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A Study on Simulator of Human-Robot Cooperative Manipulator for Dental Implant Surgery

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***Abstract*-Implant surgery is generally accepted as the good technique to replace the teeth completely. Development of CT(Computerized Tomography) and 3D visualization technique help to make the treatment plan and the surgical navigation assists the dentist during the intra-operative procedure. Although the navigation technique facilitates the positioning, the image guided adjustment of the angle cannot be attained easily in the dental surgery. In the paper, design and simulation of assist-manipulator for implant surgery are studied. Angulation device performs a task by cooperative manipulation. The force/torque sensor is attached to the tool and specifically designed for surgeon's input. Data acquisition board, LabVIEW software and ATI force/torque sensor are used for smooth and accurate sensing. The double parallelogram mechanism can provide a fixed entry point during the surgery, enhance the safety and quality, and give facilities for surgeons. The 3D visualization program of manipulator is developed by LabVIEW.**

I. INTRODUCTION

Since implant surgery patients are increased every year, researches on implant surgery are actively progressing globally. Developed countries have already been supporting dental medical industry for years but it hasn't been the case in Korea. As the result, people may have to pay more expensive treatment cost for receiving treatment by the most recent dental medical technology developed in overseas and national cost expenditure and foreign dependency of technology will become more serious. To change this trend, we need to strengthen the number of research on this issue. Most of the current researches on dental oral surgery are focused on two issues. One focuses on pre-operative planning and the other is in enhancing 3D visualization to give better visual help during the surgery [1]. However, success or not of dental implant surgery is affected not only by accurate pre-operative planning but also by ability of surgeon in intra-operative. In despite of the excellent pre-operative planning, the hand tremble of a dentist caused by vibration of drill, the mobility of patient, the fatigue of operator and unskillfulness turn down the success rate of the dental implant surgeries. In German Heidelberg University, introduction of robot was attempted in dental implant surgeries [2]. Since robot cannot perfectly carries out roles of physicians but it shows that more stable and rapid surgeries are possible by assisted robots in surgeries. Alternative plans for more perfect and safe implant surgeries are to introduce the human-robot cooperative manipulator that can perform the surgery task.

In this paper, the mechanism of the angle adjustment device for dental implant surgery is analyzed and simulated. A target point does not move during angular adjustment of the ARIS(Assisted Robot for Implant Surgery) by using the RCM (remote Center of Motion) mechanism which has double parallelogram structure. The dynamic behaviors of RCM mechanism are observed by visualizing a virtual prototype on the computer screen. The admittance type of cooperative manipulator is designed through a 6-axis force/torque sensor. Dentist operates the sensor and input data of sensor is transformed into signal which manipulates the ARIS. 3D picture control with OpenGL based 3D visualization is used to import ARIS in LabVIEW and display its motion generated by F/T sensor on computer screen in real-time.

II. IMPLANT SURGERY

Implant means immediate prosthesis to make people have healthy mouth by planting immediate abutment on dental parts lost. Therefore, in implant surgeries, accuracy of insertion of immediate root decides success or not of surgeries. For improving accuracy of implant insertion, establishment of surgery plans based on accurate diagnoses of patients is necessary. Implant surgery is divided into two different processes: Pre-operative and intra-operative process. A pre-operative process is a preparation process for establishing surgery plans such as CT(Computer Tomography) scan, 3D visuliztion, and guide manufacturing ande in an intra-operatives, a surgery is started using manufactured guides. Courses of implant surgeries can be largely divided into four processes like Fig. 1. First, oral status of patients are diagnosed through CT scan. Surgery plans are established by visualizing acquired CT data in 3D image. In surgery preparation process, guides are manufactured and guides assist dental surgeon in an pre-operative process. It is important that the dentist has plenty of experience and knowledge because any errors in

