Computer-assisted Preoperative Planning and Surgical Navigation System in Dental Implantology

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Abstract—**This paper presents a construction of a computer assisted system in dental implantology. Preoperative planning and surgical navigation are two main sub-systems in our proposed system. In the preoperative planning subsystem, we provide different kinds of views to the surgeons based on CT data scanned for a specific patient. And the surgical navigation subsystem uses an infra-red light based navigation camera to locate the precise position of the surgical instrument. The two subsystems will combine together to form a seamless linked all-in-one system for dental implantological surgery. Due to the tight connection between the two subsystems, the depth and orientation of drilling will be tracked under the same coordinate space, which will guarantee the accuracy of match between the preoperative planned position and the real-time navigated position. The main objective of this paper is to present how to build such a system under the direct clinical requirement from dentists. At last, the experiments in phantom study demonstrate that the mean errors of the depth and the angle are 0.772(mm) and 0.554(degree) respectively**

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

I. INTRODUCTION

In the rehabilitation of edentulous patients, dental implantology overtakes other method in terms of aestheticism and duration [1]. The conventional implantology treatment uses study templates to guide the procedure of placing the dental implants, which has two main disadvantages: one is the high requirement of experience and the other is the high cost of templates. [2]

The development of computer assisted techniques is helping to improve this situation. For instance, SimPlant and SurgiGuides, developed by Materilise [3], provide an interactive 3D implant planning system and a corresponding guide to transfer simulated plan to surgery [4]. However, problems still exist: 1. There are chance of mismatching the templates [5] during surgery. 2. Dentist cannot get a whole sight of the jaw of patient. 3. The depth of drilling and the implant placement are not guaranteed exactly with those in planning.

An all-in-one system, with the help of an optical navigation camera [6], which consists of two subsystems each of which addresses the above mentioned problem respectively is proposed here. We build this system according to the direct clinical requirement from dentists, and specially design an architecture which will make the incorporation of any new feature easier and smoother

II. METHOD

A. Architecture of the whole system

The proposed system is developed on a PC environment with Python and VTK development software. We build the system on MVC pattern [7], which will make the data, control and display more independent, thus improving the system's extensibility. Take the preoperative planned track drawn in the preoperative subsystem for example. This track is where the final implant is supposed to locate. The dentist draws the track in one view of the oral data (e.g. a 2D-slice view) and would like to see its outcome in the other views (e.g. 3D view) simultaneously. We maintain the data of the track in one model and let the different displaying views to enquire the track model when they need to render the track in itself. Once this MVC pattern is established, adding new views as well as the other features will be easy.

Fig 1 shows the whole architecture of the system. Each subsystem includes several logically independent modules.

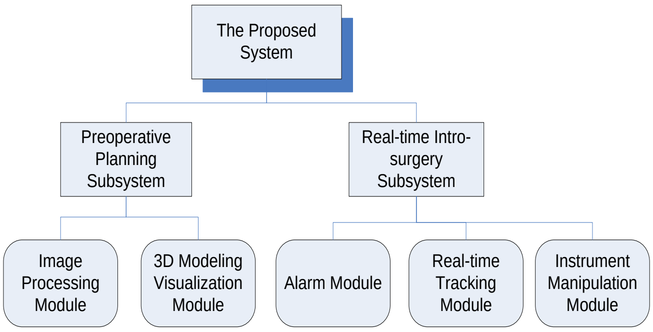

Fig.1 The hierarchy of architecture

B. Preoperative Planning

All the preoperative planning is based on the CT data scanned from a specific patient. According to the clinical requirement from the dentist, there are three processes to go through before drawing the track. All the three steps are processed in the Image Processing Module.

1. Determine occlusal plane. Pinpoint three spacial points and the plane will be determined.
2. Determine dental arch and generate the sliced views perpendicular to the arch. Draw out several control points to determine the dental arch which is interpolated according to these control points. After the arch is done, the sliced views along the arch is automatically generated which provides the views the dentist exactly want. At the same time, a panoramic view will also be generated.

3. (If planning on mandible) Draw mandibular nerve line. Mandibular nerve is vague in CT image, so we have to use a manually drawn line to indicate its position. Pinpoint the nerve hole in the sliced views, and the system will generate a bright line indicating the mandibular nerve. (Currently we simply use interpolation; an advanced algorithm will be used in the future for the mandibular nerve generation).

