The number of unnecessary points was 68-95% of the original content, depending on the anatomical parts of the face. Figure 12 shows the original and the reduced point cloud.

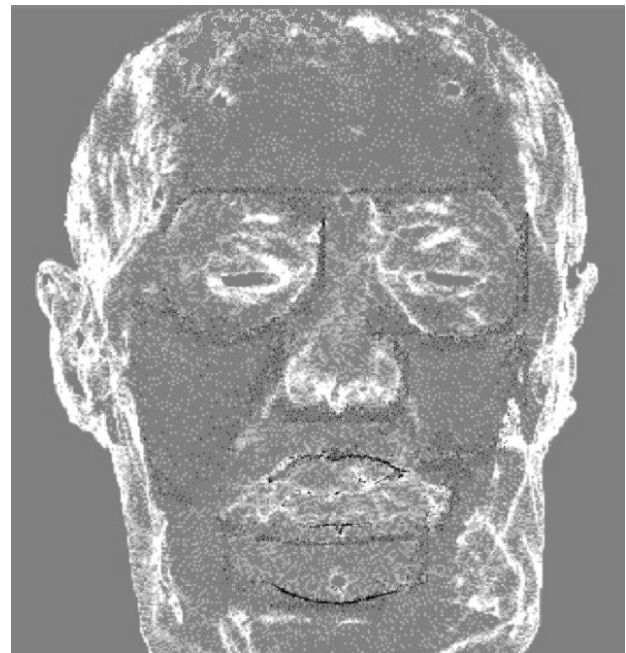


Figure 12. white/grey: measured points; black: undisposable points

3. CONCLUSION

The preliminary results of our work can be summarized as the followings:

- A special material was developed for X-ray photogrammetric purposes. This resin is transparent both for the visible light and the X-ray, and suitable to have adequate marking in it. Using this test-field, numerical accuracy values were given to the usability of X-ray images and Direct Linear Transformation.
- Accuracy of CT-generated 3D model was analyzed, and it suggests that this method is suitable for face

reconstruction purposes. Living humans' skull can be digitalized by CT, but the soft tissues have to be measured by another way.

- Laser scanning applied the way we tested (fixed scanner with mobile desk) is simply not applicable to live people, almost the same can be told about the structured light 3D scanner. However, the precision of these methods is acceptable and for this reason it should be further investigated whether there is a possibility to use high speed scanners based on the same principles.
- The attainable accuracy of close range photogrammetry is well documented in the literature, we did not test it, but this technique obviously can be used for our purpose. We are focusing on minimizing the time and effort requirements by estimating the certainly necessary measuring points and by developing new image matching algorithms.

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