Method for hidden surfaces attitude analysis based on photogrammetric technique

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Abstract

For many applications it is important to know how two adjacent parts of a system are located. Measuring outer parameters of parts is relatively simple task. But it is a problem to determine relative attitude of inner surfaces of adjacent parts and to measure given parameters of conjunction. Such applications as manufacturing, dentistry have a need for a solution this problem.

A photogrammetric method for hidden surfaces attitude analysis is developed. It uses original photogrammetric system for parts' surface reconstruction, 3D model alignment in the position according real parts joint and 3D model joint attitude analysis.

The developed technology is demonstrated for dentistry application (jaws occlusion analysis).

Keywords: *Photogrammetry, Calibration, Non-contact measurements.*

1. INTRODUCTION

For successful dental treatment and denture making it is important to have information about relative position of upper and lower jaws and to know distances between corresponding teeth in given section. The determination of these distances is a problem for a dentist because there is no means for performing required measurements neither in a mouth nor on plasters casts due to teeth occlusions. The only information which a dentist can get about teeth position is information about presence (or absence) of contact between upper and lower teeth. This information can be obtained using thin color sheet of paper to mark off the place of contact on teeth (occlusion) when closing jaws.

A photogrammetric technique for the solution of this problem is proposed. It supposes generating 3D models of jaws and positioning them in given position for analysis. The procedure includes the following stages. At first plaster models of upper and lower jaws are made. Then 3D models of upper and lower jaws are generated using a photogrammetric system based on two CCD cameras and structured light projector. For whole jaw 3D model generation a set of partial 2.5D models is scanned which then are merged using original software realizing iterative closest point algorithm.

The next step is bringing 3D models of upper and lower jaws in a given position according their location and orientation in a mouth. For this purpose plaster models are installed in given posture using dental articulator or plaster form for setup. Then mutual position of the jaws is registered. The surface of upper and lower teeth rows is scanned in given position of jaws plaster models. Then the jaws 3D model position is determined using a set of this surface scans as a reference surface using iterative closest point algorithm.

2. PHOTOGRAMMETRIC SYSTEM FOR NON-CONTACT MEASUREMENTS

2.1 System outline

For surface 3D reconstruction original photogrammetric system is used. The system is PC-based and it includes the following hardware:

- Two SONY XC-75 CCD cameras
- Structured light projector
- Multi-channel frame grabber

The exterior view of the photogrammetric system is presented in Figure 1.

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

The system is designed for dentistry application and it have to provide measurement accuracy of about 0.04 mm. To meet this requirement with given cameras the working space of the system is chosen as 60x60x60 mm.

Cameras are used for non-contact 3D measurement of surface coordinates using a photogrammetric approach. For automated identification of given surface point in images from left and right cameras (correspondence problem solution) structured light is used.

2.2 System Calibration

The metric characteristics of 3D models produced by the system are provided by system calibration. Calibration allows estimating parameter of camera model (so-called camera interior orientation) basing on a set of images of special test field with known spatial coordinates of reference points. The problem of parameters determination is solved as estimation of unknown parameters basing on observation. Additional term describing non-linear distortion in co linearity equations for perspective projection are taken in form:

$$\Delta x = \Delta x_p + \bar{x}r^2 K_1 + \bar{x}r^4 K_2 + \bar{x}r^6 K_3 + (r^2 + 2\bar{x}^2)P_1 + 2\overline{xy}P_2$$

$$\Delta y = \Delta y_p + \bar{y}r^2 K_1 + \bar{y}r^4 K_2 + \bar{y}r^6 K_3 + 2\overline{xy}P_1 + (r^2 + 2\bar{y}^2)P_2$$

$$\bar{x} = m_x(x - x_p);\ \bar{y} = -m_y(y - y_p);\ r = \sqrt{\bar{x}^2 + \bar{y}^2}$$

where x_p, y_p,-the coordinates of principal point,

m_x, m_y - scales in x and y directions,

K_1,K_2,K_3 – the coefficients of radial symmetric distortion

P_1,P_2 - the coefficients of decentering distortion

Image interior orientation 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) are determined as a result of calibration [1].

Figure 2: Test field on two axis positioning stage

Calibration process is fully automated due to applying two axis positioning stage and coded targets for reference point parking. Calibration program captures a set of test field images at different position controlled by positioning stage.

Original calibration software controls test field orientating for image acquisition and test field image capturing at given positions. Then camera orientation parameters are estimated basing on image reference points coordinates as observations of points with known spatial coordinates.

