

COMPUTER AIDED SYSTEM FOR ORTHOGNATHIC DIAGNOSIS UTILIZING 3D GEOMETRIC HEAD MODEL

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Abstract

In this paper, we propose a computer aided diagnosis system that facilitates the drafting of treatment plans, the simulation of orthognathic surgery and the prediction of postoperative features.

The three-dimensional (3D) display of the oral and maxillofacial region is very efficient for dentists to understand a patient symptom and draft an appropriate treatment plan. To achieve this purpose, we propose a construction method of a 3D head model, which consists of soft and hard tissue. Utilizing feature points extracted from ortho-directional X-ray images and facial images, a standard head model can be modified to adapt an individual head shape. Using this head model, we can predict surgical modification of soft and hard tissue.

Keywords

Computer aided diagnosis, Surgery simulation, Anatomical modeling, Facial model, Visualization.

1. Introduction

In recent years, technology of computer graphics and virtual reality plays an important role in a medical field. Especially, 3D visualization of human body information is the most applicable topics to comprehend medical symptoms. By combining the medical image processing and scanning technology, highly realistic medical images can be visualized in two or three dimension for medical treatment and planning.

As for medical applications related to a craniofacial region, some visualization and modeling methods have been proposed to facilitate the drafting of treatment plans, the simulation of craniofacial surgery and the prediction of postoperative features. The 3D images reconstructed by CT, MRI and visualization techniques in computer graphics enable doctors to understand patient symptoms accurately and select appropriate treatment plans. The two main aspects are of interest in the craniofacial surgery simulation: the individual head modeling and the

facial surgical simulation. The 3D head model of a patient is required to investigate the morphology of soft and hard tissue, and execute preoperative surgical simulation.

In the field of dentistry, the three-dimensional visualization of maxillofacial region is strongly urged by doctors for both of orthodontic studies and actual diagnosis. Nishi proposed a method for integrating the maxillofacial 3-dimensional CT image and the 3-dimensional dental-surface image for the sake of obtaining maxillofacial 3D images applicable to surgical orthodontic treatment simulations [1]. Miyajima developed a 3D measuring system for transferring measurements from 3D reconstructed CT, X-ray images (cephalogram) and a dental cast [2]. Both of the studies visualize a maxillofacial region of a patient for assisting dental surgeons to plan surgical procedures. 3D-CT used in these systems is the most effective way to acquire accurate 3D shape data of bone and soft tissue together. However, 3D-CT scan exposes patients increasing amount of radiation so that it is hard to use for normal dental treatments. In addition to this safety problem, a CT scanner is expensive.

In this paper, we propose a computer aided diagnosis system that facilitates the drafting of treatment plans, the simulation of orthognathic surgery and the prediction of postoperative features.

The 3D display of the oral and maxillofacial region is very efficient for dentists to understand a patient symptom and draft an appropriate treatment plan. To achieve this purpose, we propose a construction method of a 3D head model, which consists of hard and soft tissue. For effective and low cost visualization of a head, a 3D wire-frame model is introduced to express standard head shape of a man/woman. Utilizing 3D coordinates of feature points extracted from ortho-directional X-ray images and facial images, a standard head model can be modified to adapt an individual head shape. This method realizes quick, realistic, and safety modeling compared to CT-based modeling method. The constructed head model can be effectively used to execute orthognathic surgery simulation.

We organize this paper as follows: In Section 2, we summarize 3D analysis of maxillofacial morphology in orthognathic treatment. Then we introduce the basic concept of our modeling method. In Section 4, we present the standard head model that recreates anatomical structure of a head. In Section 5, we describe feature extraction method from X-ray images and facial images to construct an individual head model. Next, we demonstrate our surgical simulation system and results in Section 6. Finally, we conclude this paper with some discussion and future works in Section 7.

2. 3D Maxillofacial Analysis

This section explains how maxillofacial morphology is analyzed in treatment simulation of orthognathic surgery.

Generally, single plane cephalometric analysis can be practically used in dental field. Cephalometric analysis that uses a lateral-view (LAT) cephalogram is an integral part of a craniofacial evaluation that includes history taking, clinical examination, medical photographs, and evaluation of orthodontic study models. Fig.1 (a) and (b) show PA and LAT cephalometric radiographs. Fig.2 (a) and (b) are the cephalograms that manually traced by a dental doctor.

