3D surface scanning,
facial features analysis,

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THE APPLICATION OF THE 3D SURFACE SCANNING IN THE FACIAL FEATURES ANALYSIS

Facial feature analysis is a basis examination in everyday orthodontics practice. Traditionally it was carried out using the patients photographs and callipers. Although the devices for scanning 3D surfaces have been developed since last decade of XX century their use in supporting orthodontics diagnosis have been limited due to availability and prices. The present work examine the possibility of usage of the 3D surface scanning for orthodontics purposes using professional graphic tool RapidForm. The landmarks-based analysis of facial features and asymmetry of soft tissue is described. Possibilities of surface-based analysis are also illustrated and their limitations are discussed.

1. INTRODUCTION

The main point of orthodontic diagnosis is the qualitative and quantitative assessment of the level of malformation in the facial and oral area of the skull. The diagnosis is based, depending of the kind of the malformation, upon a single cephalogram (X-ray film taken in lateral, frontal or axial projections), a pair of cephalograms taken in two orthogonal projections, or slices and 3D reconstructions yielded by Computer Tomography. The aim of these examinations is to precisely visualize and measure the anatomical structures that allow the patient to be classified to a group with a specific syndrome. Through the same examinations, the progress of the malformation can be assessed and the effects of therapy evaluated. The choice of examination is a trade-off between accuracy and costs and risks connected with each procedure. The slices given in CT examination allow for 3D reconstructions of the structures of bones, muscles and skin. However, every CT imaging has to be strongly motivated due to the significant dose of radiation the patient is exposed to. It cannot therefore be applied in routine procedures for all patients, and cannot be repeated too often even for patients undergoing surgical treatment.

Analysis of facial features is basic examination and is performed intuitively by an expert during every patient examination. To make these studies more repeatable, facial measurements are performed using calipers or are done on photographs of the patient [1, 2]. Since the last decade of XX century, optical methods have been developed to record and visualize 3D surfaces of a head. Those systems described in [3,4] were prototypes or were designed for technical applications and as such they were not widely available for orthodontics purposes. It is, however, possible, in principle, to adapt them. Nowadays when it becomes possible to scan the patient's head in three dimensions, the last requirement is appropriate software to support facial analysis.

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The present work discusses the use of a 3D laser scanner to support the orthodontics diagnosis. After the discussion of traditional methods, and brief description of a 3D surface scanning system, the single-case analysis of 3D head scans is carried out. The use of the landmark-based and surface-based techniques are illustrated together with the inferences that should be taken into account for supporting the orthodontic diagnosis.

2. TRADITIONAL EXAMINATION

The analysis of facial features is a basic examination that is prerequisite for the differential diagnosis of craniofacial malformation, for the choice of therapeutic management method and for the evaluation of treatment results [1, 2]. Usually, the examination is carried out on the patient positioned in standardized conditions, looking at his face from front and from both sides. Additionally, persons with intensified malformation and asymmetric configuration of facial soft tissues are examined in some local areas, such as the body of the mandible, the base of the nose, or the lip areas.