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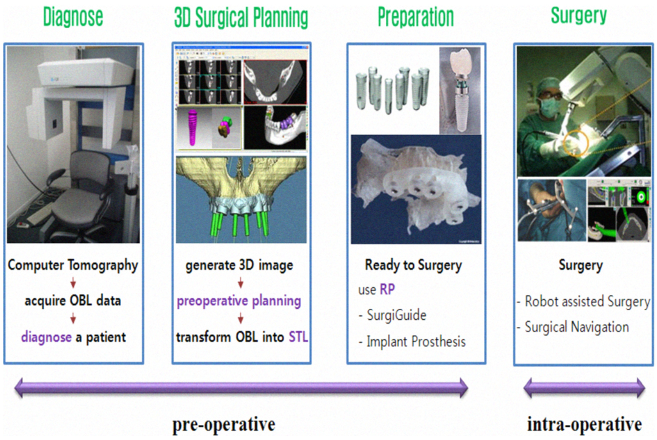


Fig. 1. Implant surgery process

mislocating the site of implant can have a crucial damage in the anatomical structure and the recovery time of patient can differ based on the precision of the drilling.

Current technologies of research and development used in the field of dental implant surgeries are indicated in Fig. 2. 1) In order to insert the implant, one relied on the intuition of the surgeon or used a template that was produced using a resin. 2) More accurate surgeries have become possible by development of 3D visualization and navigation technology based on CT scan. 3) In Tactile Company, maxillofacial structures were found out using a needle probe technology and a unique guide manufacturing technology was developed. 4) In NobelGuide, Simplant, and etc, guides were manufactured in RP (Rapid Prototyping) based on 3D visualization technique and they assist implant surgeries more rapidly and conveniently.

A field of the most common research for improving accuracy in implant surgeries is a guide manufacturing technology. Guide manufacture technology is the field to be researched most actively in the field of implant surgeries and current level of technology is significantly high. A guide manufacturing method depending on manual works, which is the oldest method, but it is a method used relatively a lot in domestic dental clinics which have high dependency on foreign technology and which are relatively underdeveloped. Existing guide manufacturing technologies mainly used methods depending on resins by existing manual works or other templates and lots of times and manpower were required. Afterward, methods using Computer-Driven Drilling Machine using CT data during pre-operative plan for more accurate guide manufacturing were introduced [3]. And now, guides can be manufactured more easily and fast with 3-dimensional rapid prototype due to development of technology of 3D visualization. The most widely used methods for manufacturing guides currently are guide manufacturing methods using technologies of 3-dimensional rapid prototype and there were lots of problems in accuracy in early period but now, accuracy has been improves a lot as the frequency of application in actual surgeries.

Besides, there was Custom Guide of Tactile Company using needle probe technology and also there was an attempt to assist angle and location of implant insertion by attaching guides to commercial robot arms [4]. Current developed guides can provide location and angle but are difficult to provide information regarding accurate depth. Since failures of depth adjustment during implant surgeries are very dangerous, it can be the most important element. There are stoppers mounting on drill tips of dental handpiece of implant in markets but they are very cumbersome for uses. Development of technology providing visual supports by applying existing medical navigation technology to dental clinics was established and actually, commercialized products were launched [5][6]. Dental navigation technology has helped accuracy and convenience of surgeries with helps of existing guides while having improved one step further safety in implant surgeries by providing up to visual images information. Since dentists observe location, angle, and depth of patient and dental handpiece in real-time, roles of implant guides were significantly reduced. However, companies providing navigation technology recommend dentist to use guides and navigation technology simultaneously. Since movements of patients and dental handpiece in real-time must be detected, if movements of DRB(Dynamic Reference Base) are twisted or not only spacial limits between vision sensor and DRB but also occurrences of errors can invite dangers of fatal results. Researches on dental implant surgeries were mainly concentrated on guide manufacturing technology in pre-operative process. However, fatigue by repeated works and drilling vibration, unstable drilling posture, and hand tremble of dentist still remain as problems to be solved in implant surgeries. As these problems are difficult to solve only with guide manufacturing. The most ideal methods are semi-automation of implant surgeries through introduction of robots.

