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Three-dimensional Determination of Dental Occlusion and Facial Structures using Soft Tissue Cephalometric Analysis

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Introduction

Soft tissue normals, in the form of facial lines and angles were established in some traditional cephalometric analyses, but they were limited in their number and description – emphasis was placed on skeletal and dental structures within the headfilm. More recently, there has been a re-emphasis on facial balance. Subsequently, new cephalometric analysis was proposed, which suggested a method of soft tissue cephalometric analysis (STCA) and soft tissue cephalometric planning [1]. There have been different attempts to bring a non-radiographic alternative to cephalometric radiograph using 3D scanning of patients, but it has been suggested that the measurements be interpreted with caution.

The aim of the study was to develop a morphometric method as alternative 3D diagnostic technique for evaluation relationship between the occlusion and the structures of the face.

Structure of 3D dental cast scanning system

For acquisition of surface shape of plaster dental arch models, a structured-light 3D scanner was used. This is a device for measuring the three-dimensional (3D) shape of an object using projected light patterns and a camera system. Usually a single camera and single projector system setup is used. This system has the problem of measurement shadow caused by projector and occlusion caused by the camera. For solving these problems the system is composed by two high-resolution cameras, a digital light projector (DLP), rotary table and computer.

A two-axis rotary table automatically reorients dental cast being scanned. The DLP projector projects computer generated digital fringe patterns composing of vertical straight stripes onto the dental cast surface. The dental cast distorts the fringe images so that the vertical straight stripes are deformed because of the surface profile, two cameras from different viewing angles capture the distorted fringe images into the computer, and the computer then analyzes these images to obtain 3D shape information using geometric triangulation typically used in stereoscopic systems. For development of high accuracy 3D scanners usually the scene is illuminated with series of phase-shifted cosine patterns. A four step phase-shifting algorithm was chosen with 90^o steps. In this case, the value of phase φ in camera pixel (x, y) can be expressed as [2]

$$\phi(x,y) = \arctan\left(\frac{I_4(x,y) - I_2(x,y)}{I_1(x,y) - I_3(x,y)}\right), \quad (1)$$

where $I_n(x,y)$ is the intensity value of pixel (x,y) when the n fringe image is illuminated.

The phase, obtained in the interval [0, 2π], is piecewise continuous. In this case, it needs to be unwrapped to obtain true surface profile. To eliminate the need of phase unwrapping procedure the special time-encoded binary code also known as Gray code is used. After displaying and capturing those patterns, the images of both cameras are processed to decode the patterns by matching every camera pixel to unique projected pixel. Once those correspondences are established, the depth of each imaged point can be determined by triangulation. Illumination with a sequence of Gray code patterns yields absolute distance values, but only with poor resolution. In case the number of cosine fringes of phase-shifted pattern is equal to 2^n, the fringes can be aligned with transitions in a sequence of n Gray code patterns. The combination of Gray code patterns and phase-shifting cosine patterns allows forming a continuous function that describes the absolute fringe position in the field of view. The result of those calculations is a point cloud, which is a dense series of unconnected points representing dental cast surface. For surface meshing a special construction named the Power Crust is used [3, 4].

To get the whole 3D shape without missing areas and to get view of small details around undercuts the dental arch cast has been digitized from several different aspects and reunited using algorithm and software for 3D model registration [3].

Fig. 1 shows a photograph of the actual 3D scanning system. In this system Vivitek Qumi Q2 LED pocket projector with resolution of 1280x800 is used. The optical system of projector is changed to achieve smaller working distance. The cameras are digital CMOS cameras with image resolution of 2560 X 1920 and GiGE Ethernet interface (IDS UI-5481SE). Both cameras use Tamron M118FM16 lenses with a focal distance of 16 mm.

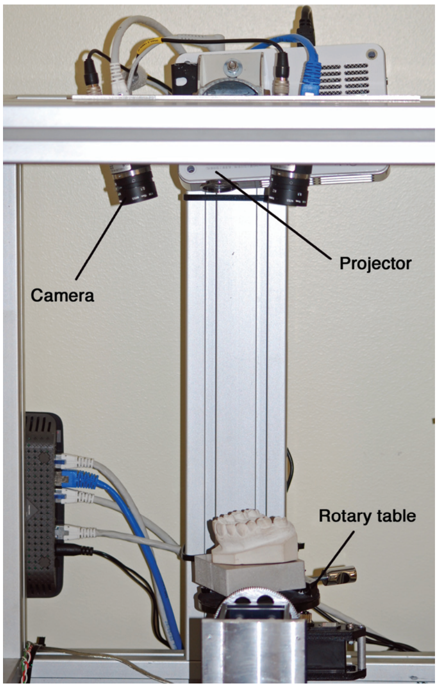

Fig. 1. System setup

3D scanning system software, which was developed by C++ language, can be divided into three stages:

- Capturing the images of the scenes using different projected patterns;
- Decoding captured images and recovering scene depths values;
- Meshing and alignment of 3D models of different views.

