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FACIAL RECONSTRUCTION FROM SKULL USING FREE FORM DEFORMATION

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Abstract

The purpose of facial reconstruction is to estimate the facial outlook from a discovered skull with the intention to provide a positive effect for deceased identification. In this paper, we tried to develop a novel method for facial reconstruction through the use of Free Form Deformation. The target face was obtained by deforming the craniometric landmarks of known skull into unknown skull. Forcing soft tissue on the known skull to the unknown skull with correspondent deformation gives the desired shape of the soft tissue for the unknown skull. Modified from Rhine's landmarks, the 33 craniometric landmarks were used in this work. For the deformation process, the application of Free Form Deformation was employed. The resulting face from this scheme shows promising forensic facial reconstruction.

Keywords*: Facial Reconstruction; Free Form Deformation*

Introduction

One of the most complicated tasks for criminal investigation is dealing with unidentified skeleton remains. There are several reasons why identification is essential. For every unidentified deceased person, there might be someone who cared about. Family members should have known what happened to their lover. Most of the time, an unidentified body is found, crime remains unsolved and the murderer may be still walking around. If usual protocols are impossible to identify the skeleton remains, then possibility of facial reconstruction from skull shall be considered. It is true that there are many ways in which soft tissue may cover such the same skull leading to different facial outlook. So, the purpose of facial reconstruction is not to produce an accurate likeness of the person during life but the task is considered successful if it is able to provide a positive effect on deceased identification. With an assumption that the underlying skeleton directly affects the overall aspects of facial outlook, we considered that facial reconstruction from skull is possible.

Being still in use and constantly evolving, an old technique is a manual clay facial reconstruction also known as sculptural technique (Wilkinson, 2004). This method utilizes average skin thickness data derived from the craniometric landmarks. From tissue thickness of the landmarks, the remaining open spaces are interpolated to form the features of the face. This process is done according to the discretion of the artist resulting in a very subjective and not reproducible face (Taylor, 2001). There are no exact rules for the manual clay facial reconstruction which makes computerization of the process more challenging.

This paper introduces a novel approach to computerize facial reconstruction through the use of Free Form Deformation method. This approach differs from other researches that try to interpolate all face features from small set of tissue thickness data. Stephen et al (2008) stated that the relationships between connective tissue and skull are not completely known at this moment. The assumption behind this novel approach is the changing in the facial soft tissue responding to the changing in the skull. The reconstruction is obtained by deforming the craniometric landmarks of known skull into unknown skull. Forcing soft tissue on the known skull to the unknown skull with the associated deformation offers a desired shape of the soft tissue for the unknown skull.

The remainders of this paper are organized as follow. Materials and related theories to the method are mentioned in the next section. After that, the methodology workflow is presented. Then, the result and discussion of this approach are mentioned. The paper conclusion is summarized in the last section.

Materials and Method

Image Acquisition

The 3D data of skull and face used in this paper are acquired from CT scanner (Fig. 1). The Cartesian coordinate is used to represent 3D data in the form of (x, y, z) also known as point cloud. Meshing, shading and shadowing are used for the visualization purpose.

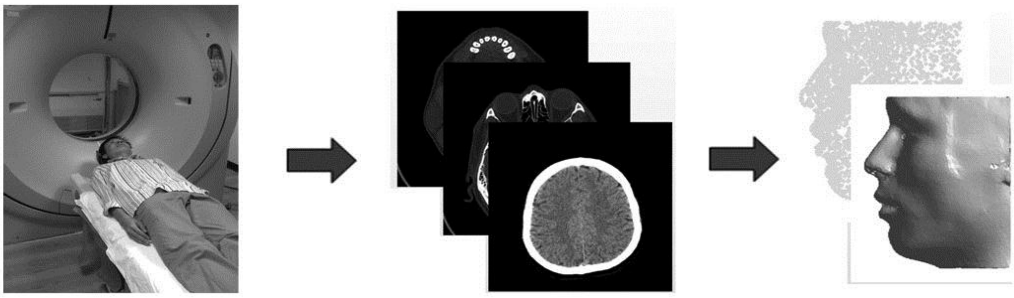

Fig. 1. 3D head data acquisition from CT scanner.

Craniometric Landmarks

Craniometric landmarks are anatomical landmarks on the skull. For manual clay sculpturing method, average skin thickness data table is applied. From tissue thickness at the landmarks, the remaining open spaces are interpolated to form the features of the face. In this work, the reconstruction is obtained by deforming the craniometric landmarks of known skull into unknown skull giving a desired shape of the soft tissue for the unknown skull. The craniometric landmarks used in this work are modified from Rhine's landmarks (Fig. 2).

