



Position-Position Difference Based Haptic Force Feed-back Robotic Control System

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Abstract: Autonomous surgical robotic system is required to draw up a complete and very detailed surgical procedure, which is not possible to implement in emergencies and complex surgical environments. The autonomous system is mostly based on instantaneous control signals which are acquired by vision, force sensors, navigation systems and etc. Therefore, it has some limitations in complex surgical procedures. However, modern research in robotic surgery has introduced haptic force feedback. Haptic force feedback is aimed to develop medical robots that would be capable to perform remotely with force feedback effects. These medical robots are supposed to work exactly in the manner a surgeon does in daily routine. This paper is based on the master slave tele-robotic system, designed and implemented with position-position difference (PPD) force feedback strategy with accuracy and stability by using 6-DOF haptic force feedback devices. The control strategy, haptic devices integration, application software designing by Visual C++ and experimental setup are discussed. Finally implemented system is verified on different animal tissues and material to validate the system stability, accuracy and repeatability.

Keywords: Tele-robotic surgery, Position-Position Difference, Haptic force feedback

1.

INTRODUCTION

Medical robotics is a modern interdisciplinary field related to human body and mechatronics (Rossi, *et al.*, 2005). The use of medical robotics is now common in the medical and biomedical fields due to their good advantages. It involves many operations and coordination of telemedicine system by which the medical professionals diagnose and provide treatment to patients at long distances (Podder, *et al.*, 2005). The medical robot perform the task that is normally performed by medical professionals which enhances the quality of health care system.

Medical robotics was introduced in 1980, in the field of urology. First robotic arm was introduced to perform operations (Hager, *et al.*, 2008). At that time robotics had no good quality of imaging. So, NASA started working on medical robotics that helped medical science in the field of telemedicine (Dario, *et al.*, 2003). From 1989-2003 many scientists and engineers designed and developed such medical robots, that even to this day, helps in diagnosis and performing surgeries. Previously robots were used only in operation theatres but now a days, they are used in many other medical fields such as laboratory robots, Hospital robots, Rehabilitation robots and Robotic surgery and many more (Ballantyne, 2002).

Robotic Surgery is one of the major types which is based on computer programming, plan and procedure, instructed by the doctor, which helps performing surgery (Cleary, *et al.*, 2006). Doctor and Paramedical

staff plays an important role of assistance to perform remote and live surgeries. (Katsura, *et al.*, 2006), Need of medical robotics became essential for surgeons as well as patients. They would like to see surgical system more capable and reliable during the invasive and complex surgeries (Dombre, *et al.*, 2003).

By the use of haptic force feedback technology, the robotics assisted surgeries have improved. Haptic force feedback surgeries are more transparent in terms of patient handling, precision, control on tissue dissection and perseverance of important organ structure during surgeries. Haptic systems are also suitable for distant surgeries with sense of touch, enhancing the capabilities of physical interaction between surgeon and patient. The future of surgical robotics must introduce haptic force feedback technology for the betterment of virtual and real environment surgeries, so that surgeons will be able to perform complex surgical procedures with confidence (Mizuno, *et al.*, 2009).

The new features that are introduced in this field for developing haptic force feedback element at master handheld device (Syed, *et al.*, 2011). This architecture is based on two robo-haptic system master-slave device. Position-Position Difference (PPD) control strategy is applied to establish force feedback. In this paper, the small change in slave manipulator for performing procedures that needs needle injecting and ejecting, are discussed, designed and implemented under testing and calibrating environments. The modified control strategy is designed to produce transparent force feedback in terms of position difference at operator/surgeon site.

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2. MASTER SLAVE POSITION-POSITION DIFFERENCE HAPTIC FORCE FEEDBACK SYSTEM

The Position-Position Difference (PPD) based master slave haptic system is presented in (Fig. 1). The position information is transferred to controller to achieve transparent force feedback on master handheld haptic device during slave interaction with environmental constraint. The block diagram of the proposed PPD system is shown below at (Fig. 1).