For system calibration Camera Calibration Toolbox for Matlab is used. The calibration software uses the routine proposed in [5] where the cameras capture a known pattern from multiple orientations. The extrinsic and intrinsic cameras parameters, used for calculation of depth through triangulation, were evaluated from those images.

Materials and method

In order to assess the geometric parameters of dental arches for orthodontic treatment planning the dental casts of upper and lower jaws must be scanned separately. For generation of whole 3D model of jaw presented in Fig. 2 the dental cast has been digitized from 7 different aspects and reunited using 3D registration and re-meshing software. Therefore, each of 3D models is obtained in its local coordinate system, so it is necessary to align the models of upper and lower dental arches according jaws real position in a mouth.

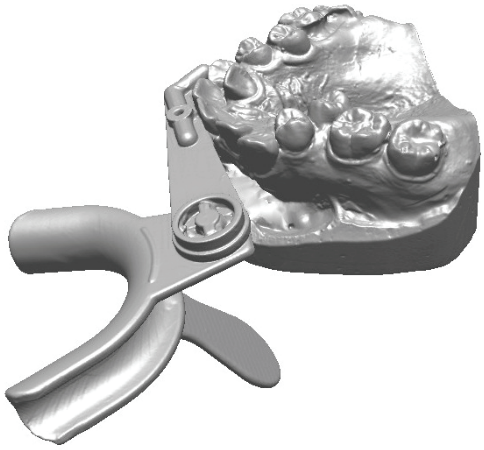

Fig. 2. The model of upper dental cast with reference tool used for this model alignment to face 3D model

True mandibular position was recorded using centric relation bite registration material by clinician dentist. The external surfaces of both plaster models fixed in centric position were scanned using our system. The scan of the models external surface (Fig. 3) was used as a reference surface for alignment of both 3D jaw models using iterative closest points (ICP) algorithm [6]. After this processing both digital models are in a position according given occlusion and can be used for treatment planning.

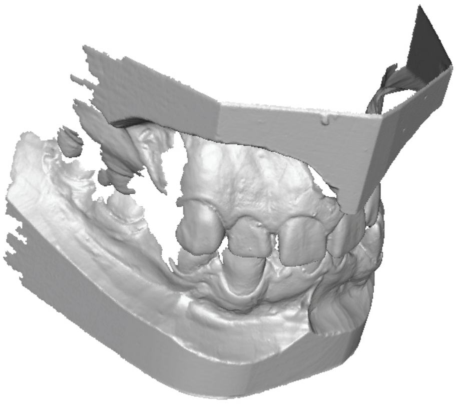

Fig. 3. The scan of plaster models external surfaces used for digital dental models positioning

The orientation and position of occlusion plane can be determined precisely by using 3D digital models of lower and upper jaw. In this case, four points were manually captured on each dental cast 3D model to define the positions of midincisal points on the edges of the central incisors and distolingual cusp tips of the second permanent molars. For each set of 3D models of both jaws, a numerical matrix was created and stored in a data file. This numerical data matrix of coordinates of 8 points was used for determining the orientation of the occlusion plane by using Principal Components Analysis (PCA) [7, 8]. This method can be used to fit a linear regression that minimizes the perpendicular distances from the data matrix to the fitted model. The coefficients for the first two principal components define vectors that form a basis for the plane. The third principal component is orthogonal to the first two, and its coefficients define the normal vector □ $\vec{n}$ of the plane [7].

In order to get morphometric parameters it is necessary to align digital dental cast models in proper position relatively 3D human face model. Human face can be scanned using the same 3D scanning system presented in Fig. 1.

For solving alignment task a reference tool was made-up for young adult referred for orthodontic treatment. This reference tool was composed from the standard molar band with headgear tube (Dentaurum Group, Germany) connected to the part of the stainless steel bow of adult size access cheek retractor (G&H®Wire Co, USA) and light cured with flow composite. The reference tool was required because alignment of the digital dental cast models and digital 3D model of human face with the teeth visible is not enough accurate even when wide smiling.