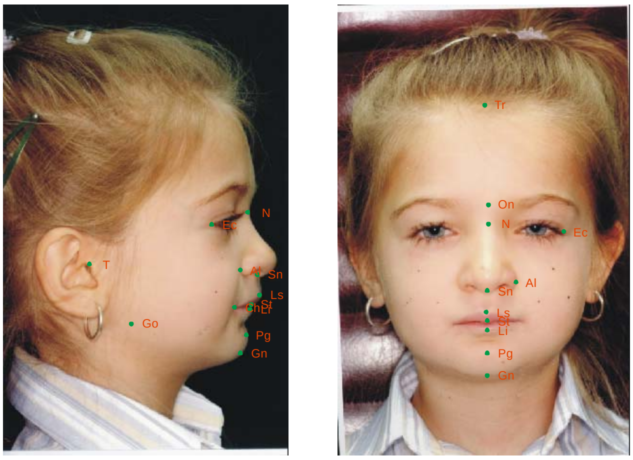

Fig. 1. Soft tissue landmarks

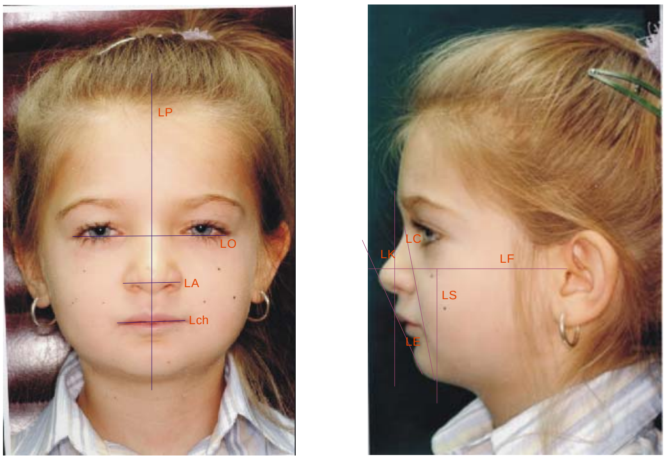

Fig. 2. Reference lines

Traditionally, the examination is carried out directly on the patient or using photos taken in the standardized conditions: during the examination the patient is placed in such a position that the transverse (eyes-ears) plane is horizontal. Other parameters, like the distance from the camera, time of exposition, and lens diaphragm are fixed. Photographs taken in such conditions can be used for longitudinal and inter group studies.

Facial features analysis is performed via a descriptive method. The location of each facial landmark is determined in relation to other landmarks or to fixed reference lines (fig. 1, fig 2). The aim of these linear measurements is the assessment of face proportions and inferences about the protraction, retraction and inclination of some facial area in the reference to other [1,2].

Table 1. Landmarks on lateral and frontal photographs

	Ladmark's label	Definition of localization [1, 2]
N	Soft tissue nasion	Point of maximum concavity between forehead and nose
Sn	Subnasale	Point at which columella merges with upper lip in midsagittal plane
Ls	Labiale superius	Outermost point on mucocutaneous border of upper lip in midsagital plane
St	Stomion	Point between lowermost point on vermilion of upper lip and uppermost point on vermilion of lower lip in midsagittal plane
Li	Labiale inferius	Outermost point on mucocutaneous border of lower lip in midsagital plane
Pg	Soft tissue pogonion	Most anterior point on chin in midsagittal plane
Gn	Soft tissue gnation	Most antero-inferior point on chin in midsagital plane
T	Tragion	Most superior points on tragus of right and left ears
Al.	Alare	Most inferior lateral points on right and left alar bases
Ch	Cheilion	Mucocutaneous borders of right and left commissure of mouth
Ec	Ectocantion	Lateral canthuses of right and left eyes
Go	Sotf tissue gonion	The most lateral point on the mandible angle close to bony gonion
Tr	Trichion	Most antero-superior point on forehead in midsagittal plane
On	Ophryon	Point localized on the crossing of superciliary arches with midsagittal plane

Table 2. Reference lines on lateral and frontal photographs

Le	Rickets' esthetic line
LC	Andersen's central line of profile
LS	Simon' orbital plane
LK	Kantorowicz-Izard's frontal plane
LF	Frankfurt plane
LP	Midsagittal plane
LO	eyes line
LA	alar bases line
Lch	mouth line

3. 3D SURFACE SCANNING SYSTEM

The analysis using photographic method is subject to artefacts and errors resulting from using 2D representations of 3D real structures. The photograph is a projection of 3D structures of the head upon a single plane of the film. Except for a few structures of interest which lie in the plane parallel to the plane of the film, it is impossible to make accurate 2D measurements on photographs, because the structures in planes lying at different distances from camera are enlarged differently. The usage of in vivo 3D imaging systems is limited by their cost and availability (MR) and radiation risk (CT). A high-resolution, repeatable surface data acquisition can be obtained scanning the external surfaces by means of laser-light triangulation devices. Our system for 3d head scanning consists of a Minolta Vivid 9i 3D scanner moving around the patient and a special chair with a headrest, that prevents breathing-related movement of the patient's head and assures unchanging head position during the examination (fig. 3.).

Fig. 3. 3D surface scanning system.

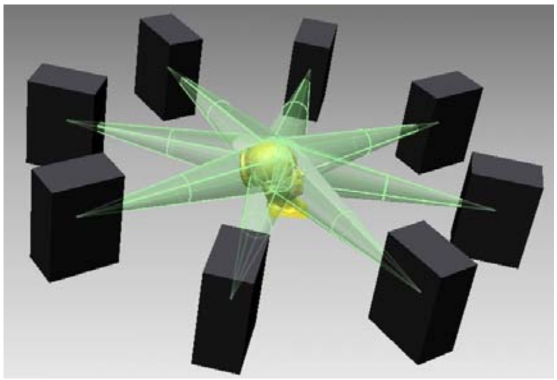

Fig. 4. Scanner viewpoints during acquisition of 3D surfaces.

The scanner can only scan those surfaces which are visible from a given viewpoint. In order to acquire the entire relevant surface of the head it must move around the patient (fig. 4). The scans should be merged together after being brought into register (transformed into a common coordinate system). The determination of scanning parameters and rules for merging scans from different viewpoints are described in detail in [12].

