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# Tele-Robotic Assisted Dental Implant Surgery with Virtual Force Feedback

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***Abstract***

*The dental implant surgical applications full of risk because of the complex anatomical architecture of craio-maxillofacial area. Therefore, the surgeons move towards computer-aided planning for surgeries and then implementation using robotic assisted tele-operated techniques. This study divided into four main parts. The first part is developed by computer-aided surgical planning by image modalities. The second part is based on Virtual Surgical Environment through virtual force feedback haptic device. The third part is implemented the experimental surgery by integrating the prototype surgical manipulator with the haptic device poses using inverse kinematics method. The fourth part based on monitoring the robotic manipulator pose by using image guided navigation system to calculate the position error of the surgical manipulator. Thus, this tele-robotic system is able to comprehend the sense of complete practice, improve skills and gain experience of the surgeon during the surgery. Finally, the experimental outcomes show in satisfactory boundaries.*

***Keywords****: Haptic, Navigation System, Tele-surgury, Pre-operative Planning*



## 1. Introduction

The numbers of dental surgeries are increasing rapidly therefore, researchers are focusing this area for introducing advance technologies in this field [1]. However, before starting the surgery, surgeons and paramedical stuffs need to detail planning about surgery for getting successive outcomes [2, 3]. Many CAD/CAM system had been developed for preoperative surgical planning, such as NobelGuide (Nobel Biocare, Yorba Linda, CA), SimPlant (Materialise, Leuven, Belgium), Implant Master (I-Dent Imaging, Ft. Lauderdale, FL) etc [4, 5]. On the other hand, intraoperative navigation systems are also being researched and put into use, either on a jaw splint or a real patient [6]. With the help of computer softwares, we are capable to introduce the patient 3D model in the virtual environment. This technique really helps to perform virtual surgery [7]. However, the positive results not only based on accurate surgical planning but also surgeons experience in intra-surgery. There are many issues remain after excellent per-operative surgical planning like hand tremble due to dental drill, mobility of the subject, and fatigue during surgery. These issues decrease the success rate in the surgeries. In addition to remove above problems, the robot-assisted surgeries planned in German Heidelberg University [8]. It is true; robot cannot perform as an experience surgeon but it shows more stable and rapid. After observing above issues, we move step forward and design following tele-robotic system.

The objectives of the purposed tele-robotic system are to introduce the integration of the four main areas of surgery to archive safe and secure experimental surgical outcomes. Preoperative surgical planning and its implementation are presented. Virtual environment and patient model with virtual force feedback are integrated with haptic device. Six degree of freedom (6-DOF) surgical manipulator is controlled by surgeon using handheld haptic device. Image guided tracking system is used to monitor the movement of the 6-DOF manipulator in the operation area.

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## 2. Overview of the System

As shown in Figure 1, Surgical Planning and Implementation using Virtual Force Feedback and Image Guided Navigation System for Dental Implant Surgery are composed into four major parts. The first one is the preoperative surgical planning system consist of image modalities, computer-aided software, Image Segmentation and re-construction of the 3D model in supportable format for virtual force feedback able environment.

