

PHOTOGRAMMETRIC TECHNIQUES FOR DENTISTRY ANALYSIS, PLANNING AND VISUALISATION

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ABSTRACT:

Dentistry is a field which has a need for accurate information about teeth shape, their relative position and their appearance in the face. This information is essentially important for various dentistry fields such as orthodontia, teeth treatment, denture production. Existing methods for analyzing mutual teeth arches position (occlusion) use plaster teeth arches casts and a special mechanical tools which allow registering occlusion. For investigation and visualization of exterior appearance of teeth arches only 2D images are used which do not provide full and adequate presentation. So existing means do not give required accuracy and are not convenient for a dentist. Photogrammetric approach gives solution for all described problems with appropriate accuracy of measurements and high quality data for investigation, documentation and presentation. A set of new techniques for teeth occlusion registration and analysis is proposed based on applying teeth arch 3D model instead of a plaster mould. The developed photogrammetric techniques are used for automated patient face and teeth arch 3D models generation, for occlusion registration, treatment planning and documenting.

1. INTRODUCTION

A lot of dentistry applications has a need for information about teeth shape and the relative position of upper and lower dental arches. This information is necessary for proper dental treatment as long as for accurate and convenient denture making. Most of the existing techniques for teeth measurement and analyzing of mutual teeth arches position (occlusion) use plaster teeth arches models for occlusion analysis and special mechanical positioning device -articulator - to register jaws position. For registering exterior appearance of the teeth (when smiling, for example) 2D photograph is usually used which could not give adequate and complete information.

A successful dentistry treatment is based on reliable information about relative teeth arches position and mutual location of teeth in different occlusions.

Tooth preparation is one of the key clinical procedures in prosthetic dentistry which provides necessary conditions for fixed prosthesis construction. Occlusal surface is the functionally significant part of a chewing tooth. It is difficult to observe it during functioning as when opposite (upper and lower) teeth are in contact their occlusal surfaces can not be seen. But a dentist has a need of knowing some distances between corresponding teeth in given section. Existing methods do not provide the required data. The only information which a dentist can get about teeth position is knowing if there is presence (or absence) of contact between upper and lower teeth. This information can be obtained using thin colour sheet of paper to mark off the place of contact on teeth (occlusion) when closing jaws. And how dentures will correspond to the teeth arch and a face could be analyzed after denture making.

For adequate prosthetic construction it is necessary to study occlusal surface in connection with its structure and function, to analyze results of occlusal surface preparation and to find proofs or denials for occlusal surface preparation method.

New methods for tooth preparation based on a consideration of tooth structure and its position in masticatory system will offer key clinical approaches that ensure necessary and sufficient quality in occlusal surface preparation. It allows producing anatomically and functionally adequate fixed dentures i.e. full and partial crowns and bridges, to make the process of preparation more focused and to improve co-operation between dentists and dental technicians.

It was found that bucco-lingual sections of teeth can clearly manifest the results of the experimental study. Performing such sections on plaster casts would require a large number of them and their copies, a method of obtaining a graphic depiction of sections and, due to the novelty of the preparation method, a multitude of sections for getting the ones that are of interest. Hence, such a study on plaster casts would become enormously cumbersome and "bulky". So a new a technique for occlusion analysis is needed. The most attractive method for teeth surface and relative position study is to use "virtual dentist's office" and operate with teeth arch 3D model instead of plaster mould.

Photogrammetric approach allows getting accurate and convenient solution for concerned problems. Application of an accurate teeth arch 3D model instead plaster mould gives to a dentist new possibilities for occlusion analysis and visualization of treatment forecast using patient's face 3D model.

Proposed photogrammetric system supports all necessary functions for teeth arches occlusion analysis. It uses specially

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designed hardware for generating a teeth arch 3D model and face 3D model in automated mode and original software for models setting up and occlusion analysis.

For forecasting (and then documenting) the results of treatment an original photogrammetric system for fast textured face 3D model generation is developed. The 3D model for occlusion visualization and documenting includes a face 3D model and teeth arches 3D model. It is used for presenting the teeth appearance before and after treatment.