The results of system calibration is given in Table 1.

	$\sigma_{x,\,mm}$	$\sigma_{y,\,mm}$	$\sigma_{,mm}$
Left camera	0.0071	0.0052	0.0086
Right camera	0.0061	0.0067	0.0092

Table 1: Results of calibration

σ_x, σ_y, σ are residuals of co-linearity conditions for the reference points after least mean square estimation concerning as precision criterion for calibration.

3. 3D RECONSTRUCTION TECHNIQUE

3.1 Plaster models scanning

Photogrammetric system allows measuring 3D coordinates of any point on object surface observed by both cameras simultaneously. For object of complicated shape such as jaw plaster model it is impossible to view all necessary points of the object. So a set of partial object scans has to be obtained for whole surface of the object 3D model generation. Every partial object scan is made in its local reference system of coordinates specified by test field.

Two partial scans of a jaw plaster cast are presented in Figure 3.

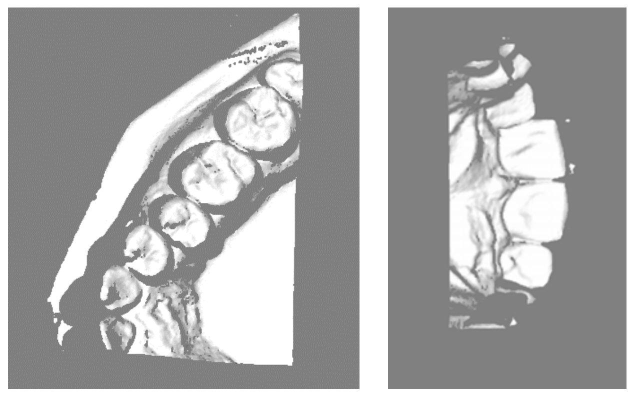

Figure 3: Two partial scans of a jaw

For whole 3D model generation from a set of scan several techniques can be applied such as reference point network designing, applying precise positioning stage with known position of axis, fragment merging using iterative closest point algorithm [2]. The latter technique is applied for fragment merging with point-to surface metrics.

This technique requires that merging scans have significant overlapping for proper work of iterative closest point algorithm. To generate whole 3D model of an upper jaw presented in Figure 4 a set of 28 scan is used. Various scans are shown in different colors to control visually a quality of merging. The mean error of scan merging is at the level of 0.02 mm.

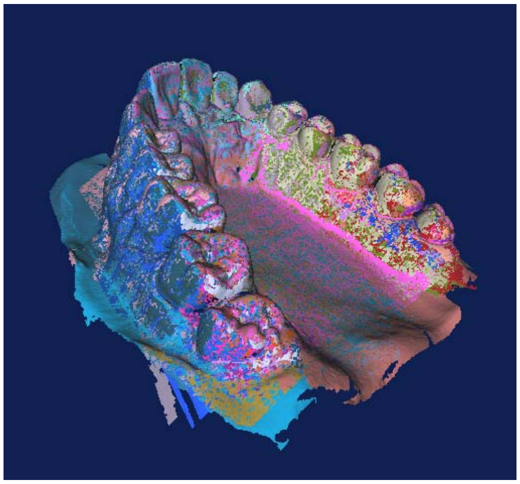

Figure 4: Upper jaw 3D model from 28 scans

The resulting 3D model consisting of a significant number of overlapping surfaces is not suitable for purposes of jaws occlusion analysis. So this 3D model is transformed in single mesh using interpolating mesh algorithm [3]. The result of single mesh generation is shown in Figure 5.

Figure 5: Jaw 3D model in single mesh form

3.2 Occlusion registration

After generating 3D models both upper and lower jaws it is necessary to install these 3D models according jaws real position in a mouth. At first registration of jaws position is performed using dental articulator or silicon moulds made in mouth.

Then plaster jaw model are installed in registered position using obtained silicon moulds. In this position the front surface of upper and lower teeth rows is scanned. The scan of the teeth front surface is then used as a reference surface for jaw 3D models translating into attitude corresponding real jaws occlusion. Resulting reference surface is presented in Figure 6.

Then 3D models of upper and lower jaws are bringing in registered position using iterative closest point algorithm.