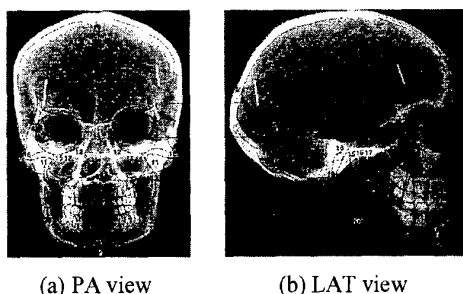


Fig.1 Cephalometric radiographic images

According to increasing requirement of 3D analysis of maxillofacial morphology, multiplane cephalometric analysis integrating information from posteroanterior (PA) and lateral (LAT) cephalometric radiographs have been proposed, although it involves radiographic image distortion and tracing measurement error [3][4]. Some previous studies measured the 3D coordinates of anatomical measurement points on a skull, and constructed 3D wire frame model to visualize its morphology. However, the number of measurement points is limited so that output model lacks reality.

3D-CT is currently regarded as the most effective method that for acquiring highly accurate 3D data of

bone and soft tissue. Fig.3 displays the reconstructed 3D-CT images of a skull. However, 3D-CT scan exposes a large amount of radiation so that it is hard to use for normal dental treatments. Therefore, several measurement systems using 3D-CT data have been developed, but they are not in practical use because of these problems.

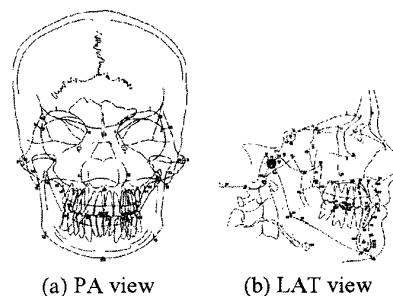
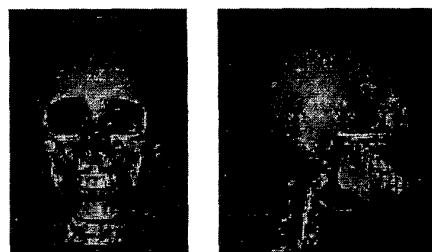


Fig.2 Cephalometric tracing (Cephalogram)

3. Basic Concept of Head Modeling



In this section, the outline of our 3D head modeling method is described. The basic concept of the method is shown in Fig.4. The modeling flow is summarized as follows :

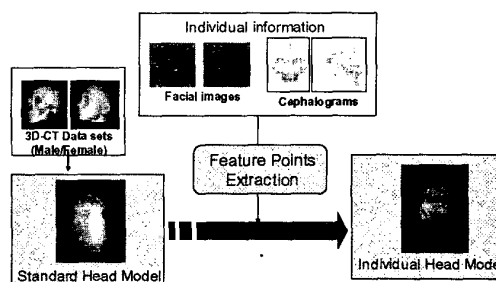


Fig.4 Concept of the head modeling

Step1. Standard skull/face model construction

Using 3D wire frame models and 3D-CT data, we constructed standard head model which is utilized as the basic model in order to represent arbitrary head shape.

Step2. Feature points extraction from facial images and cephalograms of a patient

The feature points are manually plotted and accurate 3D coordinates of them are obtained by the 3D cephalometric measurement method that involves head orientation correction and X-ray image distortion. The facial feature points are automatically extracted from ortho-directional facial images (frontal and side views).

Step3. Individual model construction by modifying the standard model

The standard head model is modified to the patient model by referring extracted feature points in step 2.

This modeling method realizes quick, realistic, and safety modeling in compared to CT-based method. The constructed head model can be effectively used to execute orthognathic surgery simulation. In the following Sections 4 and 5, we describe each step in detail.

4. Standard Head Model

4.1 Standard Skull Model

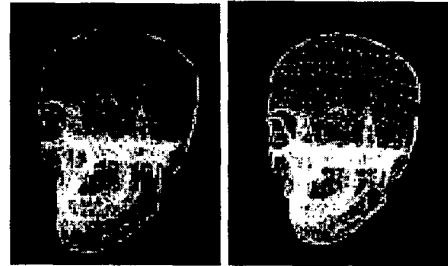
As a base of the skull model, we use an available 3D polygon model (Viewpoint corp., USA) that can be divided into three parts, a skull, teeth, and a mandible. This model has a sufficient number of points (5072 points and 7757 polygons) enabling it to display the realistic skeletal morphology in a maxillofacial region.

In order to construct an average male/female skull model, we acquired 3D-CT data of five Japanese males and five females under consent of the ethics committee of Kyushu Univ. The CT slices are integrated and the 3D image of the skull can be displayed as shown in Fig.3. We manually measured the 3D coordinates of 67 feature points of all persons using the medical image measurement software (MAGICS) as shown in Fig.5, and calculated average 3D coordinates of each point. The corresponding points were also selected on the viewpoint skull model.

According to the obtained average 3D coordinates of all measurement points, the skull model can be modified by 3D interpolation. Fig.6 illustrates the constructed male/female models that represent morphological characteristics of Japanese.