4. FACIAL FEATURES ANALYSIS

Assuming that the system described above yields repeatable surface scans [11,12,13], the aim of this work is to show the usefulness of these scans for supporting orthodontic diagnosis and to prepare assumptions for constructing such a system for routine analysis. There exist the professional, powerful graphics tools designed for technical applications, which could be used for medical purposes but usually they are too expensive for private medical practices. Using the RapidForm software (Inus Technologies)[5] for model analysis and measurement, shell registration and comparison, the analysis of a single case has been done in order to define the assumptions for the system supporting orthodontic diagnosis.

4.1. VISUALISATION

At a patient's first visit, the doctor looks at his face to intuitively assess its symmetry or asymmetry. This glance at his face is made from front when the patient's eyes line is horizontal. Then the patient is asked to slowly nod his head and then to tilt it back, as far as possible, and then to nod it again. During these movements, the body of the mandible, the base of the nose or lip areas and cheeks are examined. Next, both lateral views are compared. The first advantage of having the patient's head scanned is then the possibility to repeat this examination procedure at any time, to determine the reference planes and axes of rotation, and then to rotate surfaces by a chosen angular step.

The software supporting the orthodontic diagnosis should allow the 3D structures to be displayed from different viewpoints. The important issue is then the choice of the local coordinate system which would facilitate the proper positioning of the head.

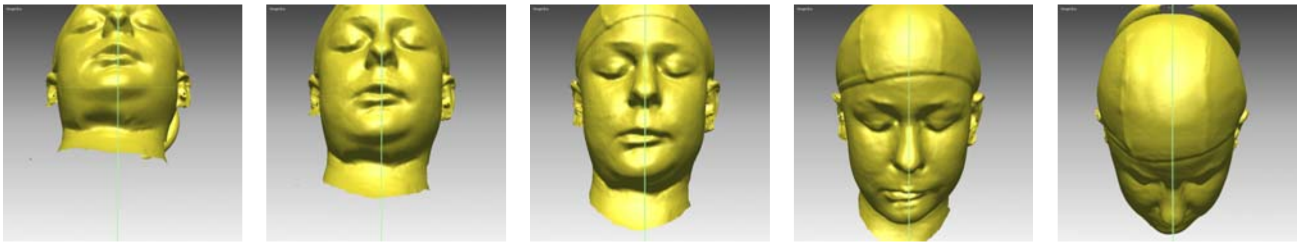

Fig. 5. Visual assessment of asymmetry.

Further advantage is the possibility to store and compare scans derived from different examination of the same patient before and after surgical treatment or from different patients who have to be compared in intergroup studies.

4.2. LANDMARK-BASED ANALYSIS

3D LINEAR MEASUREMENTS

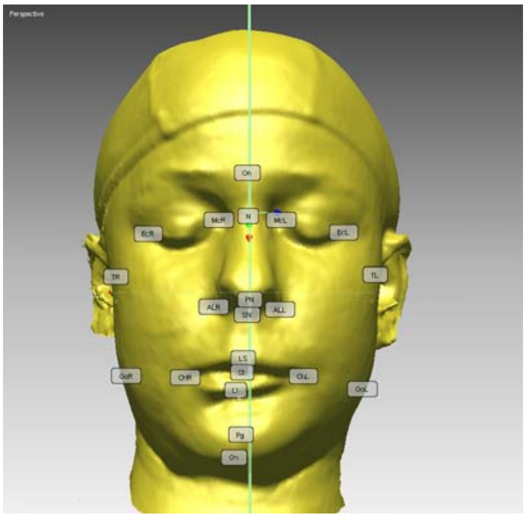

Fig. 6. 3D surface of the head with soft-tissue landmarks

EcL-McL	30.214 mm	LS-St	11.511 mm
EcR-McR	33.947 mm	St-Li	8.477 mm
McL-N	49.703 mm	Ls-Li	16.386 mm
McR-N	52.286 mm	Li-Sl	5.491 mm
EcL-EcR	89.984 mm	Chl-ChR	51.656 mm
N-Pn	45.084 mm	St-Sl	11.199 mm
N-SN	46.572 mm	Sl-Pg	17.109 mm
Pn-SN	13.991 mm	Sn-Pg	53.319 mm
ALL-ALR	29.098 mm	N-Tl	110.787 mm
ALL-SN	16.431 mm	N-TR	115.233 mm
ALR-SN	18.619 mm	Sn-Tl	119.132 mm
ALL-N	45.003 mm	Sn-TR	122.312 mm
ALR-N	44.717 mm	Pg-TL	136.206 mm
Sn-LS	19.742 mm	Pg-TR	135.219 mm

Table 3. Inter-landmarks distances.