2. 3D RECONSTRUCTION

To meet dentist requirements for dentistry analysis, treatment planning and documenting it is needed to obtain accurate high resolution teeth arch 3D models and textured 3D models of patient face. Due to different requirements to those two types of models two photogrammetric systems is developed.

A photogrammetric system for automated teeth arch 3D model generation (Figure 1.) includes two digital high resolution cameras, high resolution structured light projector and PC-controlled rotation positioning stage. It allows producing high resolution 3D of teeth arch in automated mode.



Figure 1. Photogrammetric system for teeth arch 3D model reconstruction

A system for patient face 3D model acquisition is also based on digital cameras and structured light projector. For minimizing the acquisition time cameras and projector work in synchronized mode allowing to get required set of images in a short time period of about 0.5 sec.

2.1 Teeth 3D model generation

The following requirements are established to a system for teeth arch occlusion analysis for satisfying investigation purposes:

- High accuracy of 3D reconstruction
- High resolution of tooth 3D model
- Short time for producing teeth arch 3D models
- The possibility of real occlusion reconstruction
- The possibility of occlusion investigation

To meet these requirements the configuration of photogrammetric system including two digital IEEE 1394 cameras of high resolution (2 Mpixel), structured light projector with resolution of 1440x1080 pixels and PC-controlled rotation positioning stage is chosen. For automated corresponding problem solution coded light is applied providing robust and fast scanning.

The system is calibrated using original technique (Knyaz, V., 2002) for estimating camera interior and exterior orientation parameters and for determining the parameters of positioning stage rotation axis (Knyaz, V., 2002, 2005). Special calibration test field with coded targets is used for system parameters determination in automated mode. The calibration technique provides residuals of co-linearity conditions for the reference points after least mean square estimation at the level of 0.005 mm. This accuracy is quite adequate for the concerning problem.

For whole teeth arch 3D model generation a set of scans at various plaster model positions is acquired. The number of scans and their orientation are the subject of user choice. All scans are transformed to global coordinate system using the results of rotation axis parameters estimation (Figure 2.). This first order scans alignment serves as an initial approximation for accurate scan registration by iterative closest point algorithm (Besl, 1992).

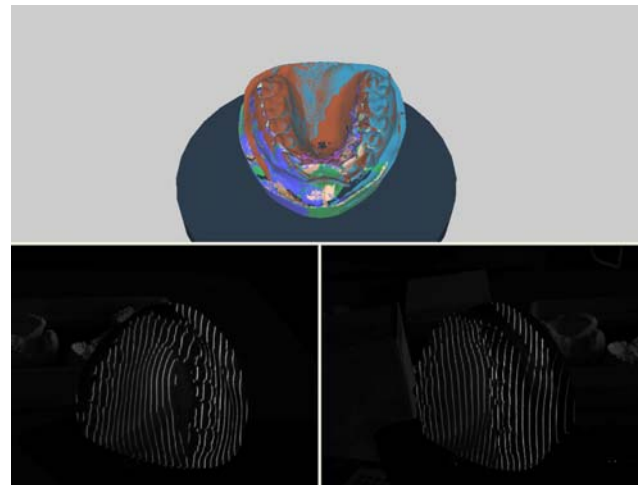


Figure2. 3D reconstruction process

After scan merging a single mesh 3D model is generated using interpolating mesh algorithm (Curless, 1996).

For acquiring teeth arch 3D model using the described automated procedure it is required about 5 minutes. The resulting 3D model has accuracy of 0.03 mm and includes about 1 000 000 points. Both upper and lower teeth arch 3D models are produced for further occlusion analysis.

2.2 Face 3D model acquisition

For forecasting (and then documenting) the results of treatment an original photogrammetric system for fast textured face 3D model generation is developed (Figure 3).



Figure3. Photogrammetric system for face 3D model reconstruction

It includes two digital IEEE 1394 cameras, structured light projector and 5Mpix still digital camera for texturing face 3D model. Texture mapping is performed in automated mode basing on preliminary system calibration and exterior orientation.

Resulting face 3D model has resolution of 1 mm which is quite enough for face measurements and visualisation (Figure 4.).

But this resolution is low for teeth presentation and could not be used for teeth arch documenting. So another problem to solve is to create multi-resolution face 3D model including high resolution teeth arch 3D models.