The dental cast with this reference tool was scanned (Fig. 2). In the next step, the reference tool was fixed on the upper left first permanent molar and human face in natural head position (NHP) was scanned (Fig.4) using 3D scanner. Using the same modified 3D scanning system human face without reference tool was scanned also.

Fig. 4. 3D human face model with reference tool

The reference surfaces are used for matching of different 3D models. The alignment procedure includes the following steps:

1) The digital 3D model of upper jaw with reference tool was aligned to 3D model of maxillary dental arch in centric position using ICP algorithm [6] only for dental surfaces;

2) The digital 3D model of human face with reference tool was aligned to digital 3D model of upper jaw with reference tool using modified ICP algorithm only for reference surfaces;

3) The digital 3D model of human face to digital 3D model of human face with reference tool in mouth using modified ICP algorithm for face surfaces;

4) The digital models with reference tool were removed from scene (Fig. 5).

The orientation of all 3D models must be performed according NHP, because most of cephalometric parameters in STCA are defined according the true vertical line [1]. This line was placed through subnasale and was perpendicular to the NHP. For solving of this task three points were manually captured on 3D face model to define the positions of soft tissue nasion, pronasale and subnasale. The sagittal plane of face symmetry passing through these points was defined (Fig. 5). All 3D models were moved to new position to achieve matching of this sagital plane and x-z plane.

For correction of frontal head inclination of 3D models, three points were manually captured on lateral cephalometric headfilm to define the positions of soft tissue nasion, pronasale, subnasale and mapped from each pixel coordinate to a world coordinate. The face model and matched dental cast models were rotated and moved to achieve matching of these points and 3 point captured on 3D face model.

Cephalometric radiograph was digitized, traced, and analyzed using Dolphin Imaging 10.1 software (Dolphin Imaging & Management Solutions).

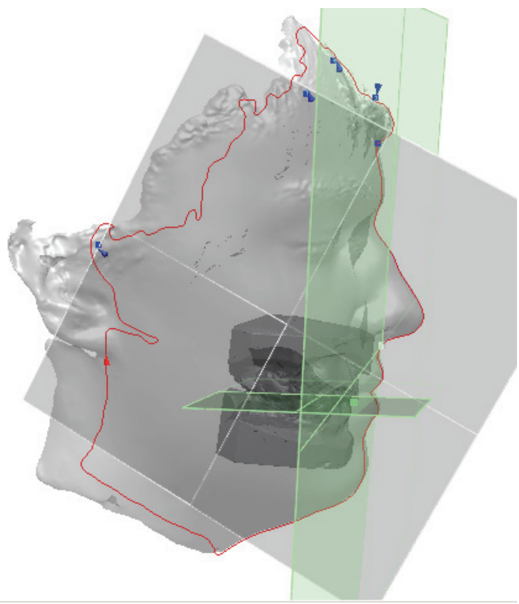

Fig. 5. 3D human face model with the dental cast models aligned according their location and orientation in a mouth. The sagittal plane, occlusion plane and true vertical reference plane are defined

Integrated 3D models of dental casts and human face allow investigating how teeth are relatively located according human face soft tissue surfaces. For definition of true vertical reference plane used for evaluation of cephalometric and morphometric parameters, the spatial coordinates of subnasal point as plane origin and normal vector of sagital plane are used. Then the angular and linear measurements between true vertical plane and occlusion plane or distances from true vertical reference plane and soft tissue landmarks to incisors can be calculated.

Results

The stone model was made by laboratory worker using the methodology practiced at Clinic of Orthodontics (Academy of Medicine, Lithuanian University of Health Sciences). To test the reliability of method the face, upper and lower dental casts of young adult referred for orthodontic treatment were scanned and presented matching procedures were applied. The standard cephalometric lateral skull radiograh was taken as follows: subject stood with the head in NHP with teeth held in centric position. The angle between true vertical reference plane and occlusion plane, the shortest distances from true vertical reference plane to midincisal points of the edges of the central incisors of upper and lower jaw were estimated using presented method and using soft tissue cephalometric analysis software. The angle between vertical plane and occlusion plane calculated from 3D models was 95,054° and resp. 95,1° in STCA; distance from vertical plane to midincisal point on the edge of the right upper central incisor was 9,63 mm and resp. 9,1 mm in STCA; distance from vertical plane to midincisal point on the edge of the right lower central incisor was 13,15 mm and resp. 13,2 mm in STCA. So, the developed technique allows evaluation of morphological parameters used for treatment planning and gives to a dentist new effective and convenient tool for teeth occlusion study and documenting.