After the above-mentioned steps, we can go to the most significant process to draw the planning drill path (track). In Track Planning module, the dentist can virtually create, move, rescale and rotate a track by mouse on 2D sliced views generated in the above steps just as Fig 2 shows. The result will be simultaneously displayed in the 3D view port. At last, segmentation can be performed to construct a 3D view of the patient's jaw as shown in Fig 3.

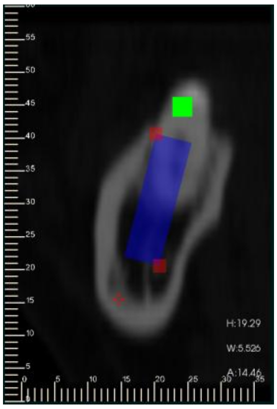

Fig.2 Drawing track on sliced view

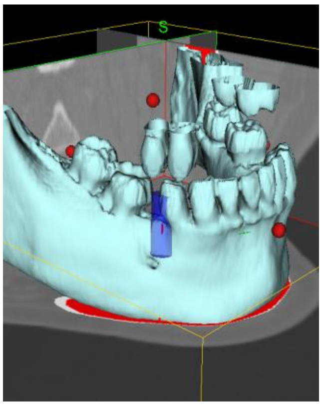

Fig.3 Track and segmentation on 3D view

Fig 4 shows the data flow in preoperative planning subsystem illustrating how dentist interacts with the system.

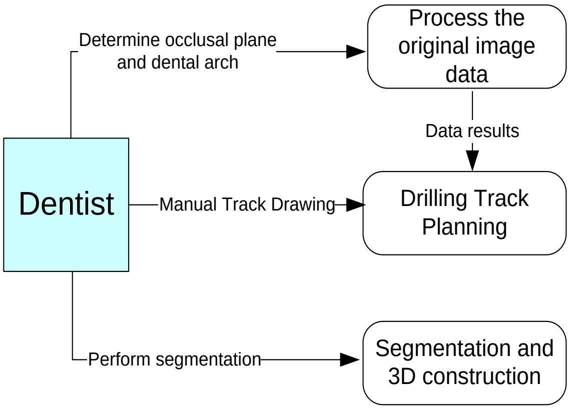

Fig.4 Data flow of preoperative planning subsystem

C. *Real-time Intro-surgery Guidance*

In Real-time Intro-surgery module, an optical tracker, NDI Polaris® Vicra™ (NDI, Waterloo, Canada) is employed. Three highly reflective spheres, which can be "seen" by the tracker, are attached to the surgical instrument. The position of the tip and the orientation of the driller will be calculated according to the data transferred from the Vicra Tracker. 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. After the registration, the data calculated are guaranteed to be correct to some extent. The 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 compare result will be treated as input to a real-time alarm module which will track and monitor the difference between the planned track and the manipulation of the instrument. If the difference is out of a predefined tolerant range, the alarm system will give out some warning signal to the surgeon. The alarm module is shown in Fig 5.

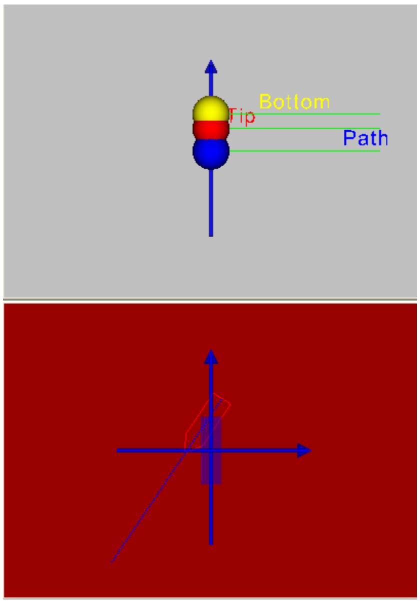

Fig.5 Shows the relative positions of the driller (tip and bottom) and the planned path. The upper is on the normal direction of the sliced plane and the lower one is on the parallel of the sliced plane.

The figure below depicts how data flow in this subsystem.

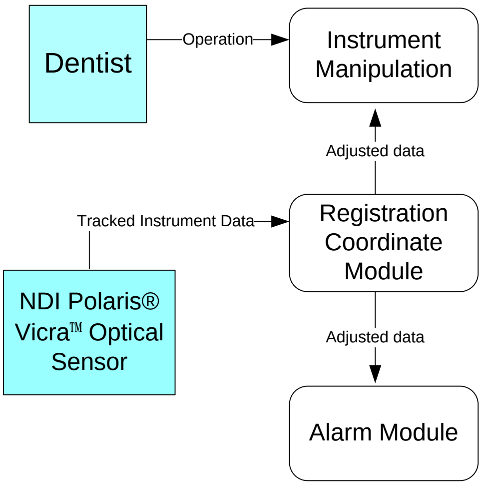

Fig.6 Data flow chart of real-time subsystem

III. EXPERIMENT AND RESULTS

The system and experiment was run on a normal PC(CPU: Intel® Pentium™4 2.66GHz, Memory size: DDR 1.0GB, Graphic card: nVIDIA® GeForce™ 6600GT).