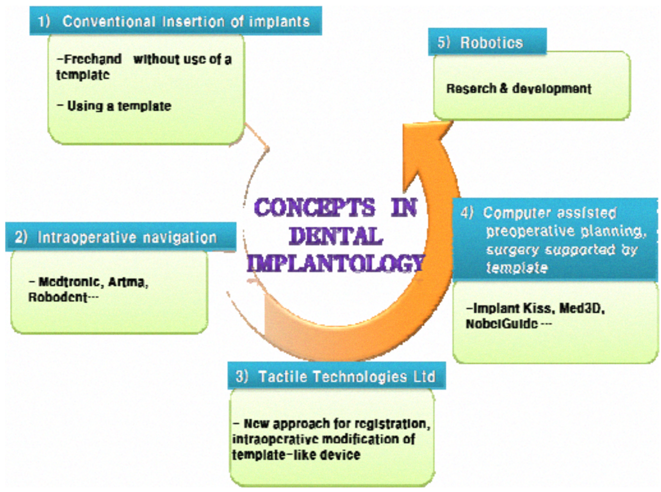


Fig. 2. Concepts in dental implantology

III. MANIPULATOR MODELING

Dental implant surgery manipulators has applied mechanism of double parallelogram for realizing angular adjustment while fixing location of drill tip. In addition, for realizing precise angular adjustments and stiffness movements, linear motion kinematics were used. Movements of slider-crank cause angular changes of drill tip. Linear motion kinematics have precise positioning during rapid movement and stiffness and allowable load are big. Fig. 3. indicates parallelogram mechanism for realizing remote center of motion. $L_2, L_3, L_4, H, \gamma, \delta$, and ζ are finalized in design stage and variables varying according to translational motions of actuators are $x, \alpha, \beta, \theta_h$. L_4 by linear slide motion is changed as much as x for realizing angular change θ_h of hand piece. β and α values also vary as much as variation of x and after all, θ_h also varies as much as variation of $\alpha + \beta + \delta$.

Length of each of link in RCM mechanism is calculated by the following equation.

$$\gamma = const, \delta = const, \zeta = const \tag{1}$$

By the secondary *cos* principle, α is

$$\alpha = cos^{-1}\left[\frac{(L_1^2 - L_2^2 + L_3^2)}{2L_1L_3}\right] \tag{2}$$

and by H value, β is H

$$\beta = sin^{-1}\left(\frac{H}{L_1}\right) \tag{3}$$

Therefore, θ_h can be expressed like the following.

$$\theta_h = \alpha + \beta + \delta \tag{4}$$

Each variable was referenced on manipulator modeling. Modeling of RCM mechanism is indicated in Fig. 4. It is divided into insertion part adjusting depth of drilling and angulation part adjusting angles of drilling. Angulation part is composed of translation stage and rotation stage.