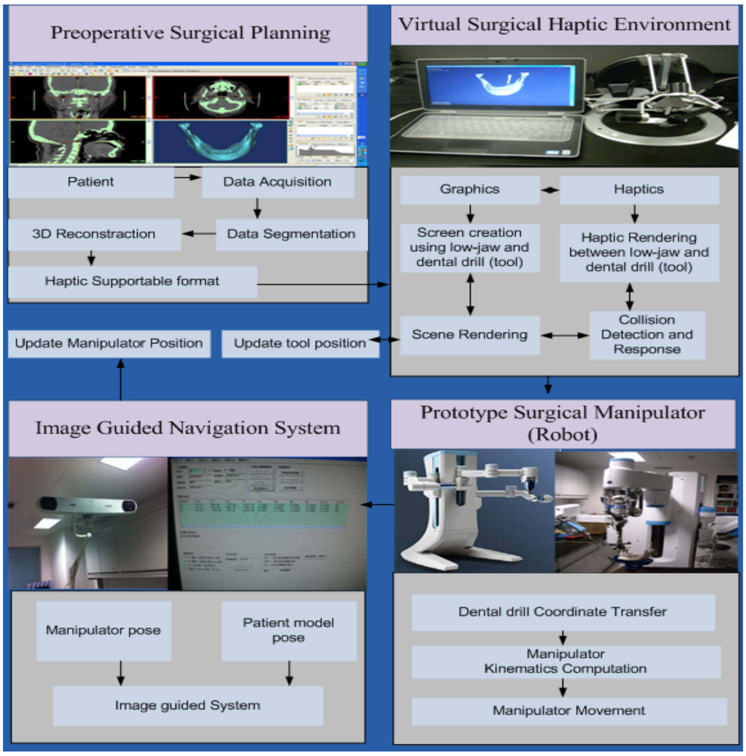



Figure 1. Overview of the system

The second part based on Virtual force feedback haptic Surgical Environment by importing the 3D patient model and dental drill incorporated with avatar (virtual representation of the haptic tool). Third part is implementing the experimental surgery by integrating the 6-DOF prototype surgical manipulator with the haptic device poses using kinematics computation. The Fourth part is based on monitoring the robotic manipulator and patient model poses by using image guided navigation system. The experimental result and reproducible error are calculated by the manipulator position. As shown in Figure 1.

## 3. Preoperative Surgical Planning

The preoperative surgical planning is for set the steps of surgery and pre-imagines the complex surgical process. In our case, the preoperative surgical planning plays an essential part for virtually imagination and haptic interaction with patient model. The first step of surgical planning mainly based on a Computer Tomography (CT) or Magnetic Resonant Imagines (MRI) [9].

Today´s image modalities (CT scan and MRI) allow a variety of non-invasive data acquisition of the normal position of patient organs and it's surrounding [10]. Mostly preoperative CT and MRI imaging have to match for receiving unique integrative 3D model. Various processing steps lead to a segmented model of different volumes describing bone structures, vessels, nerves, tumors etc. To support an exact intra-operative experiment we applied tomo-graphical procedures on lower jaw patient model as shown in Figure 2.

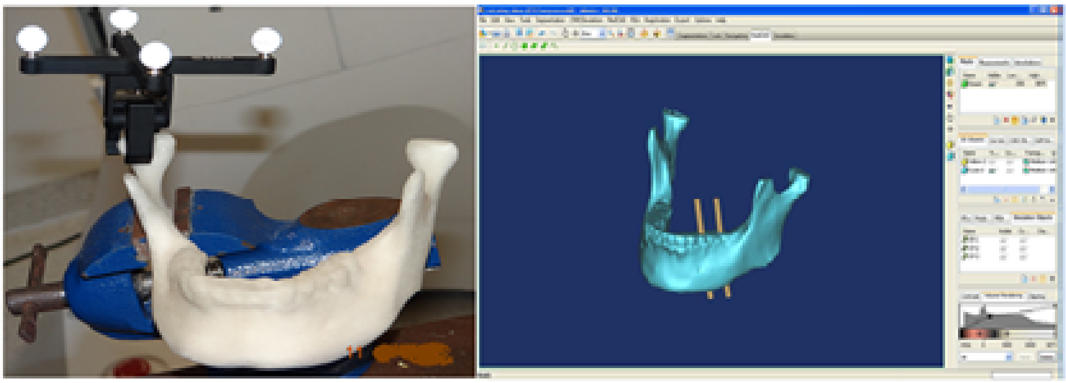


Figure 2. MIMICS Software with Lower Jaw Patient Model

Due to computer capacity and real-time processing problems today´s solution is the very rough approximation of these volumes to 3D surface models [11]. After applying the scanning procedure, the image data are available in DICOM (Digital Imaging in Communications and Medicine) format. The visualization, segmentation and re-construction of the thresholds and operative areas of 3-D cranio maxillofacial low jaw model have done in MIMICS (Materialise's Interactive Medical Image Control System)

The MIMICS is advance medical imaging software for the visualization, segmentation, reconstruction and 3-D rendering of CT and MRI images. [12]. MIMICS is on all rapid prototyping systems and also supporting MedCAD tool for marking the interested area during surgery as shown in Figure 2. Finally, it is very useful tool for preoperative surgical planning.

## 4. Haptic Based Surgical Environment

After completing surgical planning and mark the surgical area for surgery, virtual surgical environment are designed with virtual force feedback interaction between patient model of lower jaw and dental drill (Avatar). Dental drill is connected with haptic device and the patient model as a rigid object. Haptic environment support some specific format, therefore patient model is converted into haptic format for virtual force feedback environment.