Figure 4. Textured face 3D model

An original technique is developed for determining proper teeth arch 3D models position relatively to face 3D model. The 3D model for occlusion visualization and documenting includes a face 3D model and teeth arches 3D model. It is used for presenting the teeth appearance before and after treatment.

3. SURFACE-BASED 3D MODEL POSITIONING

The developed photogrammetric systems allow generating 3D models of teeth arches and of a patient face in automated mode.

To support all tasks to be solved by a dentist a set of 3D models is required. It includes upper teeth arch 3D model, lower teeth arch 3D model, 3D models of some separate teeth, 3D models of separate prepared teeth and a 3D model of patient face. But each 3D model is obtained in its local coordinate system, so it is required to develop a technique for installing this set of models in proper position according a real case. Original techniques are developed for this problems solution (Knyaz, V., 2007).

3.1 Teeth occlusion registration

The first step is to install 3D models of upper and lower teeth arches in a given position according their location and orientation in a mouth. For this purpose plaster models are installed in given posture using a dental articulator or silicon mould for setup (Figure 5). Dental articulator is used for registering central (normal) occlusion. Silicon mould is made by dentist in a mouth, jaws being in given position according left or right side occlusion.



Figure 5. Silicon moulds for plaster casts setup

Then the silicon moulds are placed between plaster teeth arch models providing plaster models being in the same mutual position as real teeth arches in a mouth. 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 (Figure 6.).

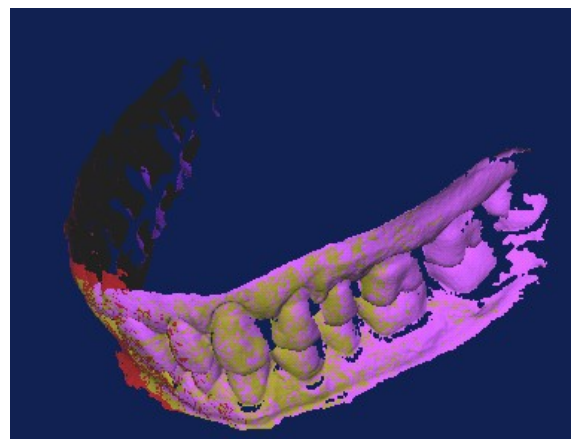


Figure 6. . The scan of the teeth front surface for teeth arch 3D models positioning

After the described procedure a dentist has teeth arches 3D models installed in a position according given occlusion, so he can perform all necessary investigations of the occlusion which he needs. A dentist can observe and study relations of opposite occlusion surfaces in different positions. In order to achieve correct spatial placement of sections, each pair of opposite dental arches was oriented with respect to a given plane in a manner similar to their position in an adjustable articulator – a device to which dental arch models can be attached according to their position in the skull and which is used in occlusion studies and prosthesis construction.

As a further step, it is possible to carry out tooth preparation on plaster casts and to obtain 3D model of prepared teeth for treatment planning. The 3D model of prepared teeth is also placed on it real position applying the developed technique. Later, the 3D model of constructed prostheses for the prepared teeth is obtained and combined with the dental arch 3D models.

3.2 Separate tooth registration procedure

Prosthetic dentistry is aimed at restoring the structure and the function of human dentition. It uses simulation and reproduction of natural features of human dentition for prosthesis manufacturing. For the purpose of the research some individuals with intact chewing teeth is selected. Silicone impressions of their dental arches are made for getting plaster casts; silicone records of different occlusal positions are made for positioning plaster casts; facial bow registrations are performed for mounting plaster casts on an articulator.

After performing tooth preparation on plaster casts restorations are designed on them. In order to obtain the required sections, precise 3D models of dental arches are obtained using plaster casts. Consequently, two opposite 3D dental arch models (upper and lower) are oriented in three positions (centric, one right and one left lateral) determined by silicone occlusal position registrations (Fig 5). Thus it is possible to observe and study relations of opposite occlusal surfaces in different positions.

