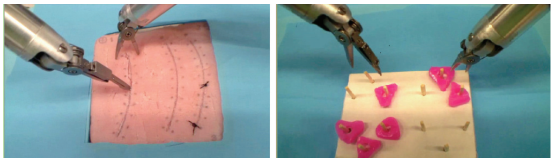

Figure 2. Left: Incision task. Right: Peg transfer task.

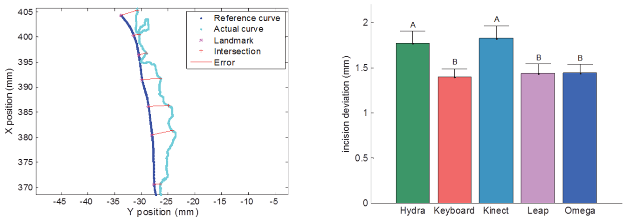

Figure 3. Deviation Error in the Incision Task

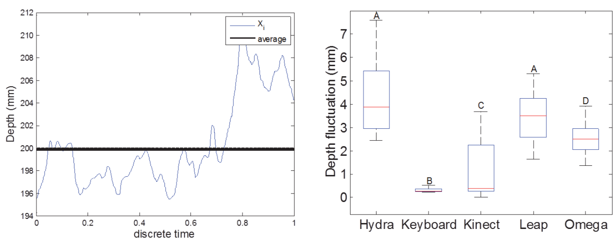

Figure 4. Depth Fluctuation in the Incision Task

TABLE 1. AVERAGE PERFORMANCE FOR THE PEG TRANSFER TASK

Interface	Time ± CI (s)	Peg Drops ± CI	Learning Rate
Hydra	$\mathbf{107.9^{A}}$ ± 10.00	$\mathbf{0.2^{A}}$ ± 0.2	92.71%
Keyboard	271.9^{B} ± 37.33	$\mathbf{0.15^{A} \pm 0.2}$	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	$\mathbf{121.3^{A}}$ ± 13.34	$\mathbf{0.2^{A}}$ ± 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

This publication was made possible partially by the NPRP award (NPRP6-449-2-181) from Qatar National Research Fund (member of The Qatar Foundation). The statements made herein are solely the responsibility of the authors.

References

Bach-y-Rita, P., & W. Kercel, S. (2003). Sensory substitution and the human–machine interface, *7*(12), 541–546.

Chaudhary, et. al.(2011). Intelligent Approaches to interact with Machines using Hand Gesture Recognition in Natural way: A Survey. *IJCSES Vol 2, No.1, 122-133*

da Vinci Surgery - Minimally Invasive Robotic Surgery. (2014). Retrieved April 19, 2014, from http://www.davincisurgery.com/

Hartmann, F., & Schlaefer, A. (2013). Feasibility of touch-less control of operating room lights, *8*(2), 259–268.

Okamura, A. M., et. al. (2011). Force Feedback and Sensory Substitution for Robot-Assisted Surgery. *Surgical Robotics* (pp. 419–448).

Schultz, M., et. al. (2003). Bacterial contamination of computer keyboards in a teaching hospital, *24*(4), 302–303.

Sodhi, R., et. al. (2013). AIREAL: Interactive Tactile Experiences in Free Air, *32*(4), 134:1–134:10