Fig.5. Measurement point extraction on CT data

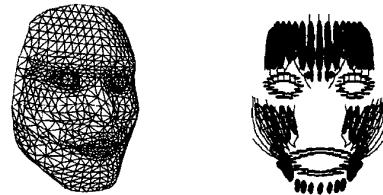


(a) Male (b) Female

Fig.6 Standard skull model

4.2 Soft Tissue Model

As a standard face model, we introduce the anatomical facial model proposed in [6]. This model is originally constructed from individual CT data of a male, which has 751 points and 1288 polygons (Fig.7 (a)). By the same method of standard skull model construction, we are planning to make standard male/female face models. This wire frame model is regarded as a mass-spring model to simulate skin elasticity. Muscular tissue underlying skin is also simulated as flex non-linear springs to express facial dynamics (Fig.7 (b)) [6].



(a) Face Model (b) Muscle Model

Fig.7. Standard face and muscle model

5. Individual Model Construction

5.1 Feature points extraction of skull

For the cephalometric analysis, anatomical measurement points are frequently used in order to discuss maxillofacial morphology. From the 2D coordinates of each point on the cross-directional cephalograms, the 3D coordinates can be calculated by integrating them. However, a head is projected onto the image planes as expanded images and rotated images. So both of radiographic image distortion and head rotation should be compensated to obtain precise 3D coordinates of points.

As shown in Fig.8, the point on the subject A_o (x_o , y_o , z_o) is enlarged and projected as the point A_{LAT} (y_{LAT} , z_{LAT}) on the picture plane (YZ plane). As for compensation of this distortion, the coordinates of the measurement point A_o can be computed by following adjustment as shown in (1). The value of k is the distance from Y axis, so that it depends on each measurement point.

$$y_o = y_{LAT} \times \frac{L_1 + k}{L_2}, \quad z_o = z_{LAT} \times \frac{L_1 + k}{L_2} \quad (1)$$

Although a head is fixed by the ear rods, slight head rotation around each axis is unavoidable in capturing X-ray images. From the symmetric measurement points, the rotation angle around each axis can be automatically detected as indicated in Fig.9. The measurement point is projected to the incorrect position (x_{PA} , y_{PA}) on the XY plane. The rotation adjustment around x-axis can be calculated by eq.(2). Then, the line ($y=y_{PA}$) is drawn on the PA cephalogram, and the exacted value of x_{PA} is obtained by the cross section with the skull contour using equation (3). The rotation angle θ around each axis can be automatically calculated from some measurement points.

$$y_{PA} = \frac{L_2(L_1 + k)(Z_{LAT} \sin \theta_x + y_{LAT} \cos \theta_x)}{L_1 L_2 + (L_1 + k)(Z_{LAT} \cos \theta_x - y_{LAT} \sin \theta_x)} \quad (2)$$

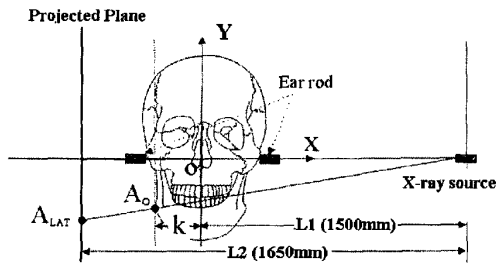
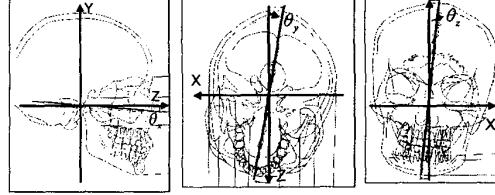


Fig.8. Radiographic Image Distortion



$$x_o = x_{PA} \times \frac{L_1 + z_o}{L_2} \quad (3)$$

Finally, rotation error around other two axes is corrected, and accurate 3D coordinates of the 67 measurement points can be acquired for the individual modeling of a skull.

For quantitative evaluation of 3D cephalometric measurement, we compared the coordinate values of points extracted from cephalograms with those of points extracted from 3D-CT. As a result, we confirm that average mean square error for each point can be decreased from 3.1mm to 1.1mm with the 3D rotation compensation.

5.2 Feature points extraction of face

From a frontal facial image, the contours of eyes, a nose, a mouth and the facial outline are automatically detected to locate facial parts of the model. The recognition is realized by the combination of popular techniques, such as skin color extraction, template matching, and active contour model. This software was developed by IPA, Japan, and we refine this to be used for our method. More detailed information about this method is described in [7]. Throughout these processes, the contours of eyes, a nose, a mouth, and the facial outline are detected and some feature points on those contours are extracted at regular intervals.

The facial profile is also important to improve the quality of a 3D model. We detect the points on the facial contour that has a large curvature as the feature points. The value of curvature along a facial profile can be computed.

From the general facial structure, the sequence of the convex points and the concave points are determined and used for the feature points detection. Fig.10 shows the detected facial feature points using this technique.