Designing the software jointly with a medical expert involves at first the computerization of the procedures that he has been performing manually. Then it becomes possible to adapt solutions found in other application areas to obtain meaningful results in a medical context. The most obvious first step is to directly adapt planar analysis of facial features to the analysis of surface scans.

Although each landmark has its definition, that would help in proper localizing, but all landmarks cannot be automatically detected. There are landmarks, which can only be found by touching real face before they could be localized on its 3D reconstruction. The definition of landmarks usually contains phrases like most anterior, superior, inferior etc. The possibility to find a point lying at min coordinate in some local coordinate system will help in the proper localization of those landmarks. Because of the fact the most measurements and comparisons are using landmarks coordinates these landmarks should be stored in the data base together with the scans for further use.

Landmarks corresponding to those found in 2D photographs were selected and localized on the 3D surface of the head (fig. 6). Then the linear measurements were performed. The results are shown in tab.3. These measurement are then a basis for 3D assessment of face proportions. Now the real 3D values of protraction, retraction and inclination of some features with the reference to other are available, and these data should be used in diagnosis and stored in medical documentation.

4.2.1. ASSYMETRY MEASUREMENTS

Facial asymmetry is a relatively common feature which concerns the orthodontic patients and healthy people as well. Furthermore the analysis of facial esthetics performed in [3] showed that a considerable number of faces regarded as beautiful or handsome (model faces) had a slight asymmetry with the left side shorter than the right while the mean faces of normal European samples were symmetrical. But facial asymmetry is often much more pronounced in patients with dentofacial deformities [1, 2, 9].

Usually the assessment of facial asymmetry consists of measurements made to the midsagital plane or by comparing paired measurements of bilateral features [1, 2]. Some newer methods suggest the use of geometric morphometry as more informative then comparing right and left measurements[6, 7].

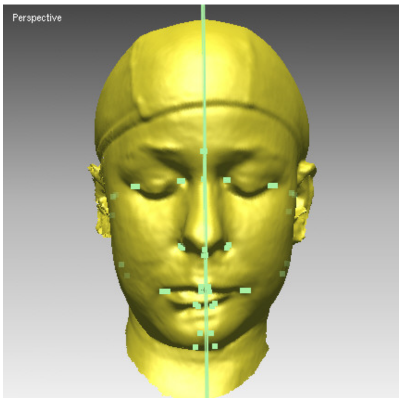

Fig. 7. Asymmetry measurement

The landmarks digitized for 3D linear measurements can also be used to evaluate asymmetry. For the current configuration of landmarks the mirror configuration can be generated. The OPA analysis [6, 7] allows those configurations to be superimposed. The individual symmetric configuration can then be generated as a mean of original configuration and the reflected version after aligning. The mean squared distances between landmarks in the original configuration and their counterparts in the individual symmetrical configuration can be treated as global asymmetry measure. A perfect symmetrical face would have this coefficient equal to 0. The coefficient increases as the face becomes more asymmetric.

4.2.2. STATISTICAL ANALYSIS,TREATMENT RESULTS EVALUATION, LONGITUDINAL STUDIES

The landmarks-based approach can be easily used to compare two or more samples. These samples can be obtained from two scans of the same patient scanned before and after surgical treatment or from different patients who have to be compared in intergroup studies. The landmarks facilitate analysis because they contain the homology information. For the analysis the methods described in [6,8] like Procrustes Analysis, Principal Component Analysis, Multilevel Deformation Analysis can be used. But methods of morphometric analysis usually are not implemented in graphical software, but they should be implemented in the system supporting orthodontic diagnosis.