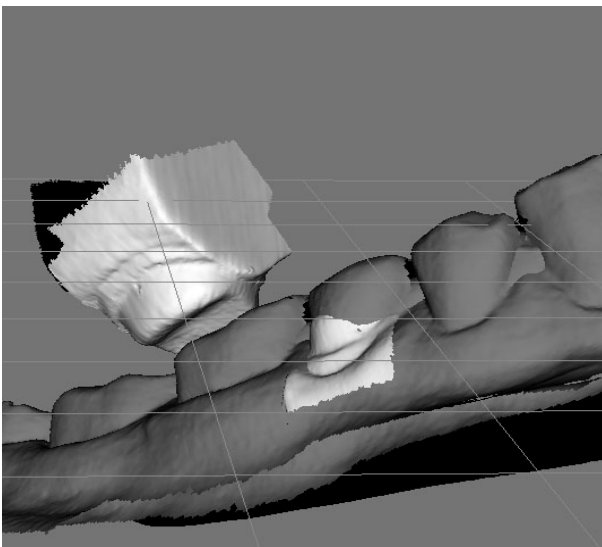


Figure 7. Separate tooth positioning

In order to achieve correct spatial placement of sections, each pair of opposite dental arches is oriented with respect to a given plane in a manner similar to their position in an adjustable

articulator – a device to which dental arch models can be attached according to their position in the skull and which is used in occlusion studies and prosthesis construction. Spatial orientation of 3D models is carried out with the help of reference points on one of the parts of the articulator. As a further step, tooth preparation is carried out on plaster casts and 3D model of prepared teeth is obtained (Fig 7).

Then the 3D models of the dental arch with those of the prepared teeth are matched. As a result the 3D models are spatially oriented in a correct manner. Each of these models consisted of one upper dental arch 3D model, three lower dental arch 3D models (showing three different occlusion positions) and 3D models of prepared teeth (typically two or four prepared teeth). Prostheses were constructed for the prepared teeth at a later stage and their 3D models were obtained and combined with the dental arch 3D models.

3.3 Face - teeth arch 3D models positioning

The next step needed for visualization and documentation of treatment planning and results is to setup teeth arch 3D models in proper position relatively patient face 3D model. For this task solving a special reference object is required because teeth arches of a patient could not be seen enough even when wide smiling.

A dentistry tool for making silicon impression of teeth arches is slightly modified for this purpose by adding a special silicon reference surface on its front (Figure 8.). This reference surface has spatial features for its identifying and matching in different 3D models.



Figure 8. Patient with special reference object for upper teeth arch position registration

For correct position of teeth arch 3D models relatively face 3D model patient face 3D model is acquired in two conditions:

- 1) normal (smiling)
- 2) with the reference object in patient mouth (Figure 8.)

Then upper teeth arch plaster cast is also scanned in two conditions: alone and with special reference object. Then positioning procedure includes the following steps:

- “Smiling” face 3D model matching with face 3D model with the reference object using iterative closest point algorithm for given face regions
- Upper teeth arch 3D model with reference object matching with face 3D model with the reference object in a similar way
- Eliminating 3D models with reference object from the scene resulting in multi-resolution face 3D model including face surface and high-resolution teeth arches 3D models

Results of teeth arch 3D model positioning is shown in Figure 9.



Figure 9. Patient face 3D model with high resolution teeth arch 3D model

For purposes of treatment results forecasting and documenting it is needed realistic presentation of high resolution teeth arch 3D models. To provide this function the system includes a tool for photorealistic teeth arch 3D model texturing using high resolution colour images of teeth arch.

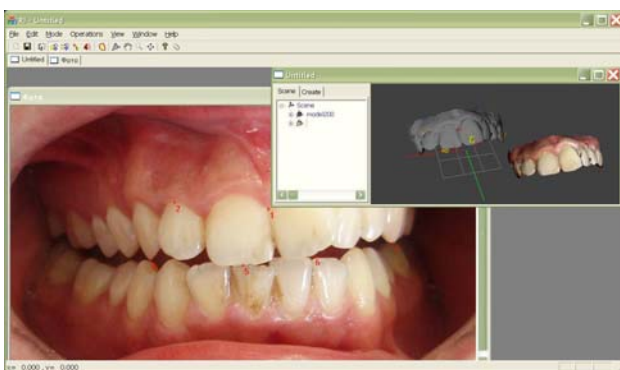


Figure 10. High-resolution texture mapping

Texture mapping is performed according to corresponding points on teeth arch 3D models and colour image marked by operator. Figure 10 presents high resolution image of teeth with markers, 3D model with corresponding points and resulting textured teeth arch 3D model.