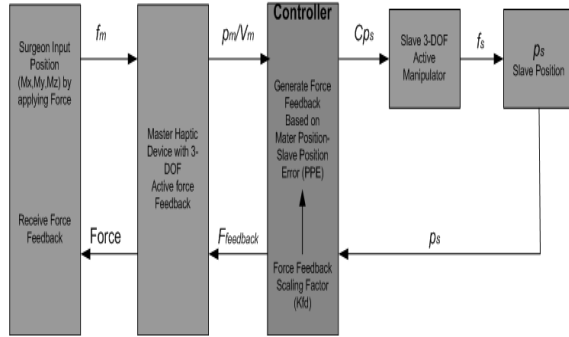


Fig.1: Position-Position Difference Block Diagram

In above Fig.1 f_m is the force, provided 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 slave actuator (Cp_s) with respect to input position, then slave start moving to desired position. Simultaneously slave feedback its current position information (p_s) to the controller. The refresh rate of the above cycle is high up to 1.5 KHz to 2.0 KHz, if the slave cannot reach the desired position, then the position difference is generated. This position-position difference is multiplied by force feedback scaling factor (K_{fd}) and then controller transfers this difference to the master haptic device as a feedback force. The feedback force produces stiffness at master device, which is transparently felt on surgeon's hand. The overall system is able to generate tactile sensing on the master site by using real force feedback strategy.

Position-Position Difference Controller Designing

The position-position difference controller depends on the real position of both master and slave devices. The new rate of the controller must be higher as much as possible in terms of slave position update. In proposed surgical system both devices have same mechanical structure and connected with USB 2.0. The latest rate of master slave system is about 2 KHz. The real time motion of the slave is maintained by setting the latest rate high. On the other hand the same

difference feedback has to be used for creating force feedback; therefore, the refresh rate of the force feedback is lower than the tracking rate. The PPD controller diagram is shown in (Fig.2).

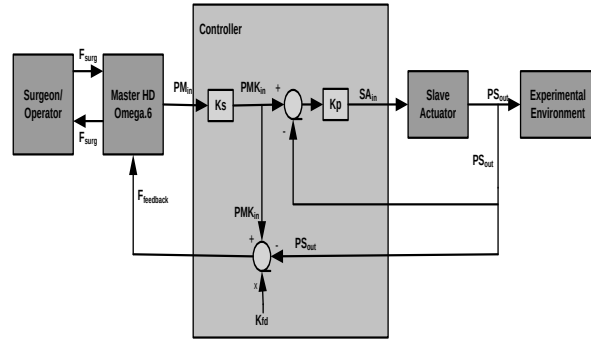


Fig.2: Position-Position Difference Controller Diagram

As mentioned above, the proportional controller (PC) is designed to control slave end-effector to track the master haptic device (HD). The proposed tele-robotic control system with PPD force feedback is presented in Figure 4. The force inputs (F_{surg}) are given by the surgeon/operator to the master omaga.6 HD. The Master HD Changes its position and the position of sensors inside the HD, update the original position of the hand according to applied force from the operator. Master positions (PM_{in}) are the inputs of the controller. Scaling factor (K_s) is used to increase or decrease workspace of the slave (default value of K_s is 1.00), therefore K_s is multiplied with PM_{in} of the HD. The PMK_{in} is the input difference. The difference is calculated between the reference point (PMK_{in}) and the slave actuator position PS_{out} (measured by the slave position sensors). The difference is multiplied by the proportional coefficient of the controller (K_p). Slave actuator input (SA_{in}) is simply the difference of master and slave positions with proportional coefficient of controller (K_p). This difference is multiplied with K_p to obtain the new position of slave actuator PS_{out} . The refreshing frequency of the system is high to get real time movement without time delay. On the other hand, the same difference has to be used for generating force feedback whenever environmental constraint occurs. The refreshing rate of the force feedback is little lower than the tracking rate of the slave up to 1 KHz. Finally stiffness coefficient (K_{fd}) is multiplied by the PPD and transfers the result to the haptic device.

Application Software Development for Position-Position Difference Based Haptics

After designing the control strategy to PPD based force feedback system, the most problematic task is to employ in real world. Visual C++ 2008 language was the first choice of application software designing. Visual C++ provides Graphical User Interface (GUI)

environment for developing application. 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 visualize the motion, watch and feel the force feedback effect on the screen and hand respectively. Application Software enhances the transparency of visual and haptic force feedback of the system. The operator/surgeon becomes more confident and comfortable during surgical (injecting and ejecting) procedures. Front-end Application software for PPD based master slave control is shown in (Fig.3).