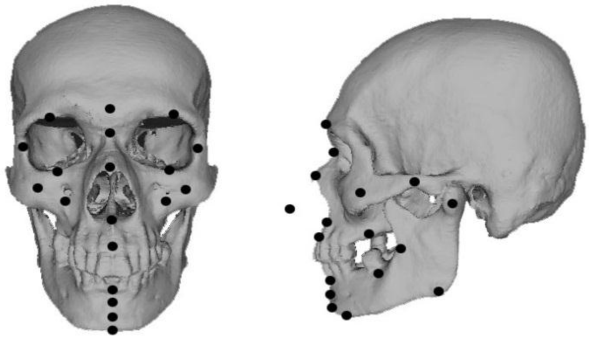

Fig. 2. Craniometric landmarks used in this work.

Frankfort Plane

All heads in the database have to be aligned to the same orientation and position. The favorite standard orientation of skull used in forensic facial reconstruction is called Frankfort plane. The position of Frankfort plane is like someone looking straight ahead. The technical explanation of positioning the skull this way is to have the lowest point on the lower margin of the orbit aligning horizontally with the top edge of the ear hole (Gibson, 2008).

Iterative Closest Point

Iterative Closest Point (ICP) is a straight forward method to align two free form surfaces (Besl & Mckay, 1992). In this paper, this method is used to align reference skull to questioned skull before doing the facial reconstruction. The algorithms of ICP to align surface X and surface P are as follows:

The Iterative Closest Point Algorithm

- Initial transformation
- Iterative procedure to minimize the distance

1. $\forall p \in P$ find closest point $x \in X$
2. Transform $P_k \rightarrow P_{k+1}$ to reduce the average distances
3. Terminate when next transformation step does not reduce the average distance

Free Form Deformation

Free Form Deformation (FFD) was introduced by Sederberg and Parry (Sederberg & Parry, 1986) is known as a powerful shape modification method that has been applied to geometric modeling. This technique deforms an object by embedding it with in a solid defined with a control lattice. A change of the lattice deforms the solid and hence the object (Fig. 3). FFD generally involves with 1D, 2D and also 3D data. We can compute a new location P' from an old location P after deforming control point from P_{ijk} to P'_{ijk} as follows:

1D FFD:
$$P' = \sum_{i=0}^{l} B_i^{\,l}(t) P'_i \tag{1}$$

2D FFD:
$$P' = \sum_{i=0}^{l} \sum_{j=0}^{m} B_i^{\,l}(s) B_j^{\,m}(t) P'_{ij} \tag{2}$$

3D FFD:
$$P' = \sum_{i=0}^{l} \sum_{j=0}^{m} \sum_{k=0}^{n} B_i^{\,l}(s) B_j^{\,m}(t) B_k^{\,n}(u) P'_{ijk} \tag{3}$$

Bernstein Polynomials:
$$B_i^{\,n}(t) = \frac{n!}{(n-i)!\,i!} t^i (1-t)^{n-i} \tag{4}$$

where point P' is a new location at (s',t',u') of an old point P at (s,t,u) after deforming control point P_{ijk} to P'_{ijk} ,and l, m, n are the number of control points minus 1 in x, y, z axis.
$(0 \le s,t,u,s',t',u' \le 1)$

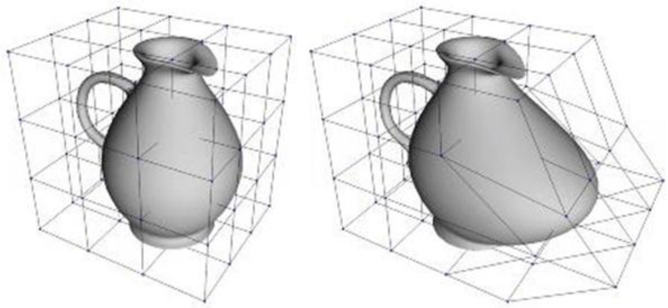

Fig. 3. Demonstration of global FFD (Barzel, 2003).

In this work, we use FFD in the manner of local deformation by applying the local lattice to the craniometric landmarks. Fig. 4 shows the deformation of face according to the deformation of incisor.

