

Performance of a 7 DOF General Purpose Haptic Device

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Abstract - A seven degree-of-freedom (DOF) haptic device has been developed with applications towards robot-assisted minimally invasive surgery. The device consists of four degrees of force feedback (three spatial and one grasping/parting) capability and seven degrees of freedom for positioning capability. The haptic device is a closed-kinematic chain with two halves (user interface and spatial force feedback mechanism) connected by a universal joint. At the end of the user interface is a grasping/parting mechanism to feedback grasping forces from manipulation tasks. While the device was developed with applications towards robot-assisted minimally invasive surgery, it could also be used in the automotive industry, gaming industry, or as a rehabilitation aid for people with finger, hand, or forearm injuries.

Index Terms – Haptic Device, Minimally Invasive Surgery, Robotic Surgery.

I. INTRODUCTION

Robot-assisted surgery has led to great improvements in open and minimally invasive procedures within the medical field. These robotic surgical systems incorporate advantages from minimally invasive surgery (MIS), such as reduced patient trauma, improved dexterity, shorter recovery time, and lower health care costs to name a few. While these systems add many advantages, they also incur the shortcoming of a lack of haptic feedback due to the indirect contact of the surgeon with the surgical site. Research in this area has led to the development of surgical tool with force measuring capabilities, for example [1-5]. These surgical tools, however, only represent half of the solution to the lack of haptic feedback in robot-assisted surgery. The other half requires the accurate reflection of the measured forces back to the surgeon through a haptic device. Several researchers have proposed solutions to the need for a haptic device in robotic surgery, for example [6-10]; however, there has been limited commercial application of these technologies in both open and minimally invasive procedures.

Based on this motivation, we have developed a haptic device with seven degrees of positional feedback and four degrees of force feedback capability that has specific applications towards robot-assisted MIS. Our haptic device is a closed-kinematic chain that consists of two halves (a user interface and a spatial force feedback mechanism). The haptic device provides force feedback along three orthogonal axes and also for grasping/parting tasks. Although the device was

developed with applications towards robot-assisted minimally invasive surgery, it has potential uses in the automotive industry, gaming industry, or as a rehabilitation aid for people with finger, hand, or forearm injuries.

II. DESIGN AND DEVELOPMENT

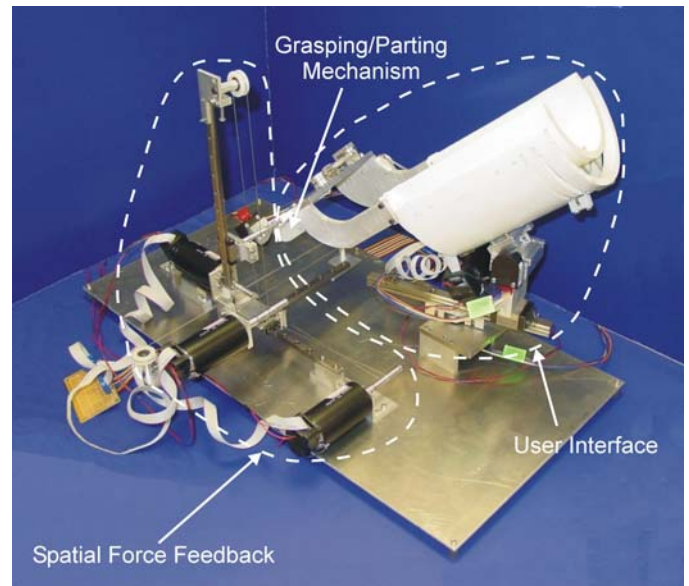


Figure 1. Prototype of the haptic device

The device consists of a closed-kinematic chain with two halves; namely, a user interface and a spatial force feedback mechanism (see Figure 1). The user interface consists of a hand and forearm rest that contains four degrees of positional feedback (roll, pitch, yaw, and linear motion of the arm rest) capabilities with a grasping/parting mechanism at the end of the arm rest. The positional feedback is obtained from the four passive joints of the user interface, of which, three are equipped with encoders (see Table I for joint limits). The position of the prismatic joint can be determined from the position of the other three joints and the spatial force feedback mechanism joints. The configuration of the joints in the user interface proceeds from the base to the yaw joint to the linear joint to the pitch joint to the roll joint and finally to the end-effector, where the grasping/parting mechanism is located. The grasping/parting mechanism contains two thimbles for the user's fingers (thumb and index finger, for example) that are

coupled to a DC motor with an encoder. The motor assembly is mounted below the arm rest near the pitch joint to reduce the moment exerted on the user by the user interface. A two-stage cable transmission connects a pulley mounted to the motor shaft to an intermediate pulley and a second cable connects the intermediate pulley to the thimble pulleys. The cable transmission was designed to allow for equal and opposite motion of each of the thimbles and linkages. This allows the user to fully control a grasping/parting mechanism, such as a laparoscopic tool at the end of a robotic surgical

TABLE I
JOINT LIMITS FOR THE HAPTIC DEVICE

Joint	Range of motion
User Interface	
Yaw joint	0° to 180°
Prismatic joint	-76.2mm to 76.2mm
Pitch joint	0° to 20°
Roll Joint	-35° to 35°
Spatial Force Feedback Mechanism	
Prismatic joint 1 (X axis)	0mm to 223mm
Prismatic joint 2 (Y axis)	0mm to 223mm
Prismatic joint 3 (Z axis)	0mm to 183mm

system, and also receive force feedback as measured by sensors in the laparoscopic tool. The grasping/parting mechanism allows for a maximum torque of 88.8 mNm which converts to a maximum theoretical force at the thimbles of 12.5N. The spatial force feedback mechanism consists of a three degree-of-freedom positioning stage that attaches to the user interface at the grasping mechanism through the use of a universal joint (see Table I for joint limits). This mechanism was designed to provide force feedback in three directions through orthogonally-mounted linear actuators. These actuators consist of DC motors with encoders that use cable transmissions attached to slide guides. Therefore, this force feedback mechanism can relay manipulation forces, such as the pulling or pushing of an object (e.g. soft tissue in MIS), to the user in addition to the gripping forces felt through the grasping/parting mechanism. Further, the spatial mechanism was also designed to apply all forces to the user at the grasping/parting mechanism rather than through the joints of the arm rest. This enhances the transparency of the haptic device by providing feedback to the user, which is more analogous to conventional open surgery where the surgeon primarily receives feedback at the point of contact with the soft tissue and/or organs. Each of the DC motors in the spatial mechanism allows for a maximum torque of 181 mNm which converts to a maximum theoretical force along each orthogonal axis of 56 N. However, frictional losses reduce this force to approximately 40 N (as measured experimentally). We have estimated the frictional forces along each actuated axes and are able to feed-forward the friction torque to the motor to ensure higher transparency of the device.

II. CONCLUSION

We have designed and developed a seven degree-of-freedom haptic device with applications towards robot-assisted MIS. The device contains seven degrees of position feedback and four degrees of force feedback capability. The haptic device is a closed-kinematic chain with two halves, namely, the user interface and spatial force feedback mechanism connected using a universal joint. A grasping/parting mechanism is located at the end of the user interface for manipulations tasks, such as the grasping of soft tissue. Future work includes using the haptic device to control the end-effector of a laparoscopic tool that is mounted to a slave robot for telemanipulation tasks.

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