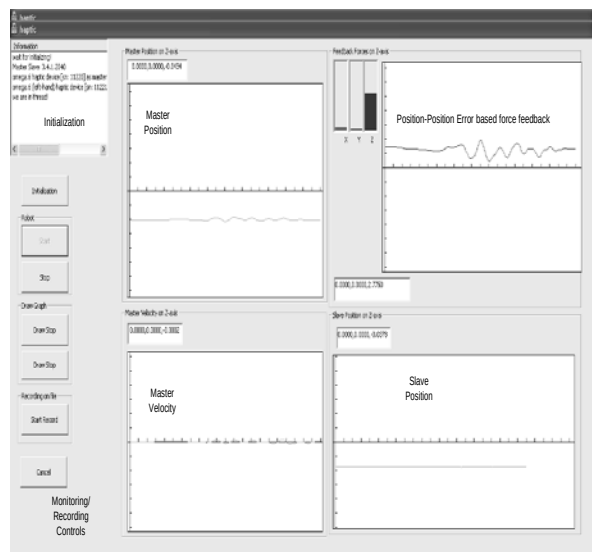


Fig. 3. Application software for Position-Position based force feedback system

As shown in (Fig. 3), the application software is mostly same as in master slave control software. The additional feature is position-position difference force feedback presentation on the developed software and haptic force feedback on master HD in real time. The procedure of the additional program designing can be summarized as follows.

- 1) When the robots are in initialization step, there is no force from the motors on master side handheld device. Hence, master should be able to receive input force from operator.
- 2) Calculate the position information from the master and slave device during Thread 1.
- 3) In same thread: we calculate the Position-Position Difference by following formula.

$$PPD = -Kfd(Mp - Sp)/Ks \quad (1)$$

Here, PPD is the position-position difference, $-Kfd$ stiffness coefficient of the haptic device, Mp and Sp are the master and slave positions respectively and Ks is the scaling factor (default is one).

- 4) After calculation of PPD , The force is transferred to the master manipulator. The default value of stiffness (K_{fd}) of master HD is set 500, it can be changed according to experimental material and the (Ks) Scaling factor default value is 1.

PPD Experimental, Measurements and Testing Setup

To ensure the stability, flexibility, repeatability, delay of PPD based haptic force feedback from the slave side to the master handheld device; the experimental setup is established, as shown in (Fig.4).

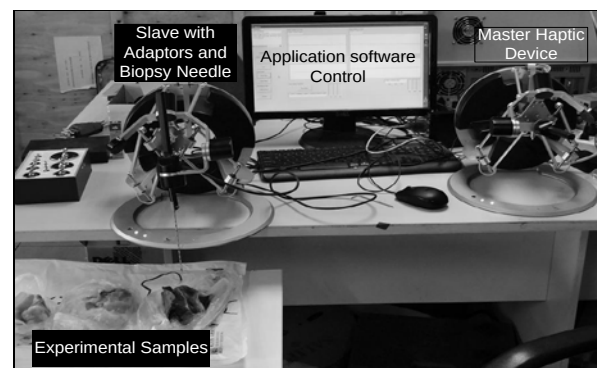


Fig.4: Position-Position Difference based Force Feedback Experimental Setup

The PPD based force feedback master slave system is checked under the observation of data collection from master slave devices and the PPD force feedback system. Different types of piecewise fresh tissues are used for experiments such as pig, beef chicken and rubber foam. The master and slave positions, and Position-position difference data are recorded from real time software in .txt file and MATLAB software is used to plot and compare them.

3. EXPERIMENTAL RESULTS

Experiments have been conducted on different types of structures to ensure the validity of the system at multiple surgical environments.

6.1 Experimental Result in free Movement:

Before starting the experiment on different structure, the first experiment is conducted in free air to calculate the offset error of the system. The experimental results are shown in (Fig 5). The first graph is about master random positioning in millimeter (mm) with three axes. The maximum difference between master and slave during free air experiment is less than ± 0.5 mm. These differences are accumulated due to random jerks during change of direction of the master device.