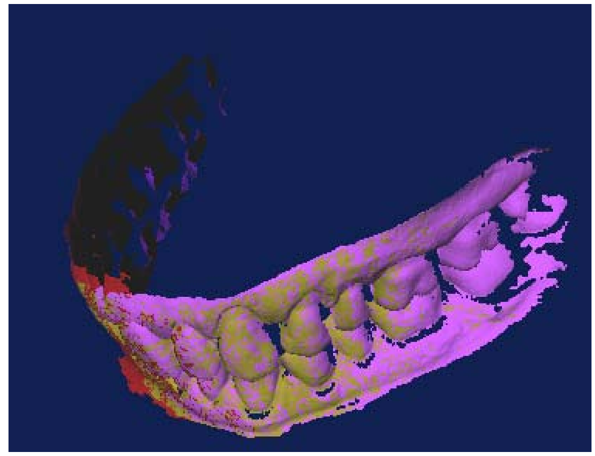

Figure 6: Jaws position registration

3.3 Occlusion analysis

Jaws 3D models installed in the position according their real occlusion allow investigating how hidden teeth surfaces are relatively located, this being important for teeth treatment and denture manufacturing. For occlusion analysis original software is developed. It supports the following functions:

- 3D model visualization in different modes,
- making given plane section of 3D model,
- section contours visualization in forms of 2d or 3D curves,
- Measuring given parameters in section plane.

Figure 7 presents the user interface of the developed software.

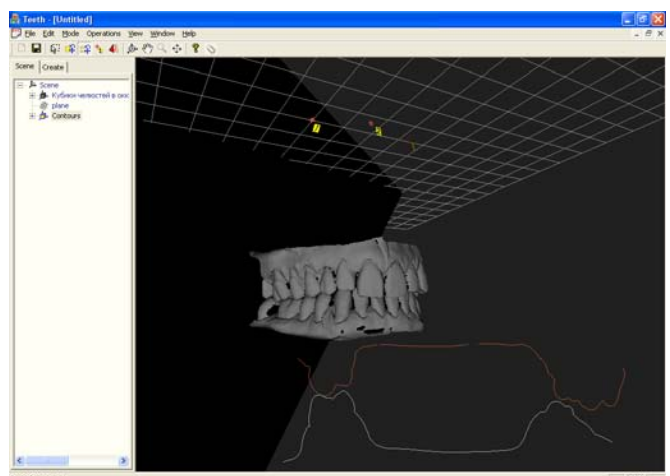

Figure 7: Software user interface

User can make section manually defining the plane position or he can choose anthropometric points on teeth and analyze occlusion in plane corresponding these points.

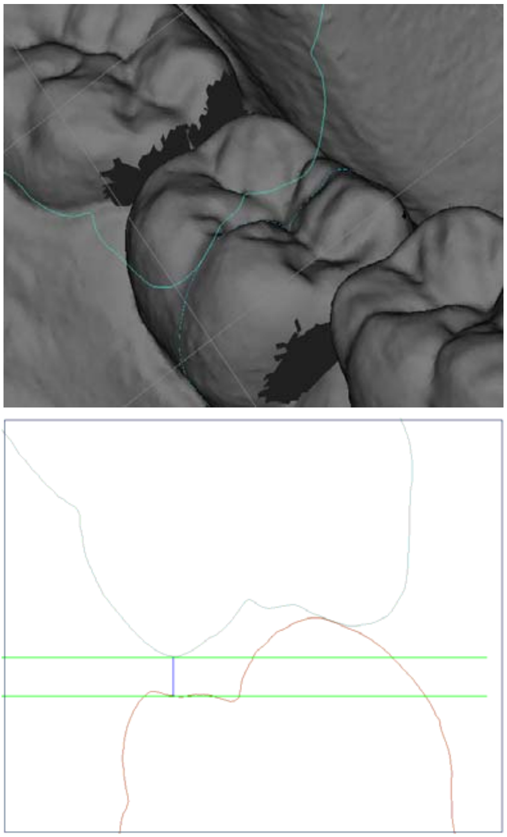

Figure 8: Jaws section and occlusion measurement

Figure 8 presents section of jaws 3D model and measuring distance between upper and lower teeth in section plane.

4. CONCLUSION

The technique for analysis of hidden surfaces attitude of joint parts is developed. It based on generating 3D models of the parts and registration their attitude by scanning adjacent areas of the parts. Then 3D models are translated in the position determined by the registration this providing a means for hidden surfaces investigating.

The developed technique is demonstrated by dental application. It can be successfully applied for analysis of joint parts of aggregates and mechanisms for industrial use.

5. REFERENCES

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