Photogrammetric Technique for Accurate Human Body 3D Model Reconstruction

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Abstract

Precise measurements of human body surface geometric parameters are very important for wide variety of applications such as medicine, identification, garment design and manufacturing etc. In most cases it is more convenient not to get measurements from a real subject but using his accurate 3D model.

A photogrammetric technique for accurate human body 3D reconstruction is proposed. The hardware of the developed system includes a set of CCD cameras, frame grabber, structural light projector. Original software for Windows XP allows to scan surface of human body, to generate textured 3D model and to perform given measurement procedures. Produced 3D models have real scale and photorealistic texture providing reliable data for processing.

Keywords: *3D reconstruction, Calibration, Texture, Measurements.*

1. INTRODUCTION

A significant number of applications has a need for a human body 3D models. The list of such an application includes medicine and biometry, sports and animation, garment design and shoe making etc. The main problem in 3D human body modeling is a need for fast, safe and accurate surface model acquisition. Another important requirement is to generate textured photorealistic 3D models.

Measuring various geometric parameters of human body is a task which is solved in many applications. Garment manufacturing requires body 3D models for taking so called key-measurements of a body for producing plane pattern for cloth manufacturing. Accurate 3D model allows making this process automotive and more convenient for designer and customer [1].

Medicine also has a need for instrument to determine given distances on body surface, areas of wounds and healthy tissues. One of the areas is plastic surgery which needs the precise measurement of damaged and adjacent healthy tissues and the accurate forecast of tissue expansion for successful results of plastic surgery operation. Existing 1D and 2D methods for measuring of the required areas on the patient body could not give accurate results because of significant curvature of the measured surface. So applying 3D models for surgery planning is very important.

The complete technology for generating 3D models includes the following stages:

2.5 scanning of the part of a body surface resulting in textured fragment 2.5D model (scan) in local coordinate system,

scanned fragments transition to a global coordinate system (scan merging),

united 3D model (single mesh) generating from a set of fragments,

color photorealistic texturing of the 3D model using images from color camera,

some special processing depending on application

The real scale of the produced 3D models and accurate texture mapping are provided by preliminary system calibration.

2. HARDWARE CONFIGURATION

The exterior view of the developed photogrammetric system for human body 3D reconstruction is presented in Figure 1.

Figure 1: The view of human body 3D reconstruction system.

In addition to general requirements of high accuracy and high productivity of measurements which any industrial 3D scanning system should satisfy, the system for human body 3D reconstruction has to meet some special requirements as:

- Short processing time because of difficulty for a person to keep immobility
- Convenience and safety for captured person
- Producing 3D model for given part of body
- Color texturing of the 3D model to capture visual features of scanning area

Regarding the described requirements the following hardware configuration is chosen:

- Two monochrome CCD cameras for non-contact photogrammetric measurements
- Color high resolution CCD camera for color texturing of 3D model
- PC controlled structured light projector for automated correspondence problem solution
- Frame grabber for image acquisition
- PC as central processing unit

The developed system is based on photogrammetric principle of spatial measurements, which allows determining 3D coordinates for any point of the object if their image correspondence for two oriented photographs is established. The system provides automated images orientation (calibration) and supports a set of methods of automated correspondence problem solution based on various structured light patterns.

3. SYSTEM CALIBRATION

The key point for generating accurate 3D model is system calibration which allows to estimate parameters of interior and exterior orientation. Interior orientation parameters describe camera model for image generation and exterior orientation parameters define camera location in given system of coordinates.

Image interior orientation (principal point x_p, y_p, scales in x and y directions m_x, m_y, the radial symmetric distortion coefficients K_1,K_2,K_3 and decentering distortion coefficients P_1,P_2) and image exterior orientation (X_i, Y_i, Z_i – location and α_i,ω_i,κ_i and angle position in given coordinate system) have to be determined as a result of calibration [2].

