30th Annual International IEEE EMBS Conference
Vancouver, British Columbia, Canada, August 20-24, 2008

The implementation of an integrated computer-aided system for dental implantology

Guangchao Zheng[1], Lixu Gu[1*], Zhe Wu[1], and Yuanliang Huang[2*], Lu Kang[2]

Abstract—**This paper presents an implementation of different functionalities on a computer-aided system for dental implantology. The integrated system consists of two subsystems corresponding to two main stages of dental implantology respectively. In the preoperative planning subsystem, we provide different kinds of views based on CT data scanned from a specific patient for the dentist. And the dentist can plan implant path according to these views. The intra-operative navigational subsystem uses an infra-red light based navigation camera to locate the precise position of the surgical instrument. At last, an improved experiment on a phantom model studied the error and accuracy, to demonstrate its feasibility on further clinical trial.**

Keywords—**Dental implantology, Computer assisted surgery, Surgical planning, Imaging, Navigation**

I. Introduction

In recent year, computer-aided methods have been introduced as supportive tools in implant dentistry, and are becoming more and more useful in both preoperative and intra-operative stages for dentists. [1] Currently, multiple kinds of commercial software have been developed aiming at the growing market of dental implantology in many developed country, such as SimPlant, Materialise, Leuven, Belgium; coDiagnostiX, IVS-Solutions AG, Chemnitz, Germany; Med3D, med3D AG, Zurich, Switzerland [2]. Most of these commercial systems are mainly for preoperative planning stage of implantology. On the other hand, intraoperative navigation systems are also being researched and put into use, either on a jaw splint or a real patient. [3]

Under the consideration of smoothing the data flow between these two stages of dental implantology, an integrated system with both preoperative planning subsystem and intra-operative real-time navigational subsystem is developed. The system is built under the close cooperation with dentists in public hospital. The implementation of the whole system is introduced in this paper.

.

II. Implementation

A. Overview

The whole integrated system consists of two subsystems. And their collaboration and architecture is introduced in a previous paper[4]. Its detailed implementation is introduced in this paper.

B. Generation of the dental arch line

In traditional dental implantology, dentist will need cross section images to perform surgery. In order to generate these images, a dental arch line should be created beforehand, so that the images can be generated along this arch line. The line will also be used to generate panoramic view. In the system, control points drawn by dentist are used to interpolate the arch line.

The dentist first decides where the control points go. After selecting which slice of the volume data to draw on, the dentist can pinpoint the control points according to experience. The control points are used to interpolate a cardinal spline which is deemed as the dental arch line. A cardinal spline passes smoothly through each control points in the array and there are no sharp corners and no abrupt changes in the tightness of the curve. So it is considered suitable for representing dental arch, shown in the following Fig 1 and Fig 2.

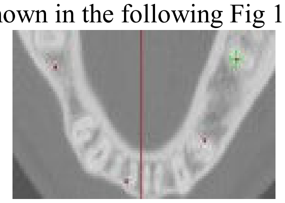

Fig. 1 Control points

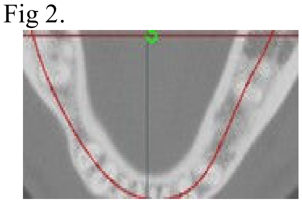

Fig. 2 Interpolation of dental arch

C. Generation of cross section images

During dental implantology, dentist relies on the cross section images to perform surgery. So in the preoperative planning stage, the system will provide a series of cross section images perpendicular to the arch drawn by pervious stage. In order to generate those images, this module should be given five inputs as follows:

(1) One basic point on the dental arch which will also be situated on the cross section images

(2) Dental arch line generated in the previous stage, from which its tangent can be calculated out. And the normal vector of the cross section image(plane) is aligned to this tangent on the basic point determined by the first stage

(3) Up vector which is aligned to the normal direction of occlusal plane

(4) The x and y offset between the basic point and the expected origin of the cross section plane

(5) Width and height of the image to be generated.

Fig.3 shows how the image is generated.

[1]Image Guided Surgery and Therapy Lab, School of Software, Shanghai Jiao Tong University, Shanghai, China
[2]Department of Dentistry, Shanghai Eastern Hospital, Tongji University, Shanghai, China
*Corresponding authors

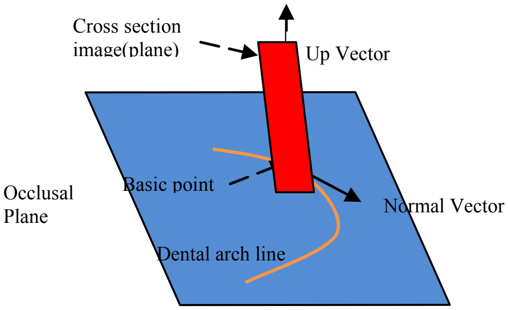

Fig.3 Spatial relation between cross section images, dental arch line and occlusal plane

For each basic point on the dental arch line, the system will generate one slice of cross section image. So the dentist can see each slice of cross section image along the dental arch line. And the number of basic points on the dental arch will be predefined when generating the arch line.