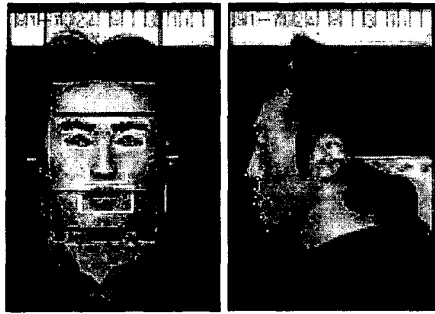


Fig.10 Facial feature points extraction

5.3 Model Deformation

Next, the standard face and skull model are arranged to the individual head shape. Referring the calculated coordinate value of each measurement point, the corresponding point of the model is moved, and the other points that have no corresponding points are automatically localized by 3D interpolation using surrounding measurement points. Fig.11 displays the constructed skull and face model. Especially, the skull model has high accuracy by introducing a sufficient number of measurement points.

For evaluation of skull modeling accuracy, we compared the projected lateral cephalogram of the constructed skull model with the actual lateral X-ray image. Fig.12 reveals that the result is approximately close to the target shape.

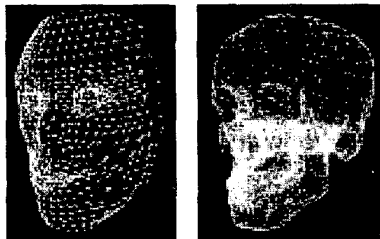


Fig.11 Constructed Individual Head Model

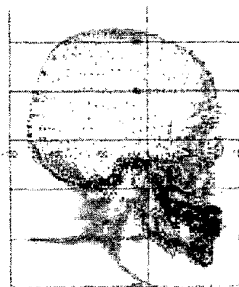


Fig.12 Evaluation of the skull modeling

6. Orthognathic Surgery System

6.1 System Overview

On the occasion of the orthognathic surgery simulation, surgical parameters are required to obtain appropriate jaw position. For instance, a jaw bone should be cut and moved backwards with rotation in actual surgical procedure for the case of mandibular prognathism. Surgeons input surgical parameters to the system, and the predicted result is displayed in the window. This system enables surgeons to select and try typical surgical procedures such as cutting and shifting of the bone by mouse operation, and helps to make plans for the surgery in advance.

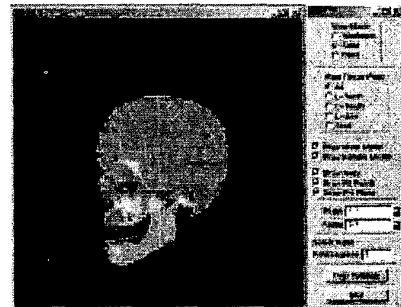


Fig.13 System Overview

6.2 Simulation Result

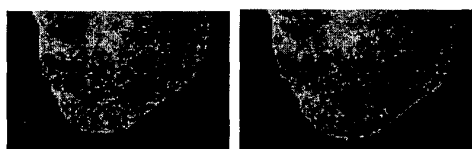
As for the orthognathic surgery simulation, we tested the simulator on actual patients who have a case of mandibular prognathism. In order to execute surgery simulation, we input surgical parameters such as the backward distance of a jaw bone, rotation angle around each axis. The values of surgical parameters are determined by the results of surgical planning of the dentists. Fig.14 illustrates the predicted skull model after surgery.



(a) Before

(b) After

Fig.14 Surgery result (Hard tissue)



(a) Before (b) After

Fig.15 Surgery result (Soft tissue)

Fig.15 shows the predicted mandibulofacial shape after surgery caused by the jaw bone deformation.

The soft tissue modification is simulated by solving kinetic equation for the whole spring system of the head model. Thus, the proposed system is able to simulate both of soft and hard tissue deformation followed by orthognathid surgery. The results confirmed the effectiveness of the system in accrual orthognathic surgery planning.

7. Conclusions

In this paper, we propose a computer aided diagnosis system that facilitates the drafting of treatment plans, the simulation of orthognathic surgery and the prediction of postoperative features.

To achieve the three-dimensional display, we propose a construction method of a 3D head model, which consists of a skull and soft tissue. For effective and low cost visualization of a head, a 3D wire-frame model is introduced to express standard head shape of a man/woman. Utilizing 3D coordinates of feature points extracted from X-ray images and facial images, a standard head model can be modified to adapt an individual head shape. This method realizes quick, realistic, and safe modeling in comparison with CT-based method so that it is expected the proposed method can be put in practical application in orthognathic treatment. Our simulation system enables surgeons to try typical procedures, predict and effectively display the surgical result of the maxillofacial bone and soft tissue by 3D image.

For future works, we should evaluate surgical simulation result and usability of the system through clinical tests for more surgical cases. We are working toward practical use of this system in actual orthodontics studies and applications.

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