An Experimental Comparison of Two User Interface Designs for a Hand-Held Surgical Robot

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1 Background

There is a trend towards miniaturization in surgical robotics with the objective of making surgeries less invasive [1]. There has also been increasing recent interest in hand-held robots because of their ability to maintain the current surgical workflow [2, 3]. We have previously presented a system that integrates small-diameter concentric tube robots [4, 5] into a hand-held robotic device [3], as shown in Figure 1. This robot was designed for transurethral laser surgery in the prostate. It provides the surgeon with two dexterous manipulators through a 5mm port in a traditional transurethral endoscope. This system enables the surgeon to retract tissue and aim a fiber optic laser simultaneously to resect prostate tissue.

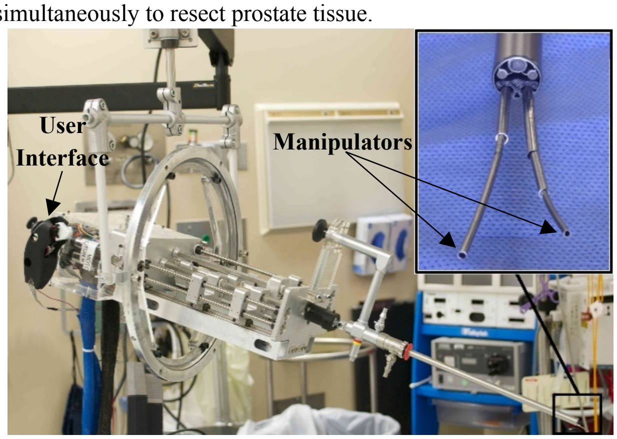

Figure 1: The hand-held robot from [3] delivers two concentric tube robot manipulators. These manipulators are controlled by a user interface which is mounted to the system.

This robot provides the surgeon with a total of ten degrees of freedom (DOF) that must be simultaneously coordinated, including endoscope orientation (3 DOF), endoscope insertion (1 DOF), as well as the tip position of each concentric tube manipulator (3 DOF per manipulator). In [3], a simple user interface was employed that involved thumb joysticks (which also had pushbutton capability) and a unidirectional index finger trigger, as shown in Figure 2 (Left). The thumb joysticks were mapped to manipulator tip motion in the plane of the endoscope image, and the trigger was used for motion perpendicular to the plane. Whether the finger trigger extended or retracted the tip of the concentric tube manipulator was toggled via the pushbutton capability of the thumb joystick. While surgeons could learn this mapping with some effort, and were able to use it to accomplish a cadaver study, the experiments made clear that further work was needed in creating an intuitive user interface – particularly with respect to how motion perpendicular to the image plane is controlled. This paper describes a first step toward improving the user interface; we integrate a bidirectional dial input in place of the unidirectional index finger trigger, so that extension and retraction perpendicular to the image plane can be controlled without the need for a pushbutton toggle. In this paper we describe the design of this dial input and present the results of a user study comparing it to the interface in [3].

2 Methods

Our new user interface design, shown in Figure 2 (Middle), employs task space control for the tips of the manipulator. An analog, 2-axis sliding joystick maps velocity commands to move the control point at the tip of the manipulator, shown in Figure 2 (Right), in the plane of the endoscope view. An analog, Hall-effect spring-return dial maps the velocity of the tip perpendicular to the image plane. The angular deflection of the dial and the linear displacement of the joystick are linearly mapped to a velocity command at the tip of the manipulator.

The original user interface in [3] used these same mappings but used a pivoting joystick rather than a sliding joystick for motion in the image plane and a trigger for perpendicular movements, as shown in Figure 2 (Left). In contrast to the new interface, the trigger enabled motion only in one direction (either toward the endoscope lens or away) at a time. To switch

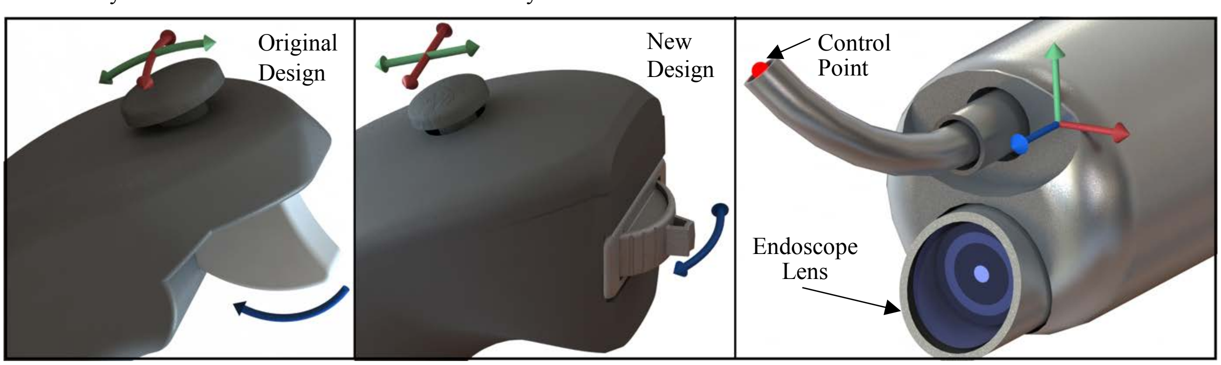

Figure 2: (Left) The original user interface design features a pivoting joystick and a unidirectional trigger. (Middle) The new design features a sliding joystick and a bidirectional dial. (Right) The control point is located at the tip of the concentric tube manipulator. The colors of the arrows in each user interface image indicate the directional velocity that is commanded to the control point in the coordinate system fixed to the tip of the endoscope.