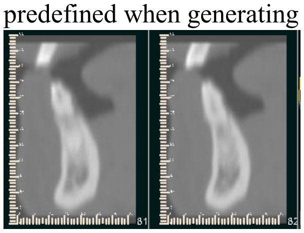

Fig.4 One slice of cross section and its neighboring slice

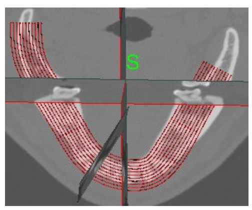

Fig. 5 The image's position on the dental arch line.

D. Panoramic view creation and mandibular nerve delineation

In the planning stage, dentist needs to know some very important anatomical structure, such as mandibular nerve, if the surgery is to be performed on mandible. However, in the cross section images generated previously, it is very difficult for dentist to identify the location of mandibular nerve. Therefore, panoramic view should be constructed for dentist. In the panoramic view, dentist will easily find the mandibular nerve, and use the system to draw out the nerve as two lines. The nerve line will be simultaneously depicted on the cross section images.

Panoramic view will be based on dental arch line created previously. Its main idea is to straighten the arch line and do the same transformation to the whole image data. A simplified algorithm is developed.

1) Panoramic view creation.

The dental arch line is not a smooth curve, but a set of straight lines. The main idea is to use these short straight lines to construct a flat plane(in Fig. 6). In VTK platform, class vtkImageAppend is applied to form this panoramic plane.

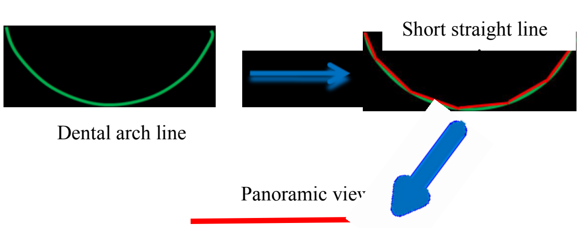

Fig.6 The creation of panoramic view

2) Transformation of the coordinate system:

After the creation of panoramic view, a map between the local coordinate system of the panoramic plane and the world coordinate system should be constructed as well, so that the dentist can draw mandibular nerve line on the panoramic view. As mentioned above, the panoramic view plane consists of several slice planes, which are in the same size w.

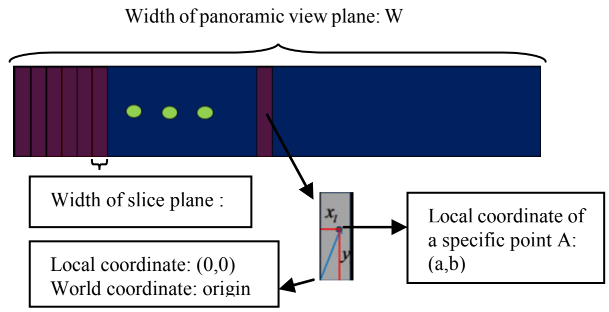

Fig.7 The relation between world and local coordinate

- *Local coordinate transfer to world coordinate:*

Each slice plane contains their own data in the world coordinate, such as origin (lower left point), level vector and up vector. From the window system, local coordinate of a specific point A is known in the panoramic view plane. After several steps of arithmetic operation and vector calculation, the world coordinate of point A will come out.

(1) Get local coordinate of the point A in the panoramic view plane: A（x_l, y_l）

(2) Find which slice plane the point is on by this equation: $n = \left\lfloor \frac{x_l}{w} \right\rfloor + 1$ Here n is the order of the slice plane, where the point locates, in the planes series. w is the width of each slice.

(3) Get the spatial data of the nth slice plane: origin, level vector and up vector. All of them are on world coordinate

(4) Get world coordinate of the given point A by the following equation. $(x_w, y_w, z_w) = \vec{v}_l \cdot x_l + \vec{v}_u \cdot y_l + P_o$.

(x_w, y_w, z_w) is the world coordinate of the given point A. $\vec{v}_l$ and $\vec{v}_u$ is the level vector and up vector of the slice plane respectively. And P_o is the origin in world coordinate.

All the above steps compose a routine called locateToWorld Transform. This transform is the core of mandibular nerve delineation module.

- *World coordinate transfer to local coordinate:*

WorldTolocate transform is the reverse transform of locateToWorld transform. This transform is mainly used when the planned drilling path is projected on the panoramic view. But the approach used is not a simple reverse operation. Suppose a point A with a world coordinate (x_w, y_w, z_w) is to be transformed to locate.