A set of 12 test field images for each camera is acquired for calibration. These images are processed for automated image coordinates of reference points determining. Then camera model parameters and camera exterior orientation are determined by least mean squares solution.

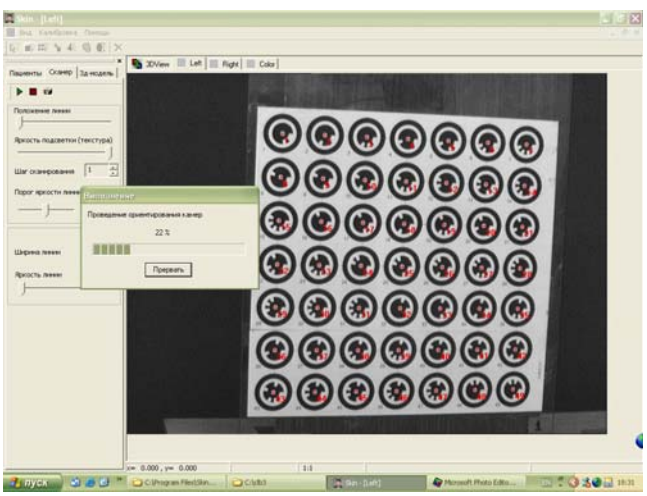

Figure 2: The process of calibration

For automation and high accuracy of calibration special coded targets are used for test field reference point marking. Coded targets provide automated identification of corresponding reference points in the images and sub-pixel coordinate determination.

Original calibration software provides automated test field image processing and orientation parameters estimation basing on observations. The process of calibration is shown in the Figure. 2.

The residuals of co-linearity conditions for the reference points σ_x, σ_y, σ are considered as a calibration criterion. The results of interior orientation for calibration process with staged expanding of unknown parameters vector is presented in Table 1.

	σ_x	σ_y	σ
eo	0.555	0.496	0.744
$+m_x$, m_y	0.472	0.418	0.600
$+x_p$, y_p	0.4150	0.364	0.552
$+K_1$,K_2	0.0290	0.036	0.047
$+K_3$	0.0250	0.034	0.043
$+P_1$,P_2	0.0250	0.033	0.041

Table 1: Results of calibration

Table 1 demonstrates high accuracy of calibration which is adequate to human body 3D measurement problem.

4. 3D RECONSTRUCTION TECHNIQUE

4.1 2.5 Scanning

Because of complex shape of a human body the 3D model of interested region of a body could be obtained by scanning a set of partial 2.5 fragments and then generating united 3D model from the acquired set. 2.5 scanning is performed by capturing a set of images in structured light. 3D coordinates of viewed points of a body are determined by solving correspondence problem for two oriented monochrome images. An image for 3D model texturing is acquired by calibrated color camera.

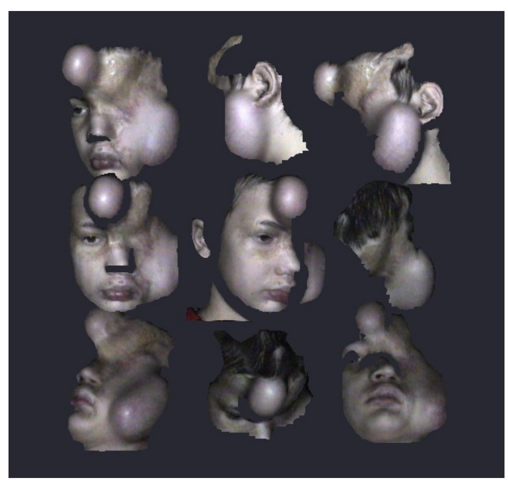

Figure 3: A set of 2.5D fragments scanned for 3D model generation

The number of fragments (scans) depends on complexity of the scanned surface. The number of scans should be great enough to cover all area of interest and to have overlapping region for merging fragments. In case of complex shape of scanning region (like the head of a patient during preparation for plastic surgery, Figure 3) the number of scans increases to capture all significant points of the surface.