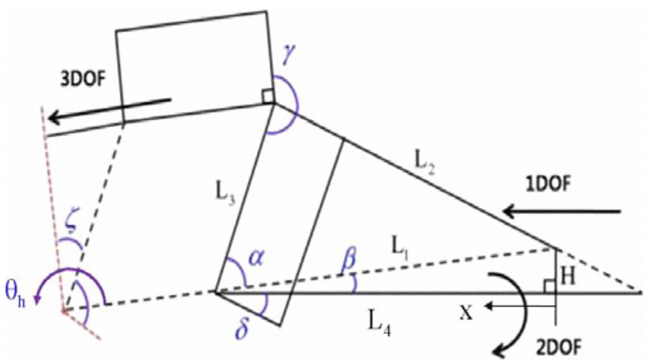


Fig. 3. Parallelogram sketch of manipulator

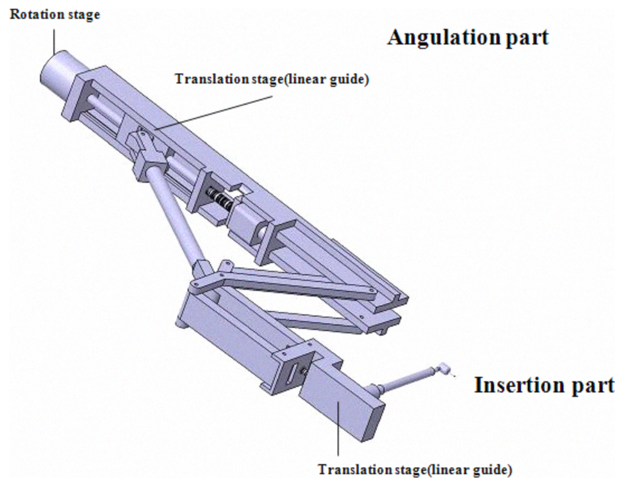


Fig. 4. Conceptual design of manipulator

IV. SIMULATION OF COOPERATION MANIPULATION

A. Acquisition of F/T sensor signal

A system was designed so that actuators can be operated by manipulation of surgeons using F/T sensor for driving dental implant surgery assistant manipulators. F/T sensor is composed to be able to measure force of X axis, Y axis, and Z axis and torque values acting on each axis. Force and torque of surgeons become input data to drive angle and depth adjustment parts during implant surgeries. In channel 1 of DAQ Board, voltage of maximum $\pm$10V is acquired. Sampling rate was set as 10000Hz. Voltage of each axis acquired from strain gauge is transformed into force and torque by calibration matrix. Bias voltages are initial voltages generated from strain gauge. In Fig. 5, angular adjustment of dental handpiece to be realized by a driving axis of an implant surgery manipulator is indicated. For realizing pitch and roll motions, only T_x and T_y among signals of six axes F/T sensors were extracted. T_x signal is transformed into input signals for realizing pitch motion and T_y signal is transformed into input signals for realizing roll motion. Angular adjustment, which is used the most in angular adjustments of implant surgeries, is roll motion. Through a harmony of roll and pitch motion, cone shaped angular adjustment is realized.

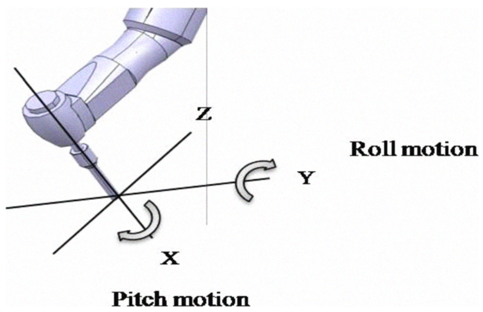


Fig. 5. Motion of handpiece drill tip

B. Signal transformation algorithm of F/T sensor

Angular adjustment of implant surgery manipulators shall maintain fixed location on dental handpiece when it adjust angle. For removing weight of the hand piece, bias torques of F/T sensors were programmed. F/T sensor shall not receive the vibration of drill and motor except force directly acting on users. Limited sensing area was set through dead zone. To compete by using Boolean switch by removing the initial bias voltage can be initialized. By adjusting gain values for torque, realization of appropriate scale adjustment was attempted and simulation of natural degree adjustment could be realized.

1) Establishment of area of Zero Out Put

As setting start and end areas of dead zone, output signal regarding input signal within the dead zone returns 0. If input signal is above the end point, it returns in output signal of sgnal exclusing areas up to the end point signal. In Fig. 6, setting of dead zone is indicated. Fig. 7(a) is a random input signal for T_x and T_y and is transformed into a signal like (b) through setting of the dead zone. Start point and end point of dead zone were set in $\pm 10Nmm$.