This is the final version of this paper submitted for typesetting.

directions, the user was required to push down on the thumb joystick. This discrete pushbutton switching between insertion/retraction of the control point was the primary drawback of the original user interface observed during initial experiments.

To explore the benefits of the new interface, an experiment was designed to quantify the ability of a user to accurately command the tip of the manipulator. The user (first author Rox) performed a path following experiment using a 3D printed path, as shown in Figure 3. This 3D path was designed to require motion in positive and negative x, y, and z directions so that bidirectional use of each of the user inputs was required to complete it. The endoscope was fixed during the experiments so that the user interface controlled all motions. A small magnetic tracking coil was placed at the tip of the manipulator and tracked using the Aurora magnetic tracking system (Northern Digital Inc.). This enabled continuous tip position recording at all times during the experiment. The 3D path was registered to the magnetic tracker's coordinate system.

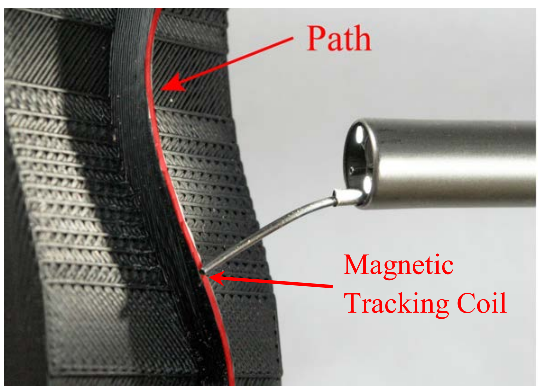

Figure 3: The path following experimental setup. During this experiment, the user commanded the tip of the manipulator to follow the path as accurately as possible.

3 Results

The purpose of this experiment was to compare the tracking ability of the two user interfaces. For each interface, the user attempted to follow the path as quickly and accurately as possible. Figure 4 shows the error tracked in time as the control point followed the path for one run of the experiment.

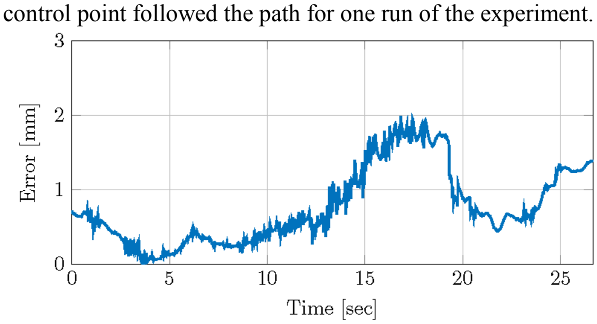

Figure 4: Tracking Error vs. Time for a representative path tracking run.

Table 1 shows a comparison of the total time taken to complete the path, the mean error for the runs, the maximum error for the runs, the standard deviation of the error for the runs, and the percentage of time the manipulator was in large error (greater than two mm). For each user interface, the user completed 11 runs.

Table 1: Experimental results comparing the original user interface to the new interface.

	Orig.	**New**	**% Change**
Time [sec]	42.2 ± 2.8	29.2 ± 2.6	30.8
Mean Error [mm]	1.15 ± 0.12	0.99 ± 0.15	13.9
Max Error [mm]	4.03 ± 2.23	2.42 ± 0.39	40.0
Error Std. Dev. [mm]	0.55 ± 0.10	0.49 ± 0.08	10.9
Large Error [%]	9.3 ± 7.9	4.5 ± 5.9	51.6

4 Interpretation

The new user interface improved the user's ability to follow a complex three dimensional path, especially by reducing total time, max error, and time in large error. While this is a promising initial result, it must be validated in future studies with more users before it can be considered fully validated. In future work, we also intend to explore a variety of alternate user interfaces, including designs that map force to velocity or position to position to determine which is most intuitive for surgeons to use.

Future work is also required to compare our robotic approach with the current standard of care. We suspect that the robot will make the surgery easier to learn and to perform, because it decouples instrument motion from endoscope (and hence endoscope view) motion and also provides the surgeon with a second hand that is useful for tissue retraction. We must experimentally validate these hypotheses and plan to do so in phantom and cadaver studies to evaluate performance in a realistic clinical scenario. An intuitive surgeon interface is a key to achieving the performance improvements we seek, and the results in this paper are a first step toward designing a user interface that makes the surgeon's job as easy as possible.

References

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