An Approach for Unknown Human Face 3D reconstruction basing on skull 3D model

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Abstract

The problem human face shape reconstruction basing on information about human skull is very important for many applications beginning with archeology and finishing with crime expertise. World recognition was received with a face shape reconstruction technique proposed by M. Gerasimov [1]. This method up to now is the general method for face reconstruction of unknown person. It operates with the real human skull and allows to an expert to reconstruct the face shape with special sculptor wax dealing with known thickness of face over the skull. Recent progress in development of 3D scanning system provides the means and techniques for generation of metric 3D models for a skull thus creating a background for development a method for automated unknown human face virtual reconstruction. This paper presents the approach for reconstruction of human face basing on metric skull 3D model and arbitrary 3D model of human face. Skull 3D models were obtained using automated PC-based digital photogrammetric system for skull 3D reconstruction. 3D model of a human face for method development was produced also by photogrammetric technique.

Keywords: *3D reconstruction, close-range photogrammetry, texture.*

1. INTRODUCTION

An appearance of virtual environments and virtual 3D model of various real objects creates a background for development of virtual laboratories for different purposes. To use virtual 3D model instead of real objects seems to be very attractive for tasks of studying and investigation due to such their advantages as convenient form of storage, easy reproducing, ability of fast transmitting to desired place of study, possibility of investigation by powerful computer means. One type of real objects, which seems to be useful to have in the virtual form, is a human skull. The possibility of operating with computer 3D model instead of real skull provides new conditions for an expert.

Providing precise metric characteristics of whole spatial skull model and photorealistic texture generation to support additional valuable visual information for an explorer are two main requirements for such a 3D model. These requirements are satisfied for skull 3D models obtained by PC-base photogrammetric system for automated skull 3D reconstruction [2]. The models produced by this system present the whole textured surface of a skull and have a precision of 0.2 mm. These characteristics are quite enough for many tasks skull analysis, for example, for purposes of skull identification basing on man's photograph [3].

Another problem, which could be solved using textured skull 3D model, is the problem of face reconstruction basing on skull. The basis method for face reconstruction was developed by M. Gerasimov. Up to now face reconstruction requires a real skull and seems to be some kind of art. The possibility of generation of virtual skull 3D model allows to apply computer technologies for this problem solution and allows to get a new quality of the final results.

This paper presents one from possible approaches for unknown face reconstruction basing on virtual skull 3D model. The approach is based on a transformation of an arbitrary face 3D model to satisfy given conditions on distances from reference skull points to face surface.

2. PHOTOGRAMMETRIC SYSTEM FOR SKULL 3D RECONSTRUCTION

To obtain metric 3D model of human skull PC-based photogrammetric system is used. It includes 3 high resolution CCD cameras, two frame grabbers providing simultaneous image acquisition from 3 cameras, PC-controlled turntable and structured light projector. The exterior view of the system is presented in Fig. 1.

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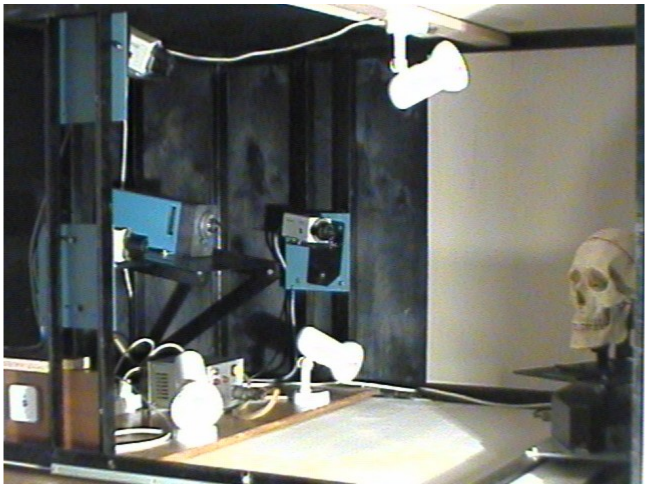

Figure 1: The exterior view of photogrammetric skull 3D reconstruction system.

The automated 3D reconstruction system allows to obtain a whole skull 3D model by one step using images from three CCD cameras while turntable rotating. Automated correspondence problem solution is provided by image acquisition in stripe structural light.

High precision of 3D reconstruction and texture mapping for non-metric CCD camera used for image acquisition provides by preliminary calibration stage including cameras interior and exterior orientation and estimation of orientation turntable rotation axis and structured light plane. Calibration process has high degree of automation due to coded target applying.