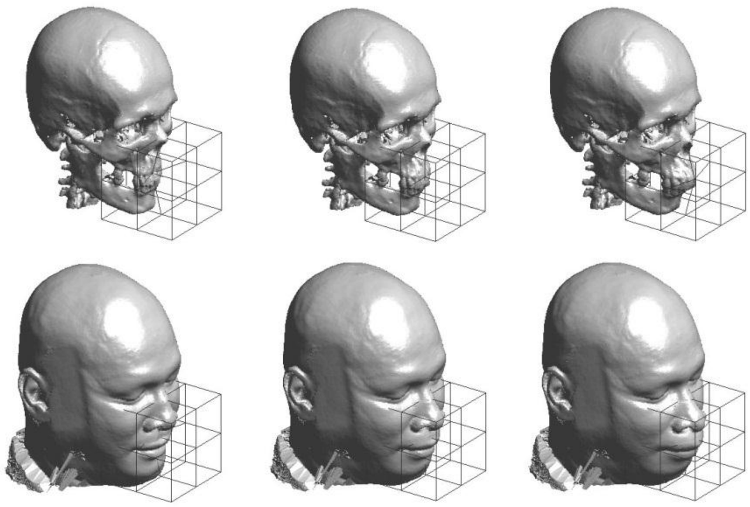

Fig. 4. Demonstration of local FFD. Middle column: original head.
Left Column: moving incisor inside. Right column: moving incisor outside.

Cylindrical Projection

In this paper, to compare skull and face, we transform head 3D models onto plane using a cylindrical projection and resample them with a specified rate. Fig. 5 shows the cylindrical projection of skull and face. Fig. 6 shows the absolute errors of cylindrical projection surfaces of skull and face.

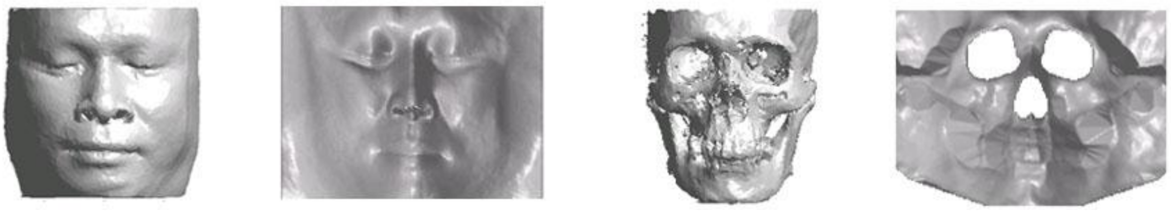

Fig. 5. Cylindrical projection of face and skull

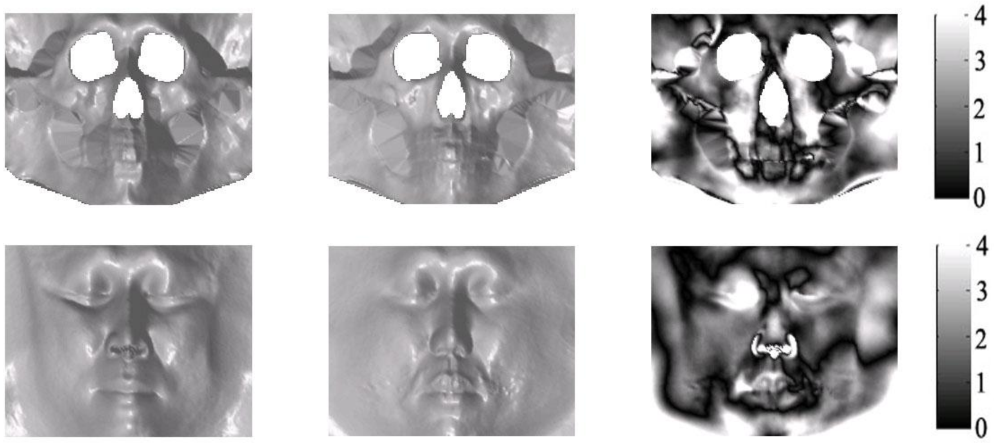

Fig. 6. Absolute errors of cylindrical projection surfaces. Errors are measured in mm.

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Nose Profile Estimation

In order to compare the two cylindrical projection surfaces of skull at the nasal part, we have to estimate the nasal profiles due to there are less information from nasal aperture. Fig. 7 shows the nose profile estimation method modified from Prokobec and Ubelaker (2002). Line A dissects the nasion and prosthion. Line B is parallel to line A and intersects the foremost point on the nasal bone. For each point of nasal aperture, the distance from line B to the nasal aperture are calculated and mirrored to form the nasal profile estimation.