(a) What should be decided first is which slice plane the point A belongs to, to be more precise, projects on. As mentioned above, the origins of each slice planes which compose the panoramic view plane are stored, in world coordinate. So the distances between point A and all these origins can be calculated out. Find the two nearest origins, namely o_{n1} and o_{n2}. According to geometric fact, these two origins belong to two consecutive slice planes respectively.

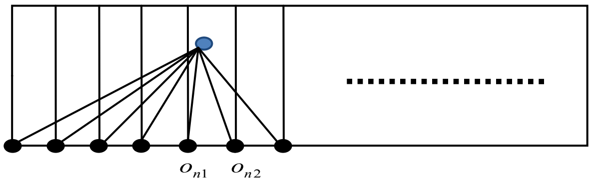

Fig.8 Decide which slice point a specific point is on

Suppose o_{n1} and o_{n2} are the two origins with the shortest distance to point A, and Distance(o_{n1} , A) < Distance(o_{n2} , A). From the figure, it is very clear that point A is situated on plane with o_{n1} as is origin.

(b) After deciding which slice plane(the target plane) point A is on, A's local coordinate on panoramic view plane can be calculated by the following:

$$x_l = n \cdot w + Distance(o_{n1}, A) \cdot \cos(\theta) \quad (1)$$

$$\cos(\theta) = \frac{\overrightarrow{o_{n1}A} \bullet \overrightarrow{o_{n1}o_{n2}}}{\left|\overrightarrow{o_{n1}A}\right| \cdot \left|\overrightarrow{o_{n1}o_{n2}}\right|} \quad (2)$$

θ is the angle between vectors $\overrightarrow{o_{n1}A}$ and $\overrightarrow{o_{n1}o_{n2}}$. They are counted in world coordinate. n is the order of the target plane, and w is each plane's width.

$$y_l = Distance(o_{n1}, A) \cdot \sin(\theta)$$

y_l is the projection of vector on the up vector of the target plane.

3) Delineating mandibular nerve

Since the transform between local coordinate on panoramic view plane and world coordinate is determined, it is very easy to construct mandibular nerve in 3D view. The dentist only has to click some points along the nerve on panoramic view plane, and the whole nerve line will be interpolated by cardinal spline. The figures below show this procedure.

Fig.9 Mandibular nerve is delineated

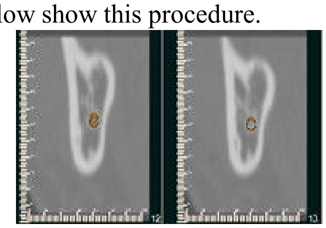

Fig.10 Delineated mandibular display on cross section image

E. Planning drilling path

After the above image analysis and process, dentist can begin to draw the planning drilling path (track). In the path planning module, dentist can virtually create, move, rescale and rotate a rectangle, representing the drilling path, by mouse on a selected cross section image. This is where the dentist should decide the implant positioning and size assignment. Many parameters have to be carefully assessed so as to properly locate the implants. [2]. Cross section images are deemed suitable for planning path, because they can clearly display the geometry of the anatomic structures in contact or adjacent to the implant and the quality of the recipient bone mass.

Dentist first chooses the most suitable image, on which he can draw and adjust the position, orientation and size of the path according to some parameters.(Fig.11).

The handles are for rotate and resize the path. The exact height, width and angle are shown in the bottom right corner.

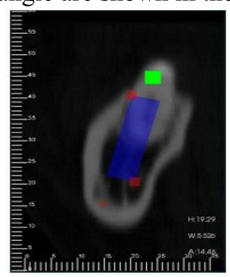

Fig.11 The implant path is drawn on one cross section image

F. Real-time intro-surgery Guidance and alarm module

In Real-time Intro-surgery module, an optical tracker, NDI Polaris® Vicra™ (Waterloo, Canada) is employed (Fig.12 left). Three highly reflective spheres, which can be "seen" by the tracker, are attached to the surgical instrument(Fig.12 right). Orientation of the driller bit and its tip position will be calculated according to the data transferred from the tracking device.

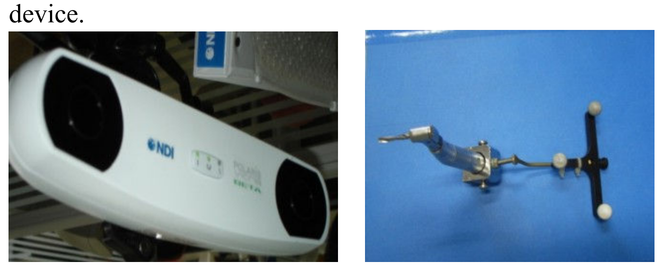

Fig.12 Optical tracker(*left*) and surgical instrument with spheres(*right*)

(1) Registration

Before the real-time tracking process, our system provides a necessary registration for the mapping of virtual space in the PC to the real world space. Registration depends on some landmarks set in the CT data. (Fig.13). The registration is done under a linear transform, in a least squares sense.