### 4.1. Supported Haptic Format

The supported format of haptic environment is wavefront.obj. Therefore, DICOM dataset patient model is converted into wavefront.obj [13]. Wavefront is 3-D image format which is store geometric objects composed of lines, polygons, and free-form curves and surfaces. The dental drill is designed into Solid-edge software and converted into supportable haptic format. During design of the drill, it should be careful to put the tip of the drill on zero position. The dental drill is controlled with haptic device for transfer virtual feedback effects on handheld haptic device. The patient 3D Model and Dental drill are shown in Figure 3.

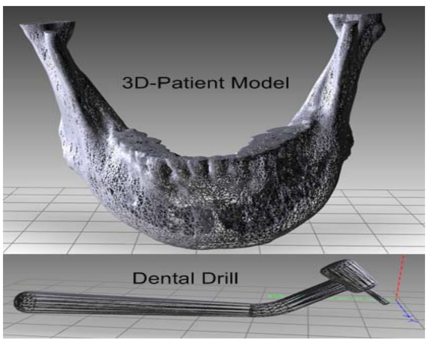



Figure 3. Haptic Supported Format

### 4.2. Haptic Device and Rendering

Haptic device became an essential part of the tele-robotic surgery and also a surgical simulation system. It works as a small robot which is transformed hand position and orientation into the slave robot or virtual tool. This is not only transform the pose but also getting the information from the virtual or real pose by using haptic loop. Whenever in virtual or real environments produce some errors in term of position and orientation due to constraints interaction. The force feedback can be felt on device that exchange mechanical energy for user [14]. Although any part of the body can interact with the device but mostly available devices are based on hand held interaction. In this project ground-based haptic device is used. Haptic interface devices can also be classified by degree of freedom (DOF). Omaga.6 is the product which is used in this project. The omega.6 is advance pen-shape force feedback device which is based on 6-DOF. 3-DOF is active with respect to position and 3-DOF is passive with respect of orientation. The omega.6 is designed for demanding applications where performance and reliability are critical [15]. Therefore we had chosen omega.6 to integrate with surgical manipulator to achieve accuracy and virtual force feedback during surgery. Omage.6 provides 6-DOF of motion and 3-DOF virtual force feedback. The details are given: workspace: translation Ø160 x L 110 mm rotation 240 x 140 x 240 deg; maximum force to be sensed: 12.0N; resolution: linear, < 0.01 mm; interface: USB 2.0.

After completing the brief introduction of haptic device, we move toward the virtual force feedback and haptic rendering system. There were two objectives: (1) the haptic device was to connect with virtual dental drill (avatar) in term of controlling position and orientation with respect to haptic device and (2) the physical interaction between dental drill and lower jaw 3-D model were to establish and transfer to the haptic device. Both objective had been achieved and integrated as shown in Figure 4.

