Paper Seminar Critical Review

Augmentation of Haptic Guidance into Virtual-Reality Surgical Simulators

Group 14

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Project Summary

The goal of this project is to incorporate haptic feedback as real-time corrective guidance to virtual reality surgical simulators with reference to the optimal path for the task. Coupled with the visual feedback, we are working to determine the efficacy of haptic feedback in teaching robotic minimally invasive surgery (RMIS) skills. We are working with the da Vinci Research Kit system running a suturing task simulation that has already been created. By augmenting this system with haptic feedback, we hope to better understand the role of real time haptic feedback in RMIS training. Our work includes running a user study to compare different methods of haptic feedback.

Paper Selected

The paper I have chosen for this review is:

> M. M. Coad et al., "Training in divergent and convergent force fields during 6-dof teleoperation with a robot-assisted surgical system," IEEE World Haptics Conf., 2017, pp. 195–200.

This paper is relevant to my project because of its similar experimental setup and its similar methods of real time feedback. It also describes the design of their user study in detail. We are able to use the details of their implementation and of their user study in order to guide us in our own implementations and as a starting point for the design of our own user study.

Summary

The authors "examined the effect of divergent and convergent force/torque fields on the learning of novice non-medical participants during a 6-DoF peg transfer task using the da Vinci Research Kit (dVRK)" [1]. Divergent force fields exaggerate the negative effects of errors by pushing the subject away from a desired path, and convergent force fields provide guidance towards a desired path. The authors hypothesize that training in the divergent force fields may lead to enhanced performance, because related research in motor rehabilitation and skill acquisition has shown that tasks are learned faster and more accurately when the environment is augmented to exaggerate negatives effects of errors [2