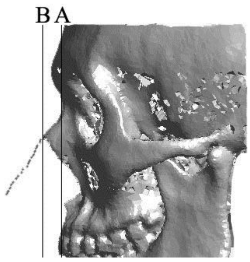

Fig. 7. The nose profile estimation method.

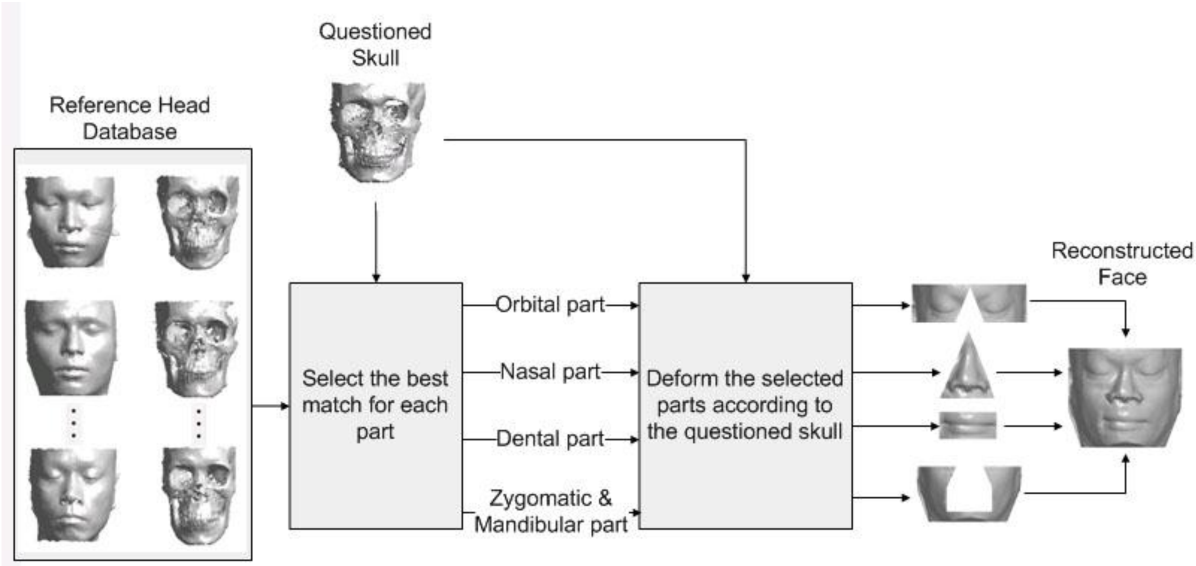

Fig. 8. Facial reconstruction workflow

Methodology

There are 11 three dimensional head models in the head database. Each of them is picked out as questioned skull and the remaining heads are used as reference heads. Fig.8 shows the workflow of the proposed method. First of all, the questioned skull is compared to all skulls in head database each part separately. In this work, the skull is sectioned into 4 parts consisting of orbital part, nasal part, dental part and zygomatic & mandibular part. This work is developed from our previous research which considering zygomatic part and mandibular part separately. In this work, we consider zygomatic part and mandibular part together because these two bones are linked by masseter muscle. It is one of the major muscles responsible for facial appearance. It is a very large and thick muscle originates at zygomatic bone and terminates at mandibular bone (Fig. 9). The best match for each part is selected as reference part. Then all of the reference parts are deformed according to the questioned skull. Finally, the deformed parts are combined to reconstruct the new face.

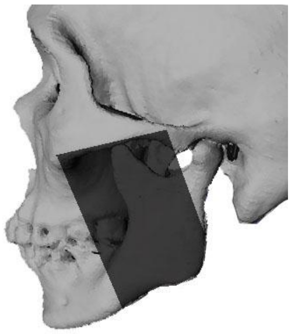

Fig. 9. Masseter muscle

Result and discussion

Fig. 10 and 11 present the facial reconstruction of subjects 1 – 11. First column and second column demonstrate the target faces and reconstructed faces accordingly. These two columns are displayed for visual evaluation. Third column and fourth column present the cylindrical projection of target faces and reconstructed faces accordingly. Then the absolute errors are computed and displayed in fifth column. Although the result shows that we cannot produce exactly the same face as the target face, it still shows a promising forensic facial reconstruction.