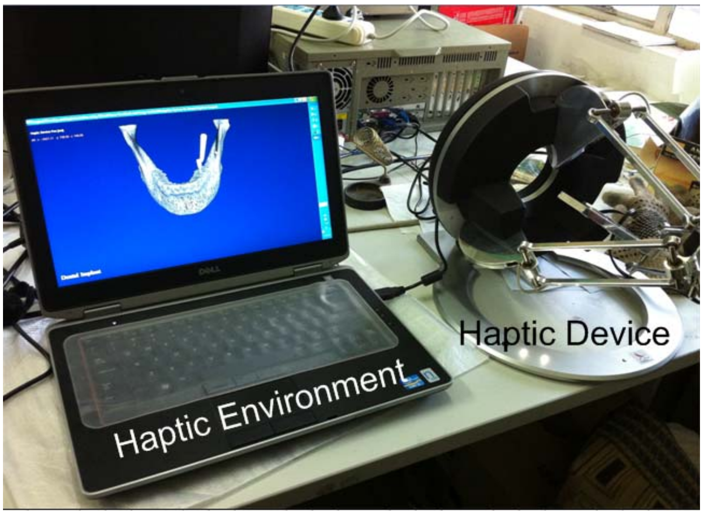



Figure 4. Haptic Environment and Device

Haptic-rendering computes the virtual interacting forces between the haptic device and the virtual environment [16]. The dental drill (avatar) represents the haptic device physical movements and also displays the information about position and orientation of the dental drill and haptic device. It can be considered both are same, one is in real (haptic device) and other is virtual (dental drill). Moreover, haptic rendering ensure that the haptic device correctly renders such virtual forces on the human operator. Several components compose typical haptic rendering algorithms. The base of rendering algorithms and Collision-detection is the position and orientation of the haptic device. Dental drill can freely move inside the virtual environment but when it collides with 3-D model the physical movement of the haptic device is stopped. Collision is detected between objects and avatar in the virtual environment and yield information about where, when, and ideally to what extent collisions (penetrations, indentations, contact area, and so on) have occurred. Their return values are normally virtual force and torque vectors that are applied at the device-body interface. Hardware limitations prevent haptic devices from applying the exact virtual force computed by the virtual force-response algorithms to the user [17].

There are calculated interaction virtual forces between device and meshes. Purposed virtual environment is based on Finger-Proxy haptic rendering model. Using this model the virtual force feedback on haptic device is developed and the surgeon can simulate the touch feeling to the patient on his finger. Finger-Proxy point virtual force model algorithms are used to detect the collision and virtual force response between patient model and dental drill as shown in Figure 6.The position of the dental drill tip is also monitored in virtual environment. The position in the virtual environment are related with the position of the robotic manipulator through image guided navigation system to maintain the alignment between prototype surgical manipulator end effector and the drill to perform the safe experimental surgery.

## 5. Prototype Surgical Manipulator

Prototype Surgical Manipulator should meet the requirements of surgeons, operating tasks, and operating environments [18]. Prototype surgical Manipulator consists of six degree of active and one degree of passive freedom. Manipulator model simplification and coordinate establishment are shown in Figure 5.

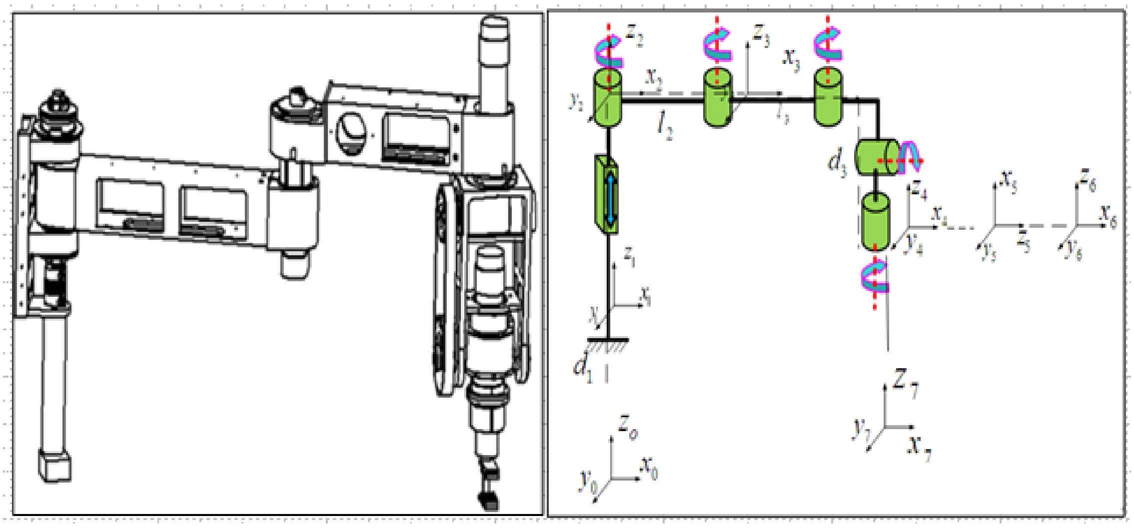
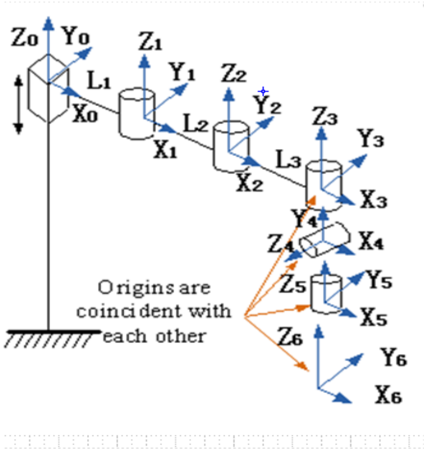


Figure 5. Model simplification and coordinate establishment

Denavit-Hartenberg (D-H) parameters are calculated and applied to establish the invers kinematics as shown in Figure 6. Inverse kinematics is used to move the manipulator to an expected poses, which are given by haptic device.