Conclusions

1. 3D scanning system and method for integration of 3D digital dental cast models and human face model is presented. Its allows matching human face model, upper and lower jaw dental cast models according their original position in human mouth;
2. The matching procedure needs to be developed to make this method useful for daily practice;
3. This system is useful objective tool for medical tasks solution and further investigations are required in order to confirm effectiveness in orthodontic patients care.

References

1. **Arnett G. W., Jelic J. S., Kim J., Cummings D. R., Beress A., Worley C. M. Jr., Chung B., Bergman R.** Soft tissue cephalometric analysis: diagnosis and treatment planning of dentofacial deformity //American Journal of Orthodontics and Dentofacial Orthopedics, 1999. – Vol. 116. – P. 239–253.
2. **Sansoni G., Carocci M., Rodella R.** Three–dimensional vision based on a combination of gray–code and phase–shift light projection: analysis and compensation of the systematic errors // Applied Optics, 1999. – Vol. 38. – No. 31. – P. 6565–6573.
3. **Adaškevičius R., Vasiliauskas A.** 3D multicamera dental cast scanning system. // Electronics and Electrical Engineering. – Kaunas: Technologija, 2008. – No. 2(82). – P. 49–52.
4. **Amenta N., Choi S., Dey T., Leekha N.** A simple algorithm for homeomorphic surface reconstruction // ACM Symposium on Computational Geometry, 2000. – P. 213–222.
5. **Zhang S., Huang P. S.** Novel Method for Structured Light System Calibration // Optical Engineering, 2006. – Vol. 45(8).
6. **Adaškevičius R., Mačianskytė D., Monastyreckienė E.** Experimental determination of computed tomography settings for jaw scanning // Electronics and Electrical Engineering. – Kaunas: Technologija, 2011. – No. 5(111). – P. 129–132. DOI: 10.5755/j01.eee.111.5.373.
7. **Adaškevičius R., Vasiliauskas, A.** Evaluation of dental arch form using 3D dental cast scanning technology // Electronics and Electrical Engineering. – Kaunas: Technologija, 2009. – No. 5(93). – P. 99–102.
8. **Vasiliauskas A., Šidlauskas A., Šaferis V., Adaškevičius R., Linkevičienė L.** Applications of 3D maxillary dental arch scanning for mathematical prediction of orthodontic treatment need for complete unilateral cleft lip and palate patients // Electronics and Electrical Engineering. – Kaunas: Technologija, 2010. – No. 4(100). – P. 107–112.

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A high accuracy 3D structured-light scanning system and method for integration of 3D digital dental cast models and human face model is proposed. The original two cameras and DLP projector system for surface 3D reconstruction is designed. The techniques for alignment of 3D human face model with the 3D dental cast models according their location and orientation in a mouth is presented. This technique allows evaluation of morphological parameters used for treatment planning and gives to a dentist new effective and convenient means for teeth occlusion study and documenting. This system is useful objective tool for medical tasks solution and further investigations are required in order to confirm effectiveness in orthodontic patients care. Ill. 5, bibl. 8 (in English; abstracts in English and Lithuanian).

R. Adaškevičius, A. Vasiliauskas. Erdvinis okliuzijos ir veido struktūrų santykio nustatymas remiantis minkštųjų audinių cefalometrine analize // Elektronika ir elektrotechnika. – Kaunas: Technologija, 2012. – Nr. 5(121). – P. 93–96.

Pristatoma didelio tikslumo erdvinio skenavimo sistema, paremta struktūrinės šviesos projektavimo metodu, ir dantų erdvinių kompiuterinių modelių bei žmogaus veido modelio integracijos metodika. Sukurta originali erdvinių paviršių kompiuterinių modelių formavimo sistema, sudaryta iš dviejų kamerų ir projektoriaus, ir metodika žmogaus veido kompiuteriniam modeliui ir dantų kompiuteriniams modeliams orientuoti atsižvelgiant į jų padėtį žmogaus burnoje. Tokia metodika leidžia įvertinti morfologinius parametrus, naudojamus gydymui planuoti. Nustatyta, kad ši sistema tinkama taikyti medicinoje ir gali būti toliau tobulinama, kad tiktų plačiau taikyti odontologijoje. Il. 5, bibl. 8 (anglų kalba; santraukos anglų ir lietuvių k.).