After calibration stage process of 3D reconstruction and texture mapping is fully automated and can be performed by "one-button-click". The time required for one 3D model generation in start-stop mode is about 4 minutes, the most time consuming part of process (about 75%) being table rotation. The accuracy of spatial coordinate determination is at the level of 0.2 mm, the point density is 100 000 points per 3D model.

Photorealistic texture is generated basing on seven images acquired in shadow-free lighting. The accuracy in texture continuity at the places of different images bordering is about 1/3 pixel. High quality of texture mapping provides additional wide capacities for expert work.

The results of system application for real skull 3D reconstruction demonstrate that the developed system provides high accuracy of produced 3D models and reasonable performance. The quality of produced 3D models is adequate for wide variety of medical and archeological applications.

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Figure 2: Results of 3D reconstruction.

The samples of skull 3D reconstruction are shown in Fig.2. Fig. 2a presents untextured 3D model and Fig. 2b presents textured model of the same skull. Textured 3D model provides more information for an expert. For example, an expert can easily find points of interest on textured model and measure all necessary parameters from model. The results of system applying show high precision of reconstruction and texturing. On the image Fig. 6b at least five texture fragments present, the accuracy of texture continuity being in diapason of 1/3 pixel.

The original software developed for Windows 9X/ME provides both automated 3D reconstruction and some interface for system calibration, image orientation and separate skull points 3D coordinate calculation basing on stereo images.

3. FACE RECONSTRUCTION

3.1 Basic concept

The main concept of proposed approach is

- For every skull a set of reference points exists, which determines a shape of the skull and the value of distance to the face surface (face thickness) are known for these points
- Arbitrary face 3D model can be transformed so that the face thickness in a given reference point has a proper value
- The surface of the face between these reference points can be described with some kind of interpolation

Basing on these general suppositions the method for virtual face reconstruction was developed. It includes the following stages:

1. A set of reference points is chosen on a skull by an expert for the following face reconstruction
2. Corresponding reference points are taken on arbitrary face 3D model
3. 3D coordinates of the reference points are calculated for the skull and for the face and given values of distances to the face surface (thickness) are added to skull reference points
4. An transformation of a common form from face reference points to skull reference points is determined
5. The rest deformation of obtained face 3D model is performed to minimize errors at reference points

Below more detailed discussion of the proposed technique is presented.

3.2 Reference points choosing

The first step for face 3D reconstruction is determining two sets of the reference points: first set – for given skull $\vec{x}^i{}_{s0} = (x^i{}_{s0}, y^i{}_{s0}, z^i{}_{s0})^T$ and the second set – for some face 3D model $\vec{x}^i{}_{f0} = (x^i{}_{f0}, y^i{}_{f0}, z^i{}_{f0})^T$, $i = 1,...,n$. At the first stage of method development fragments of skull 3D model and face 3D model are used. These fragments are obtained by photogrammetric technique from single stereo view of the object (skull and face).

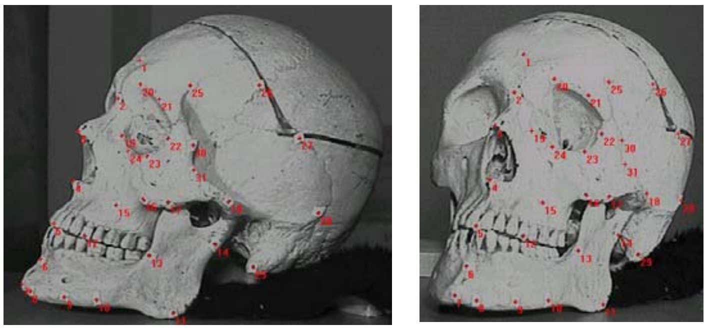

Figure 3: Reference points set on the skull.

For better accuracy 3D coordinates of reference points were calculated using stereo images of skull. Fig.3. presents the stereo pair of a skull with *n*=28 reference points used for the following face transformation.

A stereo view of a human face at approximately identical position was taken for face 3D reconstruction and calculating spatial coordinates of corresponding reference point set.

Fig.4. presents the stereo pair of a human face with corresponding reference points.

Figure 4: Corresponding reference points set on the face.

Because of absence automated means for whole human head the approach was developed using a fragment of the head presented in Fig. 5.

3.3 Surface transformation

The results of surface 3D reconstruction for the skull of Fig. 3 and the face of Fig. 4 are shown in Fig. 5.

Figure 5: Fragment of skull and 3D face model taken for transformation.