The control system is established by using CAN-bus and Accelnet Micro Module, which control digital servo-drive brush or brushless motors. Limit and zero-point sensors are also connected with servo drivers for safety and calibration. The whole control system structure is shown in Figure 7.

Haptic device is connected with virtual dental drill and also transfer the position information to the CAN-bus module. CAN card communication system receive the position data from the haptic device and transfer to the Inverse Kinematics algorithm. Inverse kinematic algorithm calculate the require values and assign to the Accelnet Micro modules. And finally motors moved according to digital servo driver.




| Link | $\theta_i$ | $d_i$ | $a_i$ | $\alpha_i$ | Range of joint |
|---|---|---|---|---|---|
| 1 | 0 | $d_1$ | $l_1$ | 0° | -600mm~0mm |
| 2 | $\theta_2$ | 0 | $l_2$ | 0° | -80°~45° |
| 3 | $\theta_3$ | $d_3$ | $l_3$ | 0° | -150°~150° |
| 4 | $\theta_4$ | 0 | 0 | 90° | -180°~180° |
| 5 | $\theta_5$ | 0 | 0 | -90° | -90°~90° |
| 6 | $\theta_6$ | 0 | 0 | 0° | -180°~180° |

Figure 6. Manipulator Kinematic chain and D-H parameter

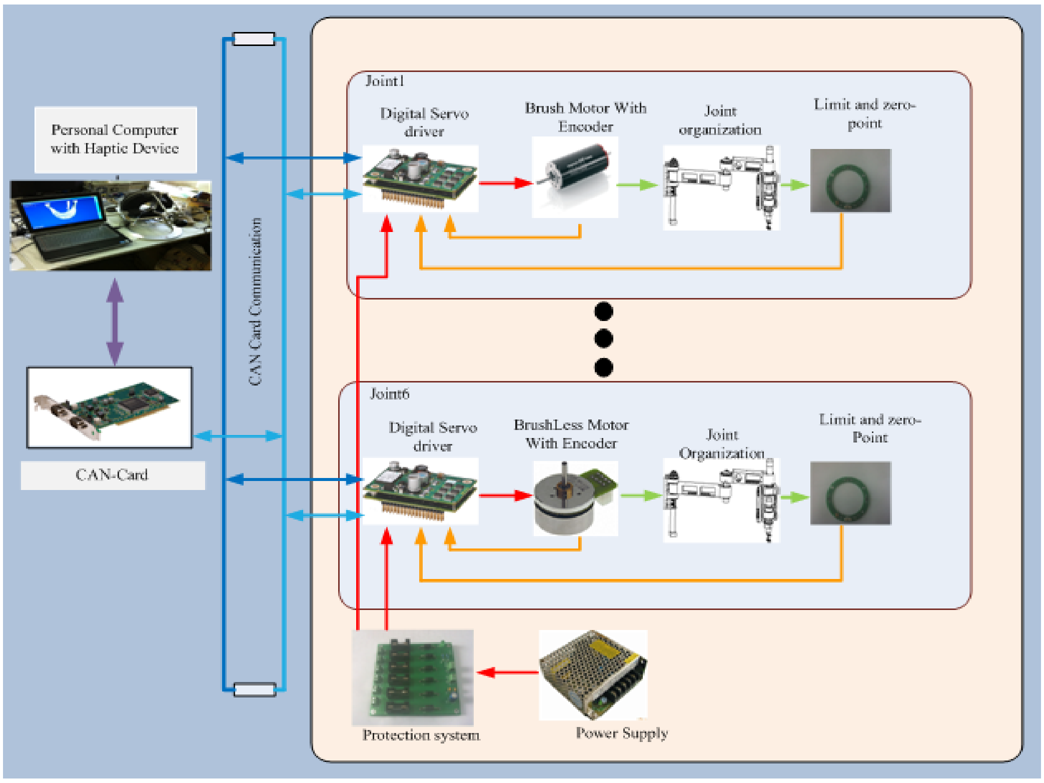



Figure 7. Manipulator Control System

## 6. Image Guided Navigation System

We designed and introduced an image guided navigation system in this project that helps a surgeon to perform experiment of dental Implant in safe. In order to implement the image guided system at surgeon/haptic end are able to monitor and control the position of the prototype 6-DOF manipulator. NDI tracking system is along two passive rigid bodies and one passive rigid probe. One passive rigid body is attached with patient model and other with robot as shown in Figure 8. The Passive rigid probe is devoted with manipulator for monitoring the position, the navigation algorithm front-end are designed for monitoring the co-ordinate as shown in Figure 8.


