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Touchless Telerobotic Surgery – Is It Possible at All?

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Abstract

This paper presents a comprehensive evaluation among touchless, vision-based hand tracking interfaces (Kinect and Leap Motion) and the feasibility of their adoption into the surgical theater compared to traditional interfaces.

Background

Teleoperated robot-assisted surgery (RAS) is becoming more popular in certain types of surgical procedures due to its dexterity, precision, high-resolution, accurate motion planning and execution capabilities, compared to traditional minimally invasive surgery which relies on hindered laparoscopic control. The most widely adopted system based on this paradigm is the daVinci robot (2014), in which the surgeon manipulates joysticks in a master console using 3D imaging for guidance. Then robotic arms mimic the surgeon's movements on the patient's side. Some of the drawbacks of this system are related with the user experience, since the surgeon has to retrain in order to learn how to operate cumbersome interfaces and in the process some of the intuitive hand gestures related with in situ surgery are lost.

Some research has been devoted to incorporate touchless interfaces in the surgical scenario (Hartmann & Schlaefer, 2013). Some of the advantages of working with touchless interfaces have to do with allowing more natural gestures, as well as maintaining asepsis which cannot be said for more traditional interfaces such as keyboards or mouse (Schultz, Gill, Zubairi, Huber, & Gordin, 2003). One of the obvious drawbacks of such interfaces is the loss of tactile information. In this regard, there have been attempts to compensate this loss by leveraging on sensory substitution, where information is provided through sound and visual cues (Bach-y-Rita & W. Kercel, 2003). Other attempts relate with touchless feedback through air or ultrasound (Okamura, Verner, Yamamoto, Gwilliam, & Griffiths, 2011; Sodhi, Poupyrev, Glisson, & Israr, 2013).

This type of solution, when applied to robotic surgery, has the potential to allow surgeons to operate as if they were physically engaged when doing in-situ surgery. By relying on touchless interfaces, the system can incorporate more natural gestures that are similar to instinctive hand movements, thus enhancing the user experience, which is a trending topic in the area of AI User Experience (AIUX). (Chaudhary, Raheja, Das, & Raheja, 2013).

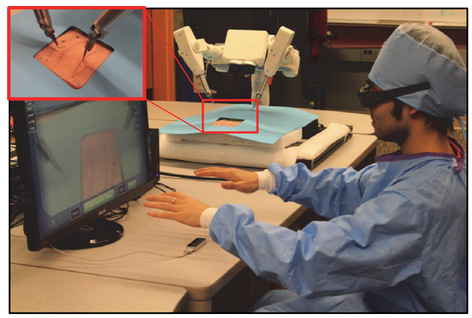

Figure 1. System Overview

System Overview

The implementation of the system is based on the Taurus robot (see Figure 1) which can hold instruments, make incisions and transfer parts. Taurus can be controlled using a combination of hand and foot gestures. The gestures are captured through optical cameras (Kinect & Leap motion) and are further compared to traditional interfaces such as keyboards and haptic controllers (Omega & Hydra).
Upon user's selection, each interface then goes through a gesture segmentation process to extract the information that will actually be used to control Taurus. Then a registration process takes place by using a foot pedal as a clutch to select the origin of the user space.

Using the continous trajectory performed by the user, a discrete trajectory is generated in the robot space, using an algorithm to perform a piece-wise linear transformation, and then converted to suitable robotic commands through inverse kinematics. Once the action is executed feedback is provided to the user in the form of bar graphs and sound cues, related to the amount of force applied to the tooltip.

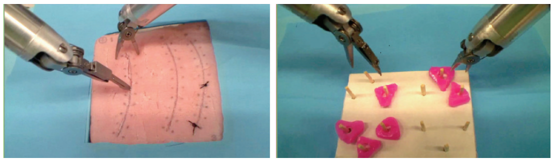

Figure 2. Left: Incision task. Right: Peg transfer task.

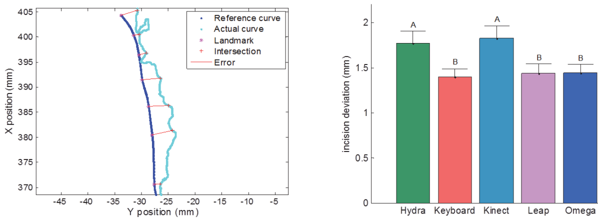

Figure 3. Deviation Error in the Incision Task

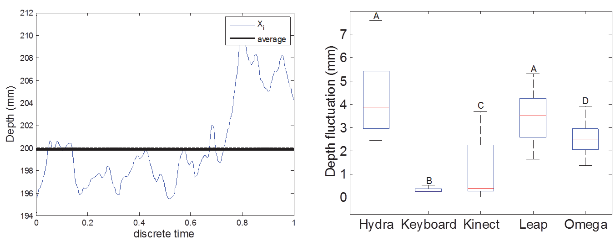

Figure 4. Depth Fluctuation in the Incision Task

TABLE 1. AVERAGE PERFORMANCE FOR THE PEG TRANSFER TASK

Interface	Time ± CI (s)	Peg Drops ± CI	Learning Rate
Hydra	**107.9**^{A} ± 10.00	**0.2**^{A} ± 0.2	92.71%
Keyboard	271.9^{B} ± 37.33	**0.15^{A} ± 0.2**	93.83%
Kinect	594.7^{C} ± 64.64	0.4^{B} ± 0.3	85.42%
Leap Motion	360.2^{B} ± 70.98	1.3^{B} ± 0.6	**69.86%**
Omega	**121.3**^{A} ± 13.34	**0.2**^{A} ± 0.2	85.69%

Experiments

Two experiments were conducted to measure the performance of different interfaces through teleoperation. Subjects used different interfaces to complete two surgical tasks while several task-related metrics were measured and further analyzed. The first task involved conducting a guided surgical incision while maintaining a fixed depth. The second task involved a Peg Transfer task common in laparoscopic surgery skill assessment. Both tasks are shown in Figure 2.

For the experimental design, ten engineering students conducted this experiment (5 male, 5 female, average age 30.5). Each subject teleoperated Taurus using two out of five interfaces, for five repetitions with each interface, resulting in 20 observations for each interface. The order of the two interfaces was randomized to compensate for the learning of the task.

In the Incision Task, each trial was compared against a reference line (Figure 3, left) by selecting twenty equally spaced landmarks and finding the closest distance to the actual trajectory. All those results are averaged to get the deviation error per interface, as shown in Figure 3 (right).

In order to measure how well the users could maintain a fixed depth, the variance of the depth trajectory was analyzed. The average of all the trials indicates the depth fluctuation per interface, as shown in Figure 4.

In the Peg Transfer Task, the metrics recorded and analyzed were the task completion time and the number of peg drops. A learning rate was calculated after fitting learning curves to the completion time, shown in Table 1.

Conclusions

This paper presents a comparison between interfaces developed for controlling a robot for surgical applications. Experimental results reveal that for the incision task, Leap Motion, keyboard and Omega interfaces exhibit less deviation error from the target than that of using Hydra and Kinect interfaces ($p<0.001$). For maintaining a fixed depth during incision, the Kinect and keyboard interfaces provided a more stable control ($p<0.001$) than the Omega, Hydra and Leap Motion interfaces. Regarding the Peg Transfer task, Omega and Hydra required shorter task completion time than the Kinect, keyboard and Leap Motion ($p<0.001$); On the other hand, touch-less interfaces presented faster learning rate (69.86% for Leap Motion and 85.42% for Kinect) than their counterpart interfaces.

Acknowledgments

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