Design of Haptic Robot Modeling and Simulation Platform

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***Abstract* — By analyzing the characteristics and applications of robotic at locally and abroad, specifies the importance of force feedback technology in the robotic system and describes the current development process of force feedback technology. The methods, design and implementation of the master/slave prototype surgical system along with force feedback facility are introduced. The basic materials is also mentioned to complete the proposed method thus to accomplish surgical procedure. The prototypes (master-slave) surgical system alone with control strategy is given. The application software is designed to control slave motion according to the master device with accurate position, velocity monitoring and controlling. Thereafter, Position-Position Difference based force feedback technique is implemented, with updated control strategy and significance experimental results. Furthermore, the force sensor (FS) placement with surgical tool to get direct force for haptic feedback on themaster haptic device is presented.**

Keywords - virtual robot modeling; simulation platform; master-slave; force feedback technology

I. INTRODUCTION

The autonomous manipulation of the medical robotics is needed to draw up a complete surgical plan in advance. The autonomy of the robot comes from the fact that once the plan is drawn up off-line, it is the servo loops, and only these, that control the actions of robot online, based on instantaneous control signals and measurements provided by vision or force sensors [1-2].

Modern research in haptic force feedback in medical robotics is aimed to develop medical robots capable of performing remotely what a surgeon does by himself. These medical robots are supposed to work exactly in the manner that a surgeon does in daily routine and are supposed to assist them in everyday surgery. Robot-assisted surgery is an alternative to conventional and traditional autonomous surgical technique [3]. Nowadays, robot-assisted surgery is advancing in terms of tele-robotic. In addition to that haptic force feedback is broadly assumed to enhance performance in robotic surgery.

Any remote Robotic Surgeries such as Maxillofacial, Neuron, Minimally invasive surgeries and etc are very harmful and unsafe for patient tissues and health without force feedback. Therefore the surgeons have not only needed the audio and video sensing but also needed the sense of touch (haptic), while surgical robotic manipulator contacts with the patient tissues. Mostly available surgical manipulators are not able to produce transparency of the force feedback and rendering to the different surgical environments and the material of the tissues. Virtual haptic force feedback is based on graphical 3D environment. However, direct haptic force feedback based on real world, therefore need to rise and improve the haptic transparency of the robotic surgeries. But its benefits have not yet been systematically assessed [4-5]. Furthermore, the design and implementation of the whole system is very difficult to implement with comfort, accuracy, precision, and stability because of the real time controlling the surgical manipulator and getting haptic force feedback.

The humans have many natural sensations such as vision, hearing, taste, smell, touch etc. The idea to build this sense (touch) into the robots is especially interesting. By studying haptic sensing of the machine, we gain knowledge about human tactile sensing. In turn this knowledge could be very useful in many areas beyond robotics itself. For example, the insights obtained from researching haptic force feedback may contribute in developing the intelligence to medical devices. Tele-therapy and tele-surgical methods provide relief to people, who are not able to come from rural areas to urban (main city) areas hospitals. This also facilitates surgeon to perform his surgical procedure from his local hospital with comfort, accuracy and precision.

Robot stiffness can be measured by stiffness and geometry of the material. Whenever you give the command to the robot to achieve and maintain their position, the stiffness of the material plays an important role to maintain the control accuracy, speed, force, and back drivability.

Speed and force is most important feature of the medical robots. The gearing of the transmitting fine deliver the force and speed of the end-effector to reach its position [6]. The tradeoff between force and speed is very precise work and it varies according to condition and application. Back drivability of the robot gives the permission to surgeon that he can drive back the robot in the case of emergency.

Dynamic range deals with the versatility of the given task of the surgical robot such as surgical manipulator is able to perform drilling as well as suturing, which needs very fine and accurate resolution. Both surgical procedures are quite different, therefore robot needs high dynamic range such as human being.

With respect to surgical robots, it is very important to understand and implement force vs position control schemes. Some procedures need to achieve accurate position but have

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to be cared to apply limited force on the manipulator. If the applied force is higher than the limit, the manipulator must stop. Bone drilling and tissue cutting manipulator must have different force limitations [7]. These parameters are being changed according to surgical application and procedures.