Figure 8. Image Guided Navigation System with Algorithm

**7. Experiment and Results**

Experimental studies should be able to guarantee the flexibility and reproducibility of the whole system. In order to check, the following setup is designed as shown in Figure 9.

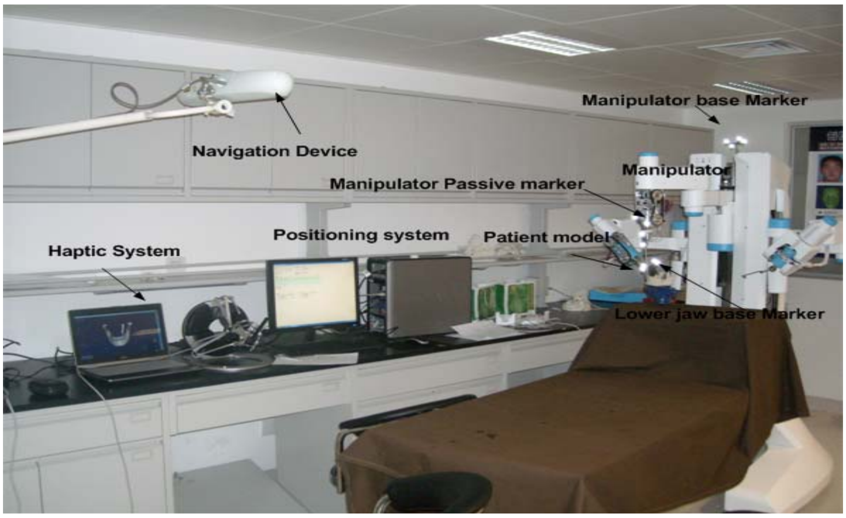



Figure 9. Experimental setup

There are two systems to calculate the error, Positioning system is given the position information of 6-DOF manipulator by using image navigation algorithm system and the haptic system shows position information about the tip of the dental drill (avatar). The haptic device selects the coordinate position and the robotic manipulator and dental drill in VE follow it.

For performing experiments: Two points are selected at virtual and real environments each. Haptic device move the position in VE form point A to point B with the 20 mm/s velocity then the manipulator also move from point A to point B at same velocity. We calculated the position error of the manipulator at point A and point B by using the navigation algorithm setup. Probe guided Navigation algorithm error is set less than 0.01 mm. The experiment between point A and point B are repeated 15 times to check the accuracy and stability of the system. Experimental results in Figure 10 are getting from equation (1).

$$e_{rr} = \sqrt{\Delta x^2 + \Delta y^2 + \Delta z^2} \quad (1)$$

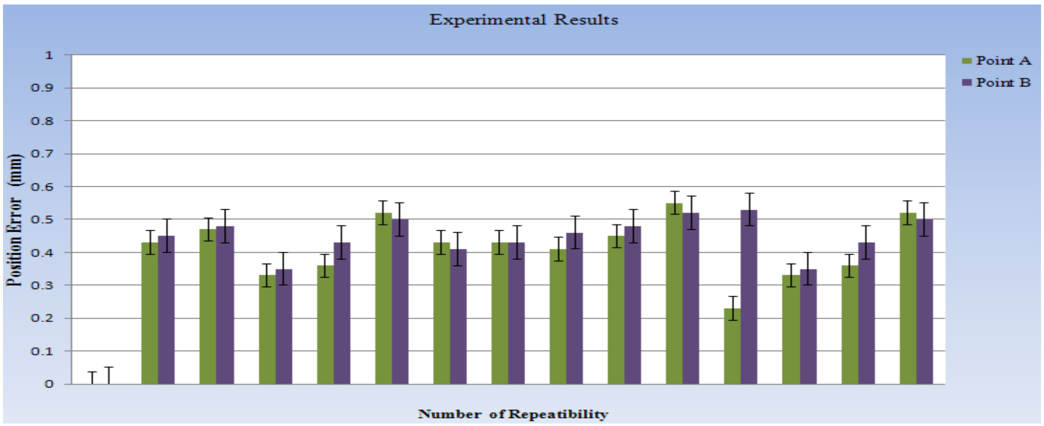



Figure 10. Experiment Result

The manipulator workspace coordinates of two points are selected and start getting position back and forth as shown in result, those locations to get the maximum error is about 0.55 mm, the smallest error is 0.23 mm, less than the positioning accuracy required by the system. The system is developed with possible virtual force feedback caused by virtual wall of lower-jaw at point A and point B. In addition, experimental work on virtual force feedback is carried out through the virtual wall of the patient 3D model with finger proxy haptic rendering model.