For the reference points set of a face a transformation in common form is determined:

$$\begin{aligned} x^i{}_f &= a_{11} x^i{}_s + a_{12} y^i{}_s + a_{13} z^i{}_s + b_1 \\ y^i{}_f &= a_{21} x^i{}_s + a_{22} y^i{}_s + a_{23} z^i{}_s + b_2 \\ z^i{}_f &= a_{31} x^i{}_s + a_{32} y^i{}_s + a_{33} z^i{}_s + b_3 \end{aligned}$$

were $\vec{x}^i{}_f = (x^i{}_f, y^i{}_f, z^i{}_f)^T$ - are the new coordinates of a set of reference points for the reconstructed face, $\vec{x}^i{}_s = (x^i{}_s, y^i{}_s, z^i{}_s)^T$, $i = 1,...,n$ - are coordinates of the skull reference point set after adding face thickness $\Delta\vec{x}^i$ to skull reference point set $\vec{x}^i{}_{s0}$:

$$\vec{x}^i{}_s = \vec{x}^i{}_{s0} + \Delta\vec{x}^i$$

The transformation written in common form corresponds to shift, rotation and scaling of initial face 3D model. The parameters of transformation a_{ij}, b_i are to be found. To determine unknown parameters least mean squares solution for deviation at reference points is taken.

After this affine transformation deviations at reference points are from 4 mm to 14 mm. To eliminate these deviations the error at every reference point is calculated.

$$\vec{e}^i{}_s = \vec{x}^i{}_s - \vec{x}^i{}_f$$

Then every reference point of the face 3D model is shifted for the vector $\vec{e}^i{}_s$. For every other point of the face 3D model a shift is calculated as bilinear interpolation between nearest reference points shifts. After this second order transformation every initial face reference point is at a given distance from the skull reference point (the errors after second order transformation are in the limits of 0.6 mm) and a shape of the reconstructed face corresponds to the given skull.

Fig. 6. shows a reconstructed face fragment after second order transformation along with initial skull fragment (mirror reflection).

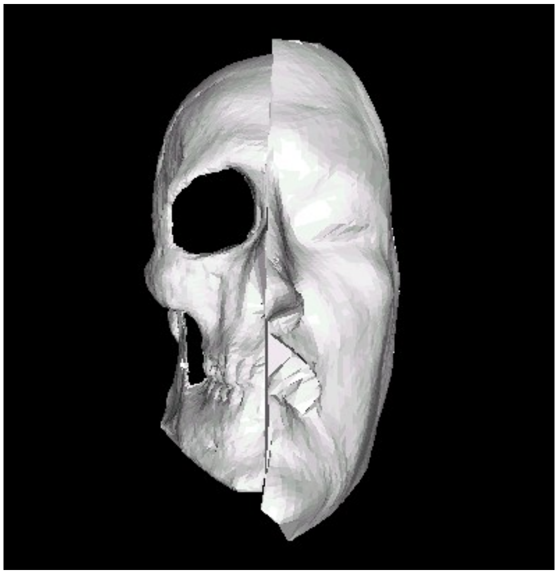

Figure 6: Fragment of skull and reconstructed face fragment

3.4 Whole face reconstruction

Because of absence of adequate technical means for 3D reconstruction of whole face the mentioned above fragment was used for whole face reconstruction. Initial whole face 3D model was obtained by a symmetrical reproduction of the given fragment.

The right part of the face model was generated as mirror reflection of the left part. The plane of symmetry was taken at the central part of the face fragment model (Reference points # 3, #4, #7 determine the plane of a symmetry). A complete 3D model of the skull was generated by the photogrammetric system for skull 3D reconstruction.

The complete 3D model of the skull and a whole face 3D model obtained by a symmetrical reproduction are shown in Fig.6.

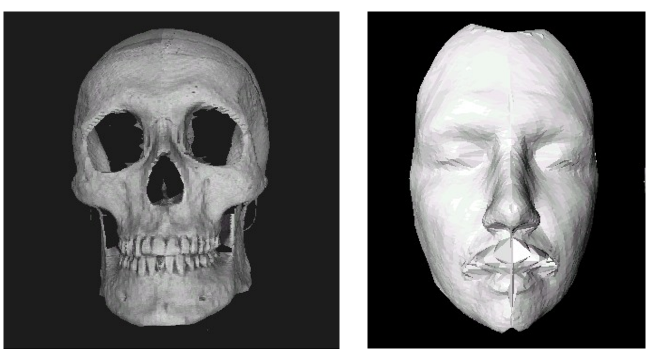

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Figure 7: Complete 3D model of the skull and a whole face 3D model

The technique described in 3.3 was applied for whole face transformation. The resulting face 3D model after first order transformation is shown in Fig 8a. and the results of second stage of transformation is presented in Fig. 8b. Model of Fig. 8a looks like an initial face but has another proportions. After the second order transformation the reconstructed face acquires new features accordingly skull parameters.