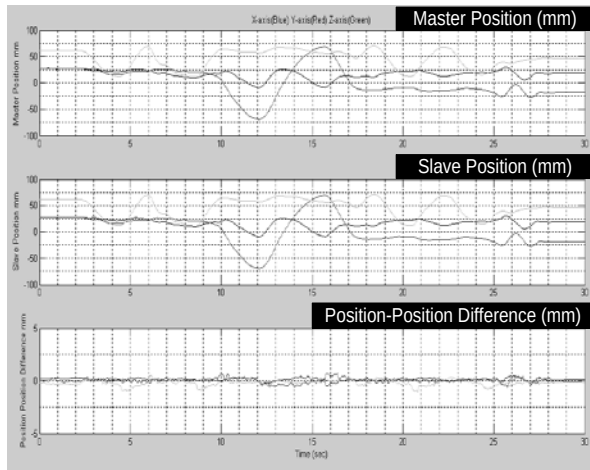


Fig .5: PPD Experimental Results in Free Movement

6.2 Experimental Result on Pig Tissue.

The experimental results are shown in (Fig 6). The first graph is shown about mastering positioning in millimeter (mm) with all axes. The upward and downward are the Z-axis movements. The biopsy needle injecting and ejecting is shown in experiment performed. Insertion and extraction on the different places of the pig tissue are repeated four times. The maximum inserting difference in positions is about 2.4mm. The maximum ejecting difference is about 2.6 mm .The little difference happens due to more injecting and variable velocity of the slave. The differences are multiplied by the stiffness factor- K_{fd} and transferred to master device. Pig tissue experiment shows that the injecting difference is little lower than the ejecting due to wire based slave haptic device. The user feels the force feedback on master device during slave injecting and ejecting as shown in (Fig.6).

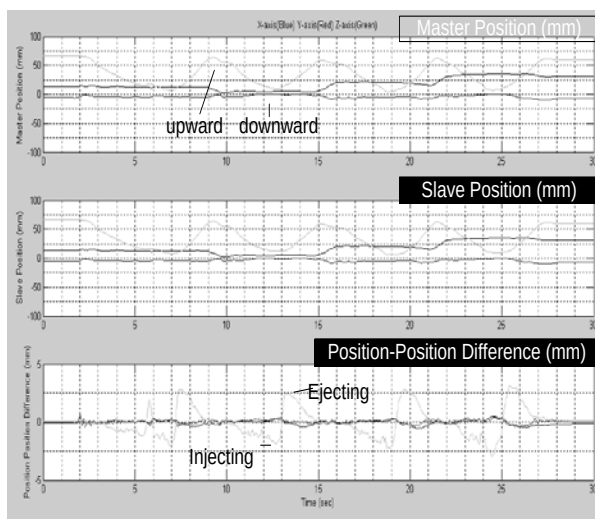


Fig. 6: PPD Experimental Results on pig tissue

6.3 Experimental result on Beef tissue

The experimental results are shown in (Fig 7).. The first and second graphs are about master and slave positioning in millimeter (mm) respectively along all axes. The upward and downward Z-axis movement is shown. The biopsy needle injecting and ejecting experiment is performed. The maximum injecting difference in positions is about -2.5 mm and it is continuing for four times. The ejecting difference is about 2.5 mm and it also continues four times. The little difference occurs in graph due to more injecting and variable velocity of the slave. The difference is multiplied by the stiffness factor K_{fd} and transfer to master device. Beef tissue experiment shows the injecting and ejecting differences almost equal. The user feels the force feedback on master device during slave injecting and ejecting as shown in (Fig.7).

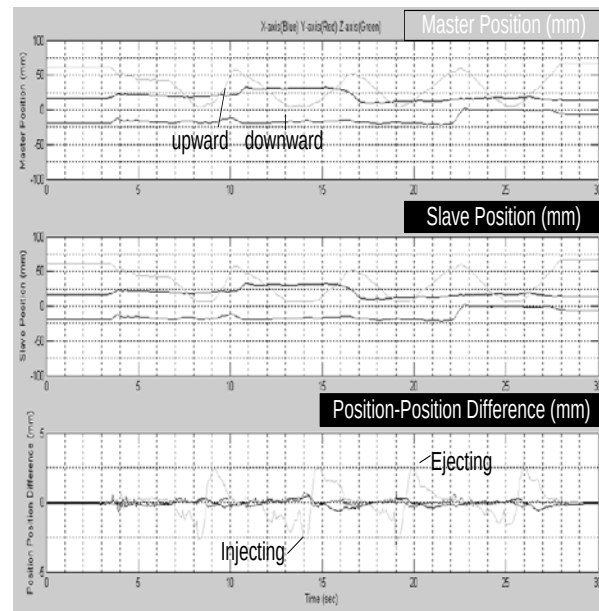


Fig .7: PPD Experimental Results on Beef tissue

6.4 Experimental Result on Chicken Tissue:

The experimental results are shown in (Fig 8). The first graph is about master positioning in millimeter (mm) with all axes. The upward and downward Z-axis movement is shown. The biopsy needle injecting and ejecting experiment is performed seven times. During injecting or ejecting on the different places of tissue, we have got differences in the maximum range of -3.0 to 4.0 mm. The results are not same as in pig and beef tissue. This difference is multiplied by the stiffness factor and transferred to master device. The master device user feels the force feedback on master device during slave injecting and ejecting. This time the ejecting differences are higher due to wire based haptic device.