The 9 partial fragments of a head scanned by developed system is shown in Figure 3.

As a result of 2.5D scanning a set of textured partial fragments is generated every fragment being in own local coordinate system.

4.2 3D model generation

To obtain united 3D model from a set of 2.5D fragments two techniques are realized. For 2.5D fragment having sufficient common parts the semi-automated technique of matching overlapped part is used. User roughly adjusts two fragments in initial approximation position and then alignment is refined automatically using iterative closest points algorithm [3].

The result of consequent fragments merging is shown in Figure 4.

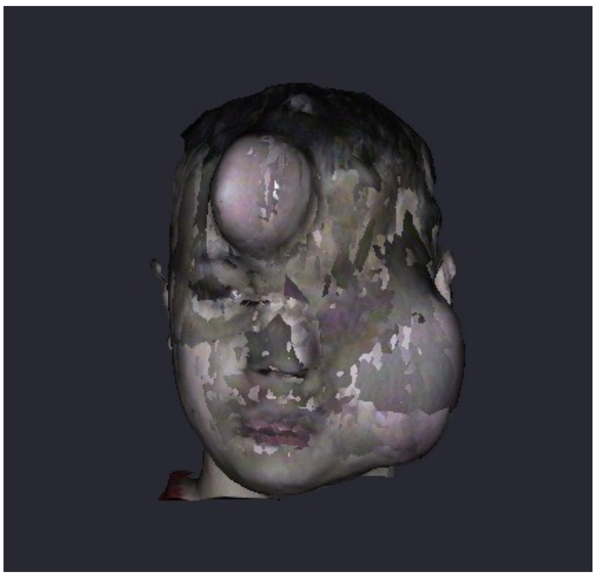

Figure 4: Fragments merging

In case when overlapped regions are insufficient for registration or merging fragments do not have significant geometric features for iterative closest points matching merging based on reference points correspondence is performed. For applying this technique user marks three or more corresponding reference points on adjacent fragments and then transition matrix is determined for fragments merging.

The 3D model obtained by fragments merging could not be directly used for specific application processing firstly because of having overlapped surfaces which hinder to perform necessary measurement and secondly because of poor texture quality which prevent to find areas of interest on the surface. So the next stages of 3D model processing are united 3D model generation and integrated texture mapping.

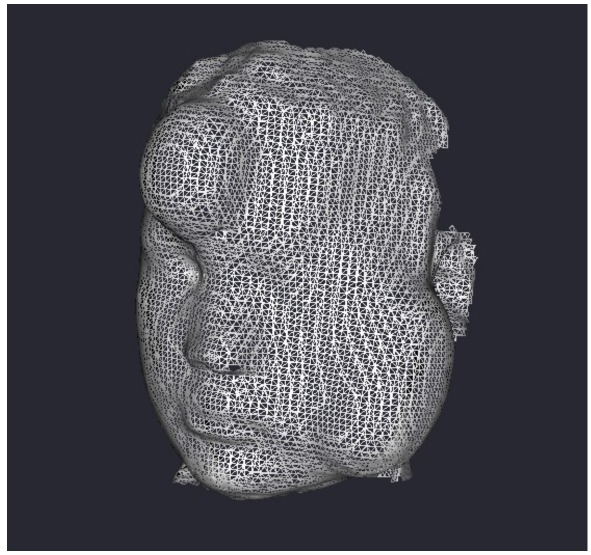

Figure 5: Single mesh generation

United 3D model is produced by integrating all scans into single mesh using interpolating mesh algorithm [4]. The result of single mesh generation is shown in Figure 5.

4.3 Texturing

Direct texture mapping from oriented color images gives poor results because of images for texture are acquired from different point and in different light condition [5]. The common case of texture representation after textured fragments merging without additional processing is shown in Figure 4.