4. OCCLUSION ANALYSIS

Further steps require making sections of teeth in bucco-lingual direction. The approaches accepted in prosthetic dentistry practice for obtaining those sections are applied. To perform necessary section and measurement using teeth arch 3D model specialized software is developed. It supports the following functions:

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

Figure 11 and Figure 12 present the user interface of the developed software in form of 3D view (Figure 11) and in form of 2D view (Figure 12).

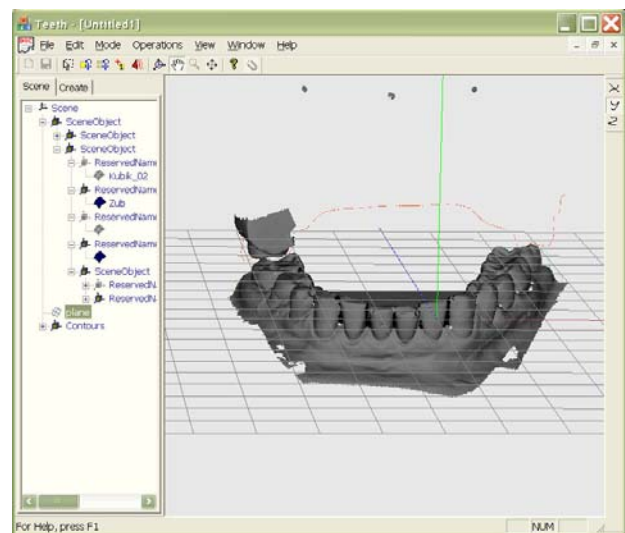


Figure 11. Teeth arch 3D view

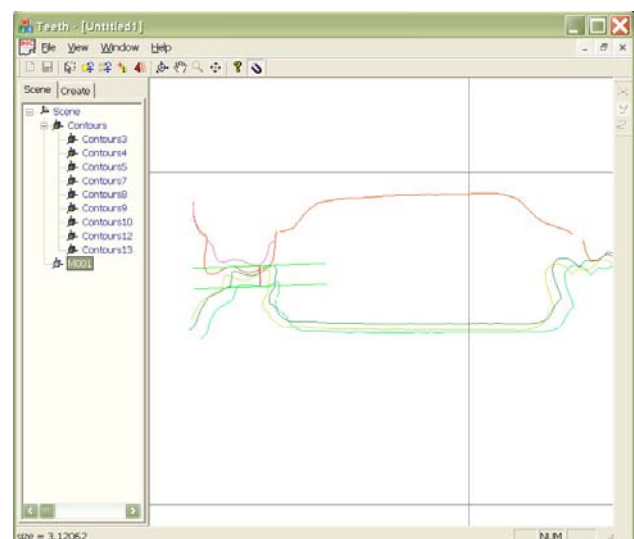


Figure 12. Teeth arch section 2D view

The software allows to section 3D models in a number of ways. Sectioning can be performed manually or in an automatic mode according to chosen reference points. There can be one or more sections, parallel to each other. The sections are depicted as contours on 2D images (Figure12). With the help of the software it is possible to study the correspondence of each prepared tooth contour on a 2D image to contours of the same intact tooth, tooth prosthesis and the opposite tooth and then perform precise measurements on them. Studying and making measurements on sections is the essence of the investigation.

5. CONCLUSION

The photogrammetric techniques for dentistry analysis, planning and visualization are developed. They are based on accurate high resolution 3D models of patient face and teeth arches. The developed original photogrammetric systems provide fast and accurate generating patient face 3D model and full 3D model of teeth arches in automated mode.

Surface-based teeth occlusion registration provides accurate opposite teeth arch 3D models installing in position given by silicon registration mould. 3D modelling of occlusion gives to a dentist valuable mean for teeth hidden surfaces analysis. The accuracy of 3D models reconstruction and arrangement for both methods is sufficient for dentistry applications.

The developed techniques allow fast and accurate generating full 3D model of a teeth arches in given occlusion and a multi-resolution face 3D model for treatment planning and

visualisation. The developed software gives to a dentist new effective and convenient means for teeth occlusion study, treatment planning and documenting.

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