(2) Tracking

After registration, a modeled 3D representation of the surgical instrument is shown correctly on the scene (Fig.14). The drill bit's position and orientation from the tracker will be compared to the planned track's position and orientation that come from the preoperative planning subsystem. The result serves as input to a real-time alarm module, which shows their accurate relative position (Fig.15) .

Fig.13 Landmarks are scanned together with patient

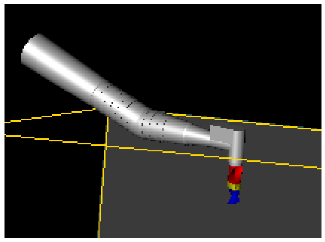

Fig.14 3D representation of the surgical instrument

Fig.15 Alarm display the relative position of the driller bit and the planned path in parallel (*left*) and normal (*right*) direction

G. *Experiment*

In the validation stage, an experiment (Fig.16) is performed on a phantom model(Fig.17) that mimics the mandible jaw with two mandibular nerve pipes. The tip points of implant slots on the top surface can also be used as landmarks in registration. It is designed using software Magic RP. Both the mandibular nerve pipes and implant slots are attached by glue which will make them visible in CT image.

Fig.16 Dentist is performing surgical experiment on phantom

Fig.17 The phantom model used in experiment

Up to 14 implants are evaluated. Three parameters are considered: the beginning point, the end point of implants and the orientation. They are all counted by difference.

Table 1 Statistics of the difference between planned and real

	Total	Max	Min	Average	Standard deviation
Beginning point	14	1.4725	0.1982	0.8152	0.3737
End point	14	1.4925	0.4647	0.8644	0.3350
Orientation	14	1.5543	0.3277	0.7527	0.3115

The result analysis table gives out the following conclusion:

(1) The average differences of beginning point are smaller than the one of end point. The main reason is because the dentist can identify the beginning point by eyes on the top surface of the model.

(2) The preliminary result of this validation shows that length errors produced by the real time navigational sub-system are less than 2mm and angle errors are within the range [0.0^0, 1.55^0], which means the system meets the requirement of implantology, and can further bring to clinical experiment

III. DISCUSSION

The system errors are majorly attributed to: specification of the 3D modeling of the surgical instrument, software calculation. The orientation of the instrument driller is calculated according to its relative position to the three spheres. If the relative position given has an error, the error will be passed to the final outcome and probably be enlarged by a non linear factor. Secondly, the relative position of the tip comes from a "pivot" operation done by manually pivoting the instrument, which will inevitably introduce error. [5] After all, the accuracy in both depth and angle tests meet the clinical needs so far.

IV. CONCLUTION

Using the system, the dental implantology surgery can be performed without templates. The preliminary experiment shows that the system is accepted in terms of both efficiency and the accuracy. As the future, we are going to improve accuracy and incorporate more features that the dentists demand and finally test it in clinical studies

ACKNOWLEDGEMENTS

This paper is partially supported by the Chinese National 863 research foundation under Grand No. 2007AA01Z312, and the Chinese National Natural Science Foundation under Grant No. 60571061.

REFERENCES

[1] Kris Verstreken, Johan Van Cleynenbreugel, Kirsten Martens, Guy Marchal, Daniel van Steenberghe, and Paul Suetens *An Image-Guided Planning System for Endosseous Oral Implants*, in IEEE TRANSACTIONS ON MEDICAL IMAGING, VOL. 17, NO. 5, OCTOBER 1998

[2] Christos C. Galanis, Michael M. Sfantsikopoulos, Petros T. Koidis ,Nikolaos M. Kafantaris, Pavlos G. Mpikos, *Computer methods for automating preoperative dentalimplant planning: Implant positioning and size assignment*. Computer methods and programs in biomedicine 8 6, 30–38,2007.

[3] Julien Dutreui, François Goulette and Claude Laurgeau, Jaime Clavero Zoreda and Stefan Lundgren, *Computer Assisted Dental Implantology: A New Method and a Clinical Validation*. Springer-Verlag Berlin Heidelberg 2001.

[4] Guangchao. Zheng, Lixu. Gu, *Computer-assisted Preoperative Planning and Surgical Navigation System in Dental Implantology*. ITAB2007, IEEE, Tokyo, Japan

[5] Northern Digital Inc in "Programming Guide" & "Application Manual