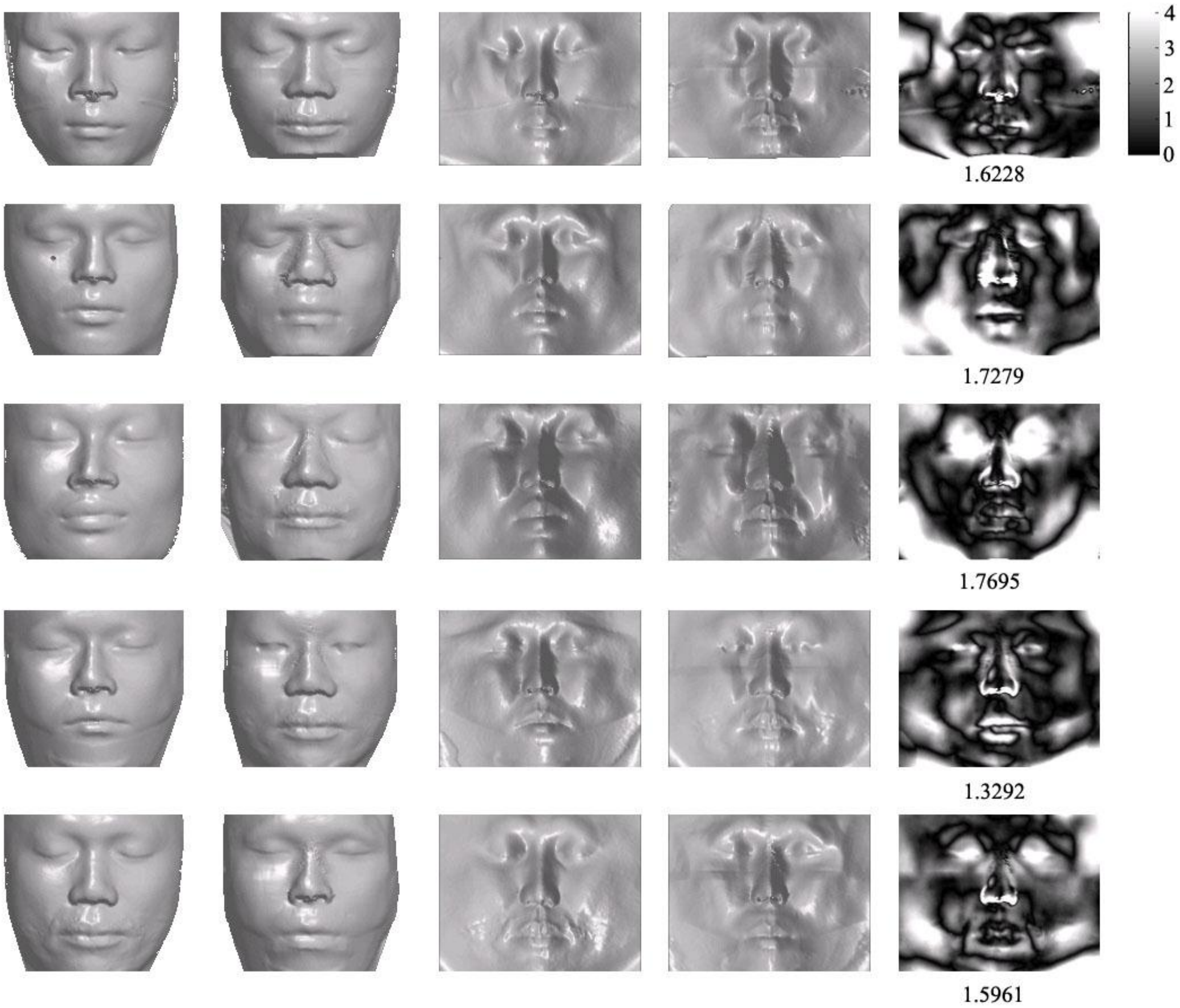

Fig. 10. Facial reconstruction of subjects 1 - 5. First column: target faces. Second column: reconstructed faces. Third column: cylindrical projection of target faces. Fourth column: cylindrical projection of reconstructed faces. Fifth column: absolute reconstruction errors. Errors are measured in mm.

