A General Purpose 7 DOF Haptic Interface*

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Abstract

A novel haptic interface was designed and developed for use in manipulation tasks. The force feedback mechanism consists of three degrees of spatial force feedback (x, y, and z directions) and 1 degree of grasping/parting (increasing the distance between two or more points) force feedback. This device also provides a net of three additional passive joints for a total of 7 degrees-of-freedom.

1. Introduction

Robot-assisted surgery has led to significant improvement within the medical field. These systems incorporate advantages from minimally invasive surgery (MIS), such as reduced patient trauma, recovery time, and lower health care costs, to name a few. While these systems have the above advantages, they also have the shortcoming of the lack of haptic feedback.

Many researchers have proposed and developed different types of haptic devices for various applications. Haptic devices have been developed using serial and parallel mechanisms [1], haptic glove or exoskeleton devices [2], and surgical haptic mechanisms that can be used for MIS and robotically-assisted MIS [3]. However, these haptic devices lack the capability of reflecting multiple surgical methods, such as laparoscopic procedures, as well as, open procedures. Based on this motivation, we have developed a haptic interface with 7 degrees of freedom position feedback of which 4 degrees of freedom also provide force feedback with applications to robotically assisted MIS. The mechanism provides force feedback along three orthogonal axes and also for the grasping/parting force. This interface can also be used for a variety of other applications such as automotive industry, gaming industry, and rehabilitation aids.

2. Design and Development

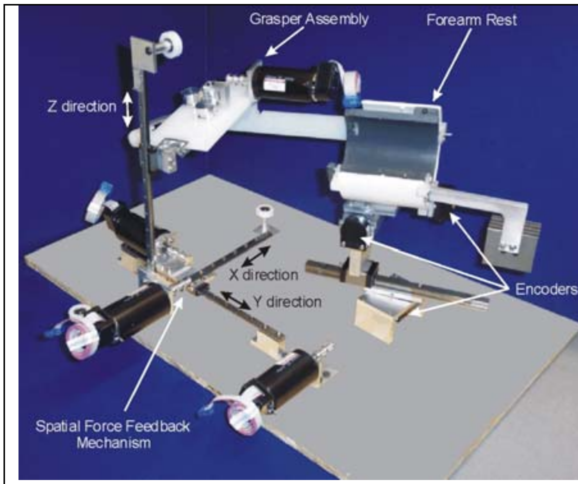

Figure 1. Prototype of the haptic interface.

The device is a closed kinematic chain that consists of a hand and forearm rest, grasping mechanism for two fingers, such as a thumb and index finger for example, and a decoupled 3 degree-of-freedom spatial force feedback component (see figure 1). The hand and forearm rest contains 4 degrees-of-freedom for positioning (roll, pitch, yaw, of the wrist and linear motion for the forearm) the user's arm. This creates an ergonomic platform that conforms to the natural motions of the human arm for manual manipulation tasks. The grasping mechanism is coupled to the direct drive DC motor that allows for grasping tasks using two fingers of the user, such as the thumb and index finger. This mechanism enables the user to control the angle of the jaws of the laparoscopic tool and also

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receive force feedback through the DC motor as detected by sensors in the laparoscopic tool. The decoupled spatial force feedback mechanism consists of a 3 degree-of-freedom positioning stage that is attached to the hand and forearm rest at the grasping mechanism through a universal joint. The force feedback mechanism was designed as such to apply all forces to the user at the grasping mechanism rather than through the joints of the hand and forearm rest. This enhances the transparency of the haptic interface by providing feedback, which is more analogous to conventional open surgery where the surgeon's primarily receives feedback at the point of contact with the soft tissue and/or organs.

2.1 Hand/Forearm Rest:

The hand and forearm rest contains 4 degrees-of-freedom as determined by the natural motion of the human hand. The design consists of a base mount, which incorporates a rotation about the vertical axis. A linear slide is mounted to this base mount and provides approximately 6 inches of motion in the global x-y plane. A vertical mounting plate then attaches to the linear slide and holds a mounting bracket using ball bearings that allow the arm rest to pitch. The forearm rest attaches to this bracket that allows for the pitch and consists of two circular arcs. The bottom part of the forearm rest is fixed to the forearm assembly while the top part rests on the bottom part with bearings between the two parts. These bearings allow for the rotation of the upper part of the forearm and thus create the roll of the mechanism. Additionally, three encoders measure the roll, pitch, and yaw motions at their respect joints for positional feedback. A link is then attached to the upper part and extends forward to support the grasping/parting assembly.

2.2 Grasping/Parting Assembly:

The grasping/parting assembly consists of a direct drive DC motor, pulleys, and thimble assembly that allow the user of the haptic interface to control grasping objects with two fingers, primarily the thumb and index finger. The DC motor has a pulley attached to its shaft with three other pulleys on the thimble mount, one intermediate and two thimble pulleys. The two thimble pulleys are attached to the thimble mount using ball bearings and each connect to a linkage on the underside of the thimble mount. This linkage then extends approximately 3 inches and has a thimble attached to the end of it. For actuation of the mechanism, we use steel cables that travel from the motor pulley to intermediate pulley, which increases the torque in a 3:1 ratio. A second steel cable then travels from the intermediate pulley to one of the thimble pulleys with a torque increase in a 3:1 ratio and a third steel cable travels from one thimble pulley to the other in a lemniscate pattern. Therefore, the two thimble pulleys rotate opposite to each other and create the opening or closing motion of the two thimbles. Hence, this assembly has the capability to provide force feedback to the user for both grasping and parting tasks.

2.3 Spatial Force Feedback Mechanism:

The 3 degree-of-freedom spatial force feedback mechanism mounts to the base of the haptic interface and attaches to the grasper via a universal joint. It consists of 3 direct drive DC motors with encoders for the 3 directions and 3 linear slide guides. The three slide guides are mounted in series to each other (Y-X-Z) and thus create a 3 degree-of-freedom mechanism. Each of the motors has a pulley system that uses a steel cable to actuate the assembly along with the linear slide guide. Therefore, the combination of the three motors and encoders can provide the positioning and force feedback at the interface to the grasper assembly.

3. Discussion

We have designed and developed a haptic interface for use in manipulation tasks. It has seven degrees-of-freedom of position feedback and four degrees-of-freedom of force feedback that includes one for grasping/parting force feedback and three for spatial force feedback. A net of three additional passive joints for positional feedback allows for a total of seven degrees-of-freedom positional feedback for the user interface. Preliminary testing and development of the software for this device is currently in progress.

References

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