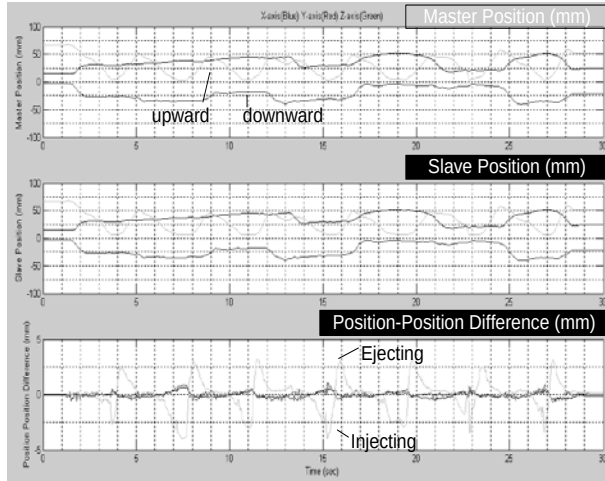


Fig 8: PPD Experimental Results on Chicken tissue

6.5 Experimental Result on Rubber Foam:

The experimental results are shown in fig9. Five times insertion and extraction procedures are performed at different places of rubber foam. We have got differences in the maximum range of -2.5 to 2.5 mm. The results are not same as for pig, beef and chicken tissue. This difference is multiplied by the stiffness factor and is transferred to master device. The master device user feels the force feedback on master device during slave injecting and ejecting. This time needle injecting and ejecting force feedback sensation is little weaker as shown in (Fig.9).

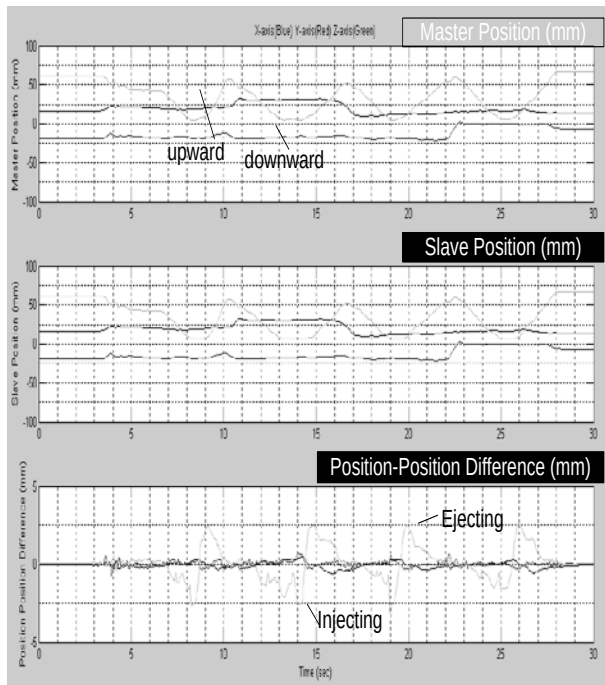


Fig 9: PPD Experimental Results on Rubber Foam

Statistical data about the difference between master and slave movement on different tissues (PPD) is shown in (Table I).

Table I: PPD Statistical data during needle insertion/extraction

	Free	Beef	Pig	Chicken	Rubber foam
Min	-0.5108	-3.428	-2.998	-4.04	-1.978
Max	1.055	2.67	3.146	3.196	2.821
Mean	0.1906	0.04044	0.02817	0.03199	0.08452
Median	0.162	0.0956	-0.024	0.147	0.0404
Mode	0.1408	0.0956	0.055	0.0524	0.0672
Std	0.2404	1.052	1.224	1.393	0.9305
Range	1.566	6.099	6.145	7.236	4.799

4.

CONCLUSION

In this paper, position-position difference (PPD) haptic force feedback system is implemented by establishing controller and application software with GUI interface. The injecting and ejecting experimental setup is designed and performed by using different types of piecewise tissues structures such as pig, beef, chicken, and rubber foam. The experimental results of the designed setup with respect to master and slave position and their differences due to injection and ejecting are shown in results. The position-position difference that is utilized as force feedback on the master handheld device is also mentioned on graph and tabular form by using MATLAB programming. In pig experiment the ejecting amplitude is quite higher than injecting, the reason was that structure behavior of tissue is relatively different to the other, therefore during ejection process the biopsy needle fond of with piecewise pig tissue, so it takes more position difference. However, the results show the stability, repeatability and transparency during injecting and ejecting; also different behaviors on different types of tissues. The significance of the design system is to implement remote biopsy needle insertion procedure with haptic force feedback effects on the master side. In future, the experimental setup will be developed by implementing force sensor over the needle architecture.

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