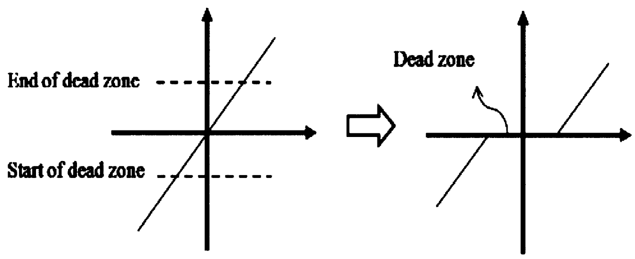
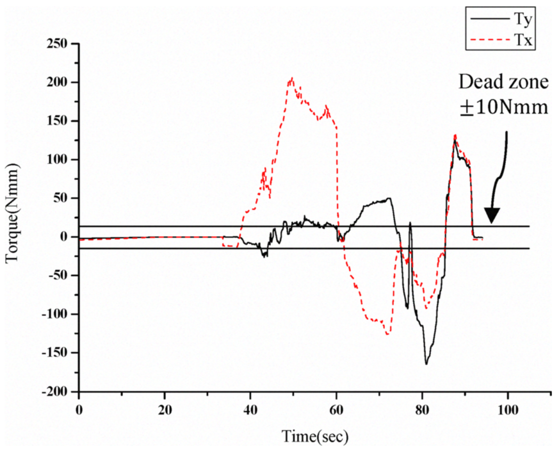
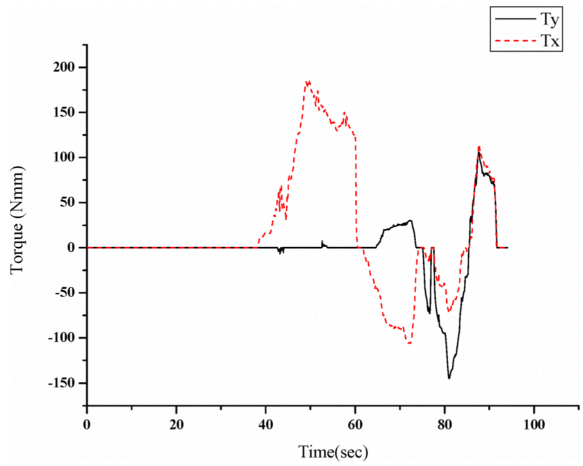


Fig. 6. Zero output within specified region



(a) Input signal of T_x and T_y



(b) T_x and T_y applying dead zone algorithm

Fig. 7. Simulation results measured from input signal of T_x and T_y when dead zone algorithm is applied

2) Scale adjustment of F/T sensor

Speed adjustment of torque signals except zero output area of dead zone through scale adjustment is possible by proportional gain of joint velocity. User's force transferred on F/T sensors is not uniform and unstable disturbance torque is generated by hand trembles of users. Angular displacement of X and Y axis regarding dental handpiece was measured. Simulation of input torques were carried out in *0Nmm* and *60Nmm*. Joint velocity proportional gain of T_x and T_y was set in each 0.005 and 0.5. Only T_x and T_y were extracted among signals acquired from F/T sensors and signals within $\pm 10Nmm$ are removed by dead zone algorithm. Torque signal is transformed into driving signal by signal scaling algorithm. Simulation is carried out by kinematic relation equation and it is indicated on screen in real-time.

C. Acquisition of 3D object shape using Lab VIEW

VRML(Virtual Reality Modeling Language) and STL(stereo lithography) were generated for real time interface of modeled each part with sensor signal. Setting of coordinates relation of each part and setting of a camera for visualization are indicated. Geometric relation according to dynamic variation is indicated in Fig. 8. Using length variables of manipulators, geometric relation of other remaining joints according to variation of angular x was obtained. If we look at changes of angular joints which are progressed as angular α is varied, HO value can be expressed as follows according to L_1value.

$$\overline{HO} = L_3 sin\,(\alpha + \beta) \tag{5}$$

Therefore, coordinates variation of x axis and y axis of joint H during the progress of angular adjustment of can be indicated as follows.

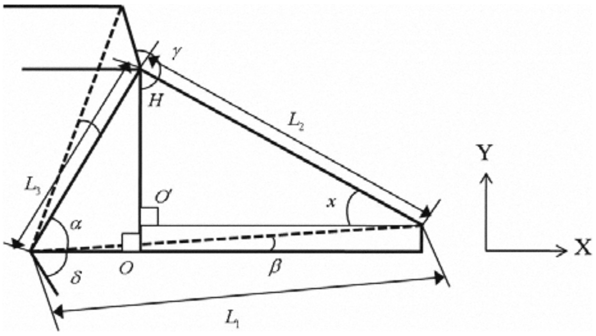


Fig. 8. Trigonometric geometry of manipulator

$$H(x, y) = \{L_3 \sin(\alpha + \beta), L_3 \cos(\alpha + \beta)\} \qquad (6)$$

Visualization program of mechanism for implant surgery manipulator was developed. Fig. 9 is a diagram of modeled manipulator visualized using LabVIEW. Each part is driven by two input data of slide, which is a displacement input for X axis, and rotation stage for Y axis. Trajectory of implant hand piece regarding the results of degree modification of X axis and Y axis can be confirmed in 3D graph. Fig. 10 indicates a sequence diagram of program. If establishment of geometric shape relation of each part modeled is finished, signal of F/T sensor is acquired. Sensor signal is again transformed into input signal for driving motors.