We have designed an experiment to verify the system's accuracy. The experiment is to use a one-surface-open hollow cube shaped PVA phantom with specification of 20*20*20cm as shown in Fig 7. 15 identified positions were defined with known coordinates, five of which were employed as fiducial markers, and the rest were measured to test the system. The phantom was scanned with the spacing of 1.25mm by a SIEMENS SOMATOM Sensation 16 CT scanner with dimension of 180*180*55.

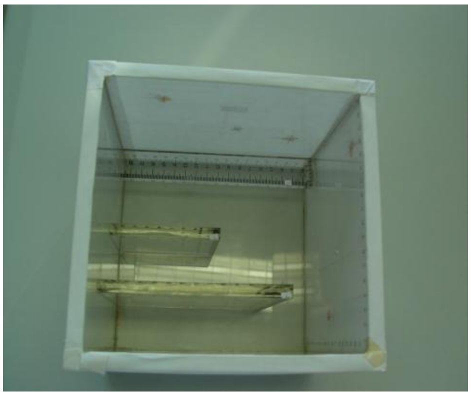

Fig.7 Phantom model used to validate accuracy of the system

During the experiment, we first made the necessary registration of the coordinate: applying 5 fiducial markers to the registration and recording the calibration error. The experiment consists of depth test and inclined angle test. In depth test, we placed the tip of the instrument driller to the other pre-defined positions and record the coordinate's outputs from the system, comparing against the true values. In inclined angle test, we had set three angle indications: 30°,45°and 60°in the phantom model, and aligned our instrument tip to the indications, read the returned value from the system.

Fig.8 The tester is doing the experiment

There were collectively 108 sets of depth data and 87 sets of angle data. The errors were calculated in the depth and the angle distribution statistic, which is shown in Table1 and Table2.

Table 1 Depth Distribution

Depth error (mm)	Position Frequency	Percent	Collective Percentage
<0.2	14	12.96	12.96
[0.2,0.4)	7	6.481	19.44
[0.4,0.6)	15	13.89	33.42
[0.6,0.8)	20	18.52	51.94
[0.8,1.0)	15	13.89	65.83
[1.0,1.2)	16	14.81	80.64
[1.2,1.4)	7	6.481	87.12
[1.4,1.6)	7	6.481	93.6
[1.6,1.8)	4	3.704	97.3
1.8<=	3	2.778	100.0
Total	108	100.0	

Table 2 Angle Distribution

Angle error (mm)	Position Frequency	Percent	Collective Percentage
<0.2	22	25.29	25.29
[0.2,0.4)	9	10.34	35.63
[0.4,0.6)	15	17.24	52.87
[0.6,0.8)	21	24.14	77.01
[0.8,1.0)	8	9.195	86.21
[1.0,1.2)	6	6.897	93.01
[1.2,1.4)	4	4.598	97.7
1.4<=	2	2.299	100.0
Total	87	100.0	

Table 3 Error statistic table

	Sample Number	Minimum	Maximum	Mean	Std. Deviation
Depth (mm)	108	0.02	2	0.772	0.24358
Angle (Degree)	87	0.01	1.5	0.554	0.22996

From Table 3, we can find that the system kept mean errors of 0.772 mm and 0.554 degrees in depth and angle, respectively. The major high errors were due to the human error which can be verified by the standard deviations of 0.24mm and 0.23 degree. In addition, mean errors of depth and angle stay in the range of [0.4mm, 1.2mm) and [0.0°, 0.8°), means that the mean errors are acceptable for clinical trial.

IV. DISCUSSION

The system errors are majorly attributed to three factors: specification of the 3D modeling of the surgical instrument, software calculation and the deformation of the real surgical instrument. The first and second are the prime contributors. 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. [8] After all, the accuracy in both depth and angle tests meet the clinical needs so far.

V. CONCLUTION

This paper depicts a new developed system to assist in dental implantology. Two subsystems: preoperative planning and real-time intro-surgery guidance are introduced respectively. We build this system on the basic of a very fundamental visualization library VTK, so we could incorporate some immediate requirement from the dentist into the system. 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.

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