## 8. Conclusion

The experimental dental implant surgery consisting of virtual force feedback system has been designed and mounted on the surgical manipulator along haptic device with Image guided navigation system. Surgical planning is done by image modalities and advance medical software. Forward and Inverse Kinematics are applied to control the manipulator by haptic device. Six degree of freedom haptic device control the position of the manipulator having force feedback by virtually designed environment. Project is equipped with Image guided navigation system for calculating the error and accuracy of the system. The maximum error is about 0.55 mm and minimum error of the system is 0.23 mm at 20 mm/s velocity. In Future, we have to work on minimize position and orientation error of the system and introduce the transparency in virtual force feedback.

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## References

[1] Gwangho Kim, Hojin Seo, Sungbeen Im, Dongwan Kang, Sanghwa Jeong. *A Study on Simulator of Human-Robot Cooperative Manipulator for Dental Implant Surgery*. Industrial Electronics, 2009. ISIE 2009. IEEE International Symposium on. 5-8 July 2009: 2159-2164.
[2] Askary AS, Meffert RM, Griffin T. *Why do dental implants fail? Part I. Implant Dent* 1999; 8: 173-185.
[3] Askary AS, Meffert R.M, Griffin T. *Why do dental implants fail? Part II. Implant Dent* 1999; 8: 265-277.
[4] Lal K, White GS, Morea DN, Wright RF. *Use of stereolithographic templates for surgical and prosthodontics implant planning and placement. Part I*. The concept. J Prosthodont. 2006; 15: 51-58.

[5] Lal K, White GS, Morea DN, Wright RF. *Use of stereolithographic templates for surgical and prosthodontics implant planning and placement. Part II*. A clinical report. J Prosthodont 2006; 15: 117-122.
[6] Christos C, Galanis, Michael M, Sfantsikopoulos, Petros T, Koidis, Nikolaos M. Kafantaris, Pavlos G, Mpikos. *Computer methods for automating preoperative dental implant planning: Implant positioning and size assignment*. Computer methods and programs in biomedicine 8 6, 30±38, 2007.
[7] http://en.wikipedia.org/wiki/Virtual_surgery
[8] C Burghart, J Keitel, S Hassfeld, U Rembold, H Wörn. *Robot Controlled Osteotomy in Craniofacial Surgery.* In Proceedings: 1st International Workshop on Haptic Devices in Medical Applications, HDMA, Paris, (1999).
[9] Surgical planning, http://en.wikipedia.org/wiki/Surgical_planning
[10] J Raczkowsky, H Grabowski, J Münchenberg, C Burghart, U Rembold, H Wörn. *Integriertes Patientenmodell für chirurgische Eingriffe (1998).* Proceedings der 28. Jahrestagung der Gesellschaft für Informatik, S. 77-86, September, 1998, Magdeburg, Germany.
[11] P Heckbert, M Garland. *Survey of polygonal surfaces implification*. SIGGRAPH'97 course notes, 1997.
[12] Mimics: Medical Image Segmentation for Engineering on Anatomy, http://www.materialise.com/mimics
[13] The Advanced Visualizer, http://en.wikipedia.org/wiki/The_Advanced_Visualizer
[14] RQ VanderLinde et al. *The Hapticmaster, a New High Performance Haptic Interface*, Proc. Eurohaptics, Edinburgh Univ. 2002 : 1-5.
[15] omega.6 brochure, http://www.forcedimension.com/omega6-overview
[16] Srinivasan, MA and Basdogan, C. *Haptics in Virtual Environments: Taxonomy, Research Status, and Challenges*. Computers and Graphics. 1997; 21(4).
[17] Salisbury JK and Srinivasan MA. *Phantom-Based Haptic Interaction with Virtual Objects*, IEEE Computer Graphics and Applications, 1997; 17(5).