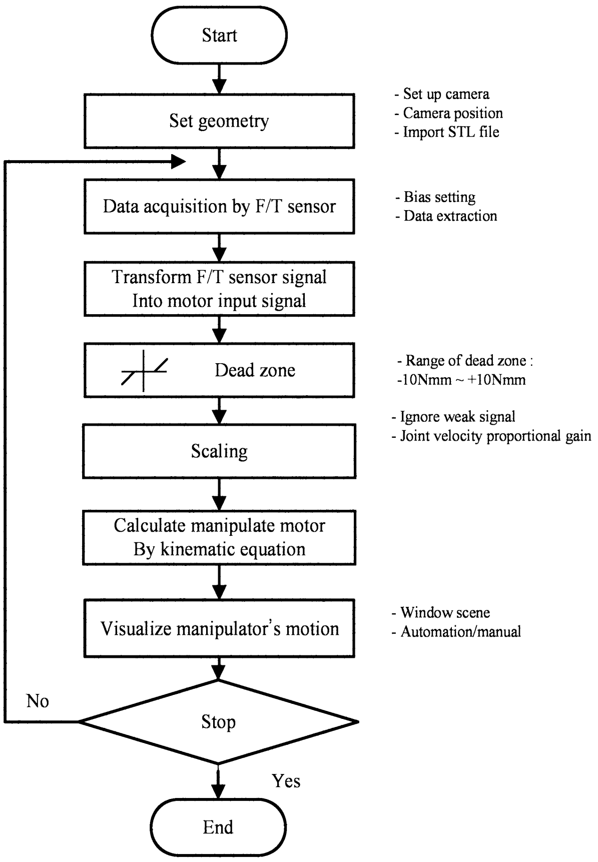


Fig. 9. Flow chart of simulation

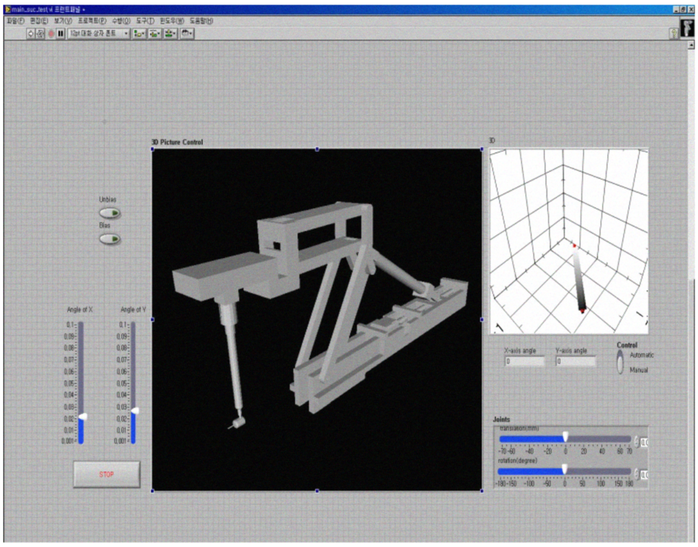


Fig. 10. 3D visualization of manipulator

V. CONCLUSION

In this paper, it was researched on surgical assisted manipulators that can complement failures of surgeries possible to occur according to hand tremble, fatigue, and level of skillfulness of dentist during implant surgeries. In order to supplement inaccurate angle and depth adjustment possible to occur during implant surgeries, manipulator based on a cooperative system possible to adjust angle and depth using F/T sensor is designed and simulated.

1) Algorithm for extraction of T_x and T_y using six axes F/T sensor and for removing bias errors is applied. Manipulator modeled is realized using OpenGL and real-time simulation programming is developed through linkage with force torque sensors.

2) Dead zone algorithm is applied to input signal for removing vibration of drills.

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