So for texturing special image processing is applied with the aim of obtaining photorealistic quality of 3D model. For every color image used for texturing the region of corresponding 2.5D scan is determined in the image. Then for every triangle of single mesh 3D model corresponding coordinates of its vertexes are found in every color image including this triangle. For every color image containing given triangle image intensity for pixels inside this triangle is averaged with weight depending on triangle location in the initial fragment. The result of refined texture generating is presented in Figure 6 in comparison with initial 3D model.

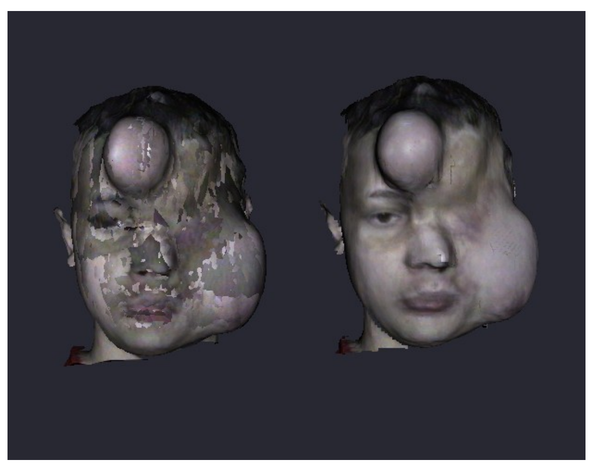

Figure 6: Merged textured scans and the single textured mesh

4.4 Measurements

United textured 3D model allows carrying out measurements required by given application. The software supports calculating of linear distances on the surface, calculating area inside the given contour marked by user on the surface. Figure 7 demonstrates the results of area calculation for 3D surface region inside the contour needed for surgery planning.

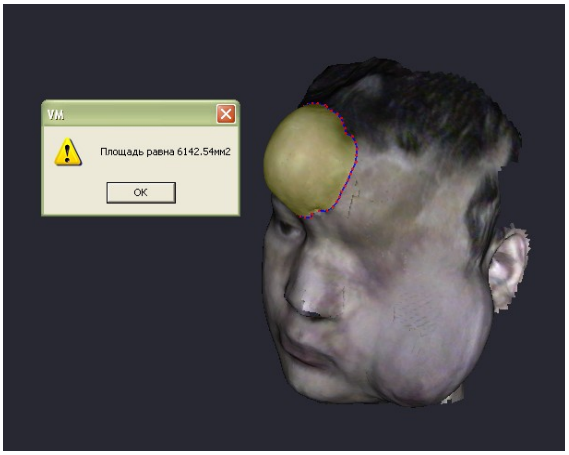

Figure 7: Area of spatial region calculation

The system is opened for including the support of specific application functions. Software realization for plastic surgery supports such functions as operation planning and forecast. Figure 8 presents the results of forecast for expanding healthy tissues instead of damaged tissues.

Figure 8: Forecast function for plastic surgery

In garment application a set of predefined key measurements used for apparel design could be calculated. These key measurements are associated with certain landmarks of the body. Body measurements taken from 3D model can be the distances or angles between two landmarks (yoke and should slope), the length of a surface curve (crotch), etc.

Software release for biometric applications supports function of measuring given points on the surface, distances between given points, estimating the photograph orientation for given 3D model. These functions are used for person classification and identification.

5. CONCLUSION

The developed system for human body 3D modeling supports the complete technology for 3D model reconstruction and accurate texture mapping. The resulted 3D models have high accuracy and photorealistic texture and can be successfully applied for wide variety of applications which require measurement of body geometric parameters.

The advantages of the proposed 3D system are high precision and fast processing in conjunction with relatively low cost, safety and convenience for a person. The 3D system could be easily modified for the tasks of given application.

As a way of the further system evolution automated 3D features (such as nose, eyes etc.) extraction is considered.

6. REFERENCES

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