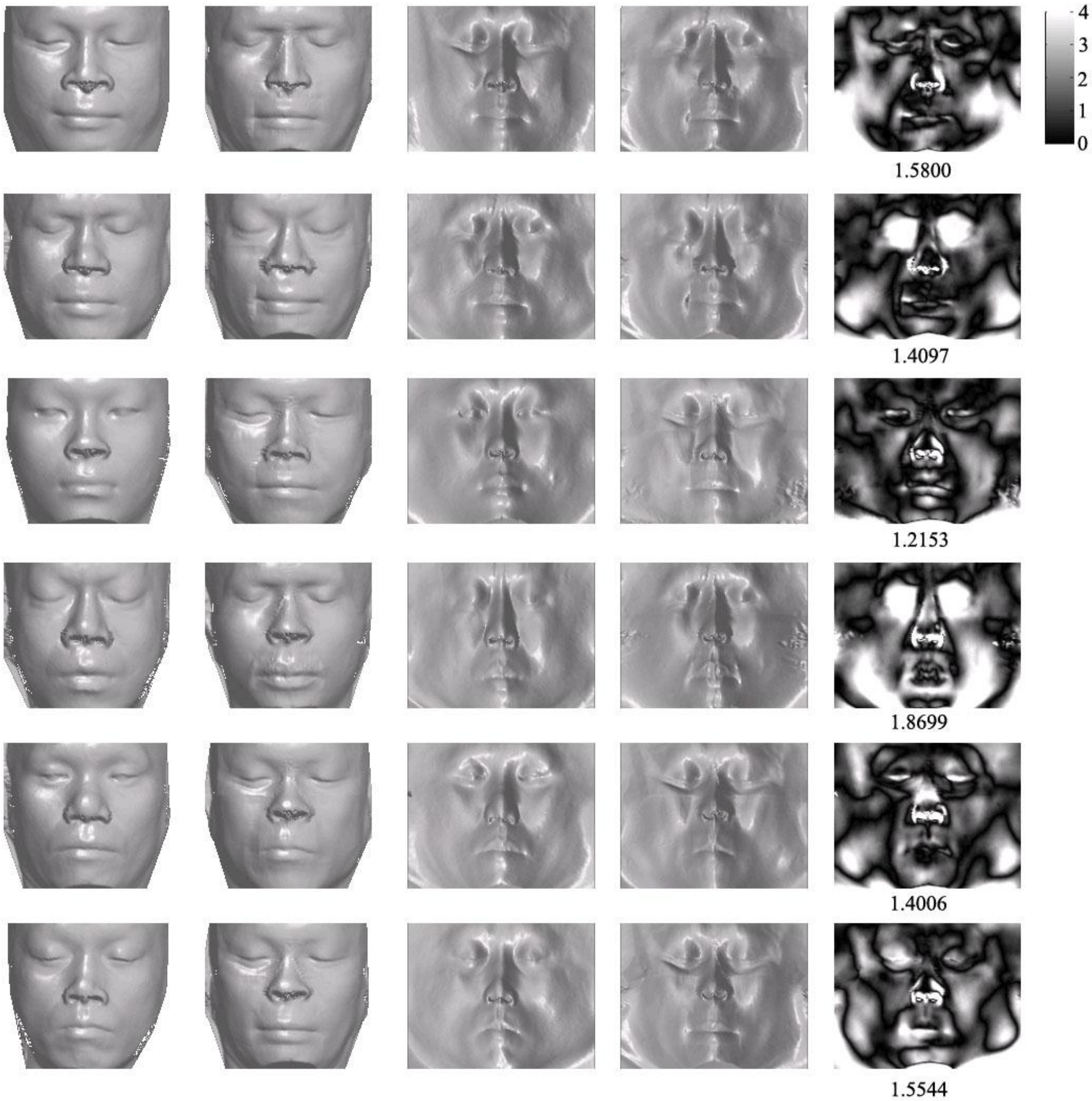

Fig. 11. Facial reconstruction of subjects 6 - 11. First column: target faces. Second column: reconstructed faces. Third column: cylindrical projection of target faces. Fourth column: cylindrical projection of reconstructed faces. Fifth column: absolute reconstruction errors. Errors are measured in mm.

Conclusions

A traditional manual facial reconstruction has been used for a long time in both forensic and archaeological fields. However, the progressive studies and medical imaging technology leads to the development of alternative computer-based facial reconstruction methods. We have to remark that there is no way to reproduce exactly the same face for discovered skull. Instead of using small set of facial soft tissue thickness data and then interpolate the large remaining area, we can use whole facial soft tissue thickness data from 3D head models derived from CT scanner and then the approximate questioned face from reference faces in face database. The approach presents possibility to use this scheme as a support tool for forensic facial reconstruction.

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