4.3. SURFACE-BASED EXAMINATION

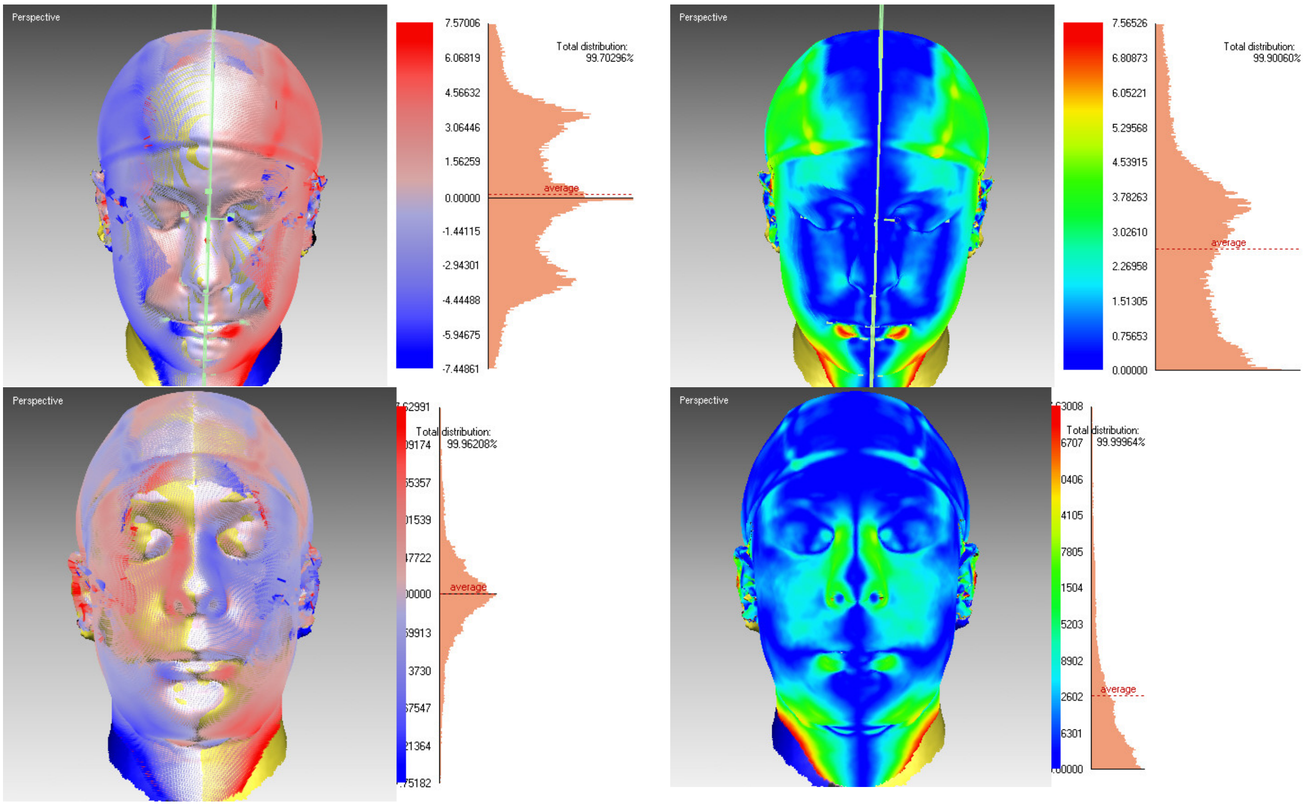

Fig. 8. Displacement and distances between original and reflected heads for two different registrations.

The 3D surfaces of a head derived from a dense 3D point cloud, contain the richest information. The obstacle to use this raw data is lack of the correspondence between points in different surfaces. All the shape analysis techniques used in previous sections requires this property of correspondence. Finding this correspondence strongly depends on the registration algorithms. Although there exist powerfull graphical techniques that enable the visualization of differences between surfaces they, can be misleading in the interpretation of results if the proper registration was not applied. In fig the upper and lower images show the differences measured in two different registrations. On the left the differences are shown as displacement vectors. On the right, they are shown as distances between two surfaces. The result is then strongly dependent on the registration technique. Without the medical knowledge it is difficult to find which registration is correct. Searching for the correct registration is then the nontrivial task which demands the cooperation between the orthodontics and computer scientists. When this obstacle is overcame it will be possible to apply advanced computer graphics algorithms for designing new methods of description of changes between two or more 3D surfaces which can be used in orthodontic practice.

5. CONCLUSIONS

The present paper shows the possible applications of 3D surface scans in orthodontic diagnosis. The typical landmarks based measurements have been described and the assumptions for this application have been established. The computer program supporting these measurements should include besides the graphical techniques also the methods of morphometric analysis. The usage of surface-based evaluation is dependant of correct registration of scans. Computerized evaluation of 3D scans can become a powerful tool of orthodontic diagnosis. Besides availability of 3D information about patients geometry stored in the database, possibility to perform real 3D measurement, one of the greatest advantage is the prospect to create 3D models and norms for soft-tissues and their growth. When using it, however, it must be kept in mind that the results obtained depend very strongly on the way the tool is applied. The geometric structure of the human head is extremely complex and its constituent elements are intricately interdependent. Consequently, the correctness - or otherwise - of any parameters measured is always assessed relatively to other parameters. In fact, it will often be the practitioner - and not the computer system - that will decide which anatomical structures are used as reference for others. It is imperative that this decision be taken with full knowledge of its significance.

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