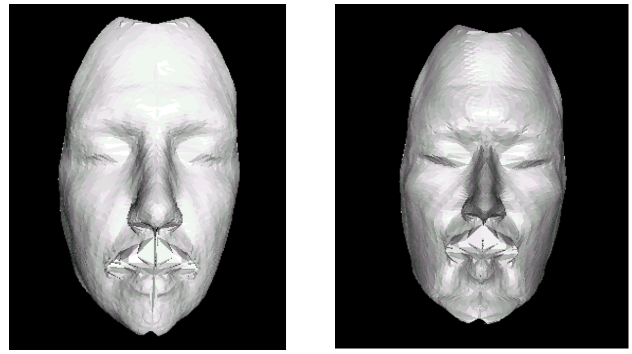

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Figure 8: 3D model of face after transformation.

It is worth to mention that applying whole face 3D model obtained be symmetrical reproduction do not affect significantly on the final result because the skull shape is the main factor of face deformation.

3.5 Texture generation

A new quality, which can be achieved by virtual face reconstruction, is a possibility to create textured face 3D model. At the current stage of method developing a texture from initial stereo pair (Fig. 4) was generated. The result of texture mapping for initial whole face 3D model is shown in Fig. 9a.

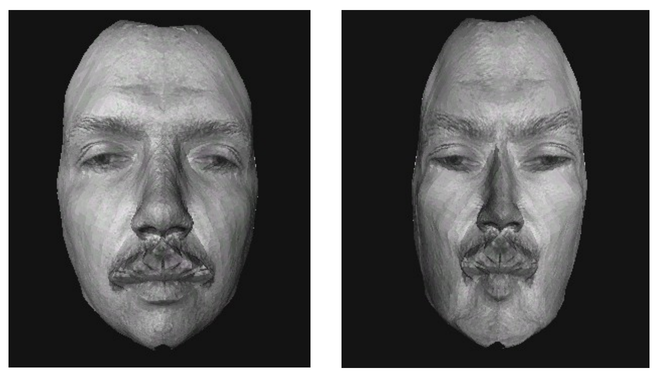

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Figure 9: Initial textured 3D model of a face and textured 3D model of reconstructed face

In general case for realistic visualization of reconstructed face model the photograph of potential or similar person has to be used. In this case the method of texture mapping for unknown camera orientation parameters [4] can be applied. It allows to generate texture on given 3D model using arbitrary image (even drawing) by establishing correspondence between some points of 3D model and the image.

The produced face model could be used for the following cranial-facial identification using a photographs of potential persons.

4. RESULTS DISCUSSION

The proposed approach allows to reconstruct face shape basing on virtual skull 3D model. The reconstructed face shape satisfies to the condition of having given distances from reference points on the skull to corresponding reference points on the face. The surface of the face in other points is interpolation between given reference point. This approach for face reconstruction requires having a 3D model of arbitrary face for describing the shape of a face in other points.

As an investigation of the approach has shown, the stage of choosing of reference points for 3D reconstruction is very important point of the technique. The more reference points are chosen the more detailed skull reconstruction is possible. A type and a quantity of reference point needed for quality reconstruction is a point of further research.

At this stage of development some important face features have not been taken into account. These are: an age, a shape of nose, lips etc. These features could be determined from preliminary investigation of a skull. To improve the method a set of typical face 3D models has to be created and the type of initial face 3D model should be chosen based on a skull primary analysis.

5. CONCLUSION

The automated method for 3D human face reconstruction based on virtual metric skull 3D model is presented. The face reconstruction is treated as satisfying to condition of having given face thickness at given points. The proposed method allows to reconstruct face of unknown person basing on given skull 3D model and arbitrary face 3D model. For face reconstruction an expert has to mark required reference points on the skull 3D model and to indicate corresponding points on a face 3D model. The resulting face model has a given distances between corresponding reference points and interpolated thickness at any other point.

The reconstructed face 3D model can be textured for realistic visualization using a photograph and even a picture of a potential person.

6. REFERENCES

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