II. THE BASIC MODEL

Bandwidth plays an important specification in surgical robots. Input signals are given to the robot for moving back and forth very rapidly. So how much time robot takes to move between two points. Whenever input frequency increases, the robot cannot meet the desired rate due to the inertia and stiffness of the robot material. This limiting frequency is called bandwidth. You can easily see the BW important in tele-operated surgery, when surgeon moves the master side handle and slave side manipulator cannot reach the desired position at time due to bandwidth limitation.

Haptic is the physical interaction via the sense of touch. Haptic is the area of computer-human interface different form the old technique like vision and sound based interaction. We use the sense of touch without knowing such as put the hand in the pocket and grasp the required object. The sense of touch gives the information about the object, without the sense of vision we wouldn't be able to do much sense in this environment [8]. The haptic devices which are designed to use is not such as sensation as our hand. Actually it is impossible to design such types of haptic device which works like our hand because our hand have lot of sensation such as texture sensing by lateral motion of hand, hardness by pressure ,temperature static contact, weight sensing by unsupported holding object, volume by enclosure and global shape by contour following as shown in figure 1.

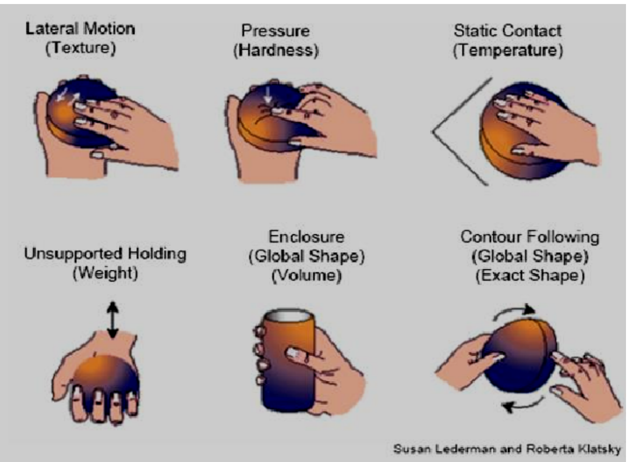

Figure 1. Haptic Feelings by Hand.

However, the haptic device transfer the interaction into the stick structure (handle) and then you are able to explore the world virtually as well as real. Simply the sense of touch has transferred in the handle and from handle to your hand. Handle of the haptic device is used as a tool to explore the environment. Haptic interface control loop is important to understand the basics of haptic.

There are two haptic devices used. One haptic device works as master manipulator while the other one as a slave actuator. Due to similar mechanical and dynamical structure of the system, we achieved linear response from the control algorithms. Omega.6 haptic devices, designed by Force Dimension, are used in this project .These devices are six degree of freedom (6-DOF) haptic device, of which three are active and three are passive.

Joint 1, 2 and 3 of the devices are used on both sides for controlling the slave actuator. The experimental arrangement and device architecture are shown in Figure 2. The omega.6 further enhances the capabilities of the omega.3 base by introducing a high-precision pen-shaped end-effector to accurately capture the orientation of the hand.

With a perfectly counter-balanced kinematic design around every degree-of-freedom, the pen combines performance, dexterity and elegance into one of the most accomplished haptic interfaces ever built. The high-precision 6 degrees-of-freedom kinematics interface features its own real-time embedded controller into a single package, adding to its versatility.

This highly ergonomic end-effector makes the omega.6 a device of choice for dental training, medical robotics, or advanced tele-operation tasks which require operating dexterous robots remotely. The omega.6 is available in left- and right-hand configuration and can be integrated in a dual workstation setup for bimanual operation.

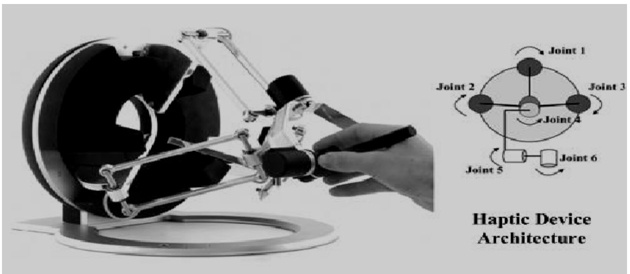

Figure 2. Haptic Device Omega.6..

Finely built around its unique parallel kinematics structure, the omega.6 is designed for performance. Its superior mechanical stiffness, combined with its real-time USB 2.0 controller, enables the rendering of high contact forces at a rate attaining 4 KHz. To provide the highest degree of haptic transparency, accurate gravity compensation is maintained in translation and orientation space by perfectly coupling passive and actuated components together. Each system is individually calibrated to ensure repeatable and optimal precision and performance. Its unique kinematics design perfectly decouples translations and rotations, enabling the omega.6 base to accommodate various interchangeable end-effectors to meet every application requirement. To that end, Force mention also provides advanced technical support for dedicated applications that require custom end-effectors. A powerful SDK provides highly advanced control over all Force Dimension devices, including the omega.x and delta.x series, in both haptic and robotics mode. The Haptic SDK offers all the basic functions to read positions and to program desired forces in Cartesian space. Expanding these fundamental capabilities, the Robotics SDK leverages the Haptic SDK by introducing an advanced set of real-time routines to precisely control the position of the device. The Force Dimension SDK provides support for multi-threaded, multi-device programming and is available on a wide range of platforms including Windows. The core foundation framework is shown in figure 3. The combination of both haptic and robotics capabilities into a single unified framework allows developers to create powerful collaborative interfaces between people and machines.

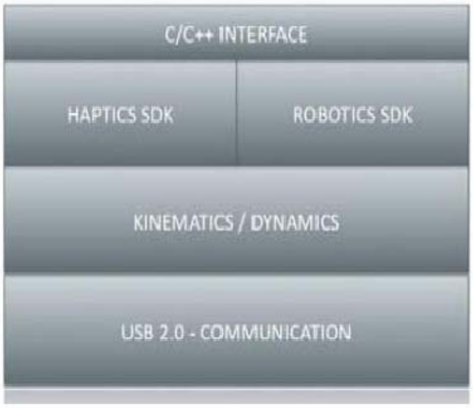

Figure 3. SDK Core Foundation (Force Dimension).

The omega.6 haptic device features some unique characteristic that make it the interface of choice for the most advanced 6-DOF, touch-enabled applications. Rotation sensing-the omega.6 features a rotation sensing extension that is fully gravity compensated and designed to avoid interference from parasitic torques generated by translational forces. Quality-the omega.6 is designed for superior performance-no plastic components are used for any critical mechanical component of the device for unrivaled reliability and haptic quality. Accuracy-a dedicated sensor provides one-time drift-free calibration. Stiffness-due to their unique patented parallel kinematics structure the omega.6 haptic device offers unequaled closed loop stiffness, allowing for crisper realism. Comfort-all omega.6 causes minimal user fatigue, thanks to active gravity compensation.

III. Hybrid Position-Potion Difference(PPD) and Force Sensor(FS) Based Haptic Force Feedback System

A prototype Master and Slave surgical system, Position-Position Difference and Force Sensor based haptic force feedback system were designed to check the efficacy and the results in last three chapters. The results have stability, reliability and repeatability thus with force feedback element in term of position, velocity, PPD and FS. In this chapter the new hybrid architecture is introduced to improve and transparent haptic force feedback elements. Force feedback element is based on hybrid PPD and (6-DOF) FS. The cohesive control strategy of PPD and FS are applied to establish haptic force feedback on end-effector of the slave manipulator. In this chapter, the changing in controller mechanics to receive the two types of force feedback data information and establish force feedback effects on the master side, are discussed. The proposed controller and software are designed to produce transparent haptic force feedback using force sensor and position-position difference.

In figure 4, fm is the force applied by the human on haptic device; pm/Vm is the position and velocity information of the master device. This information is used as an input of the designed controller in first step. The controller produces equivalent voltage signal to the 3-DOF slave actuator (Cps) with respect to input position, then slave starts moving to desired position. The refresh rate of the master slave system is about 1.5 KHz to 2 KHz. The continued position difference is transferred to the force feedback controller by master/slave controller.

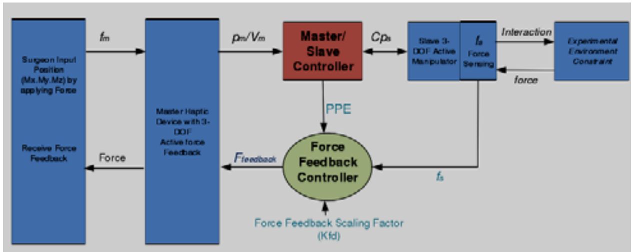

Figure 4. PPD and FS based force feedback system.

The PPD and FS based haptic force feedback controller is the integration of two techniques. The slave device is responsible to transfer two types of data information that is position and force. The proposed system is based on two controlling strategies. Master slave and force feedback. Master/Slave controller generates the difference between positions. The continuous difference between master and slave are transferred to the force feedback controller and the force sensor data is also used as an input of the force feedback controller. The related information about slave environmental constraint is integrated with stiffness factor and transferred to the master manipulator to generate transparent force feedback effects on master device. In proposed combination of PPD and FS based surgical system, the force sensor is place between slave end-effector and surgical tool. When surgical tool (surgical needle or blade) interacts with the sample the force is transferred to the sensor and the sensor generates some voltage level proportional to the applied force from the surgical environment. On the other hand position difference is generated when the slave is not able to reach the desired position of the master device.

This master/slave difference is also the input of the force feedback controller. These two information levels are transmitted to the force feedback controller and controller transforms or converts this voltage level into meaningful information for the master haptic device. The master haptic device responds according to the force applied to the sensor. The proposed PPD and FS based force feedback diagram is shown in figure 5.

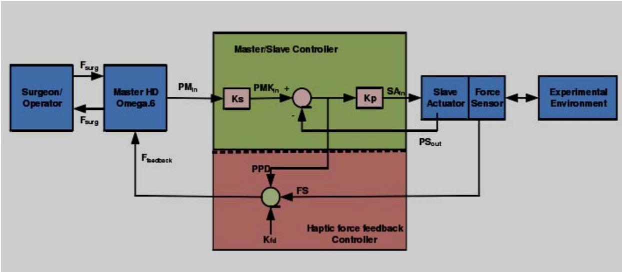

Figure 5. PPD and FS based force feedback controlller.

After designing the control strategy to PPD and FS based force feedback system, the tricky task is to implement this in real world. There are two applications, which have to be integrated for information exchange. The FS and Main application is designed in Visual C++ 2008 language for maintaining the uniformity and improvement to the data exchange rate between master/slave and force sensor application. Visual C++ 2008 application designing software is used for implementation of the system. Visual C++ provides Graphical user interface (GUI) environment for developing application. Sunrise Auto Safety Technology Co, LTD (SRI) provides application programming Interface (API) of the force sensor module to program, calibrate, and interface with computer. The force sensor supports CAN Bus or RS232 communication with different baud rate. The default Baud rate of RS232 is 11522bps and this rate can be changed by using UARTCFG command. In addition Microsoft Foundation Class (MFC) from Microsoft Corporation and Robotic and Haptic Software development Kit (SDK) from Force and Dimension Corporation are used to design and implement the application software.

Application software should be equipped with monitoring and graphical facility; hence the user can visualized the motion and feel the force feedback effect on the screen and hand respectively. There are two types of visual force feedback indicator over the main application one for FS and other for PPD. Due to this factor, Software enhances the transparency and visual and haptic force feedback of the slave side. The operator or surgeon becomes more confident and comfortable during surgical procedure. Application software for PPD and FS based force feedback is shown in figure 6.

Figure 6. Application software for FS and PPD based force feedback system.

IV. EXPERIMENT PART

To improve stability, flexibility, repeatability of the system, we introduced the hybrid PPD and 6-DOF force sensor based haptic force feedback system. The experimental setup is established as shown in figure 7. In this experiment we have two types of informative and applied data which have to be utilized to force feedback as shown in controller diagram.

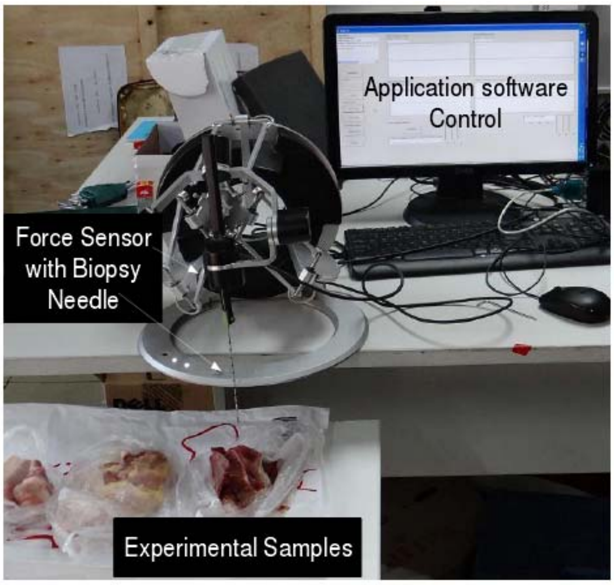

Figure 7. PPD and FS based Force Feedback Experimental Setup.

In this section, the experimental results are shown. There are five experiment conducted, each experiment have four graphs to visualize the result into different angles. Each experiment consists:

1. Graph (A) shows PPD (mm), FS (N) and Applied signal vs time and data point.
2. Graph (B) shows FS (N) vs PPD(mm).
3. Graph (C) shows PPD (mm), vs Slave (mm).
4. Graph (D) shows FS (N) vs Slave (mm).

Before starting the experiment on different structure, the first experiment is conducted in free air to calculate the offset error of the whole system. The experimental results are shown in figure 8. These graphs show some disturbance at PPD (mm) due to back and forth random movement jerks into Z-axis of the slave device. FS is stable in this experiment.

The experimental results are shown in figure 9. The biopsy needle injecting and ejecting experiment is performed into the pig tissue. The selected portion of the data is analyzed in the graph. The result shows the little vibration at insertion due to the structure behavior of the pig tissue. The force signal is calculated by the force sensor (FS) in the range of -6.0 to 2.4 N and the difference between master and slave is about -2.5mm to 2.5mm. The inserting slope of the signal is changed as per extracting slope due to hysteresis behavior of the system. The inserting response of the force

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sensor is more sensitive rather than extraction instead, the PPD response is more sensitive in extraction. The average of the both signals is sensible input for force feedback. This average amplitude multiplied by the stiffness factor is transferred to master device.

The related information about slave environmental constraint is integrated with stiffness factor and transferred to the master manipulator to generate transparent force feedback effects on master device. In proposed combination of PPD and FS based surgical system, the force sensor is place between slave end-effector and surgical tool.

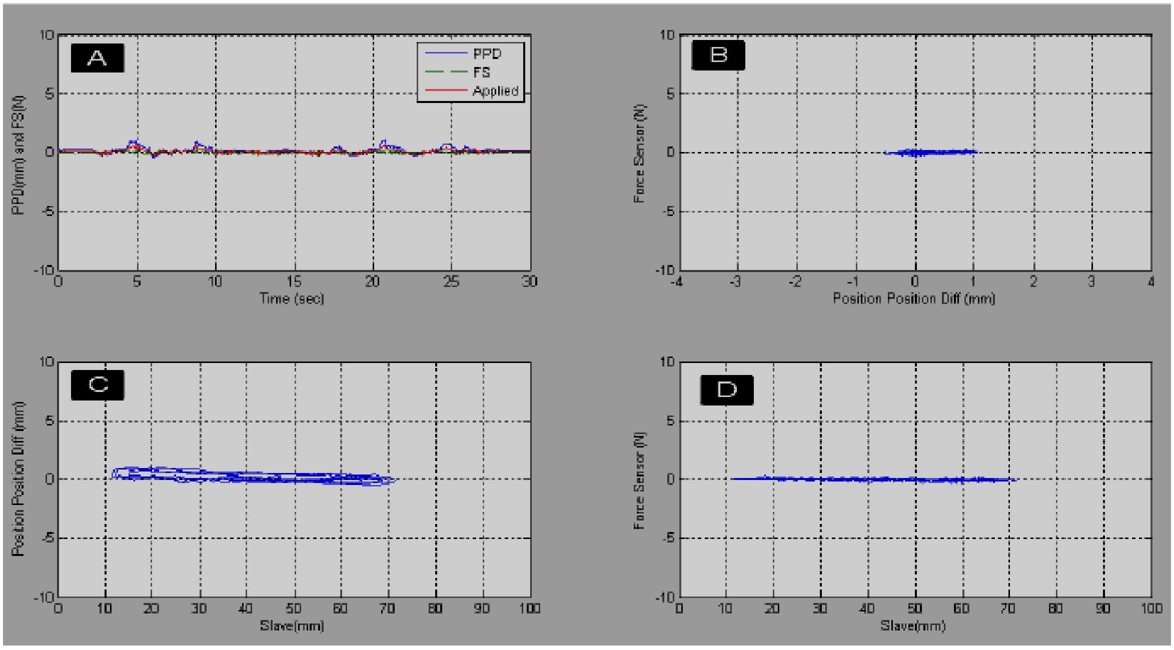

Figure 8. Experiment result.

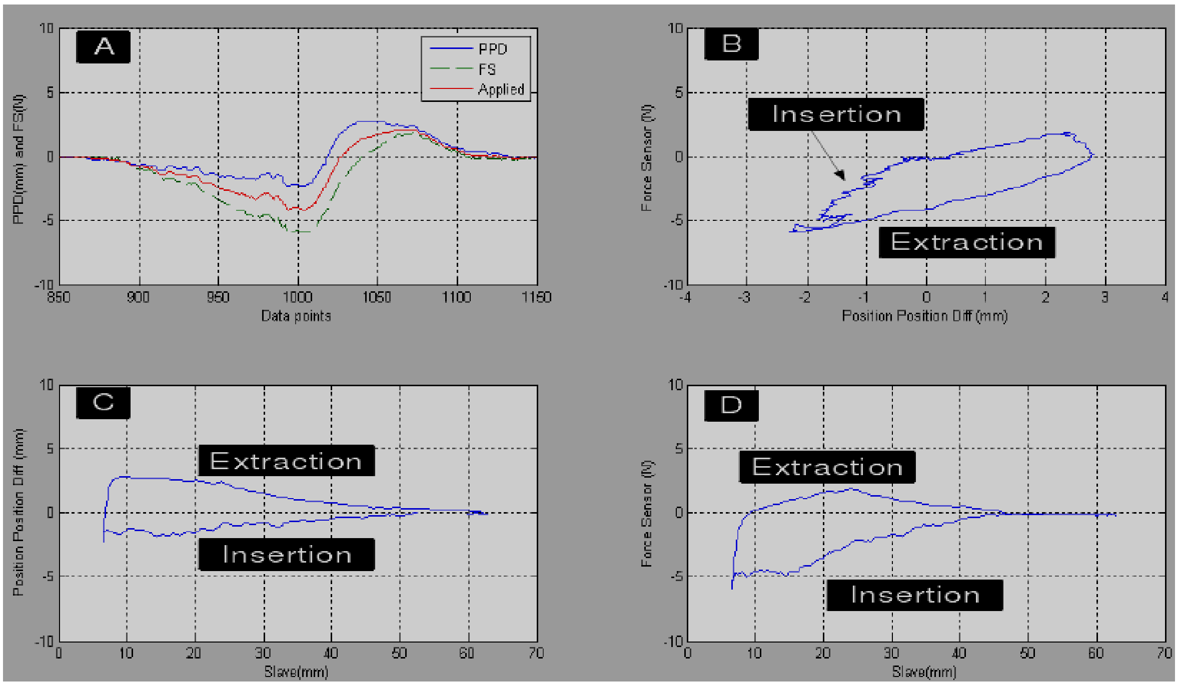

Figure 9. Pig tissue experiment result.

V. Conclusion

In this paper, the methods, design and implementation of the master/slave prototype surgical system along with force feedback facility are introduced. The basic materials is also mentioned to complete the proposed method thus to accomplish surgical procedure. The prototypes (master-slave) surgical system alone with control strategy is given. The application software is designed to control slave motion according to the master device with accurate position, velocity monitoring and controlling. The experiment results show the movement of the master haptic and actuator with force parameter. The system is able to respond according to stiffness of the experimental sample. Beef and Chicken surgical results are slightly changed due to the physical properties of tissues. The generated force obtained by beef is higher than the chicken tissue. These forces are used as input of the master haptic device in real time to generate force feedback effects. The software provides real time update about the force, position and velocity over the screen to inform surgeon during surgery.

With a perfectly counter-balanced kinematic design around every degree-of-freedom, the pen combines performance, dexterity and elegance into one of the most accomplished haptic interfaces ever built. The high-precision 6 degrees-of-freedom kinematics interface features its own real-time embedded controller into a single package, adding to its versatility. Needle insertion surgical robot with haptic force feedback system for needle intervention is developed. Overview of the complete system with their mechanical design, control strategies, and software development with experimental result are also discussed. The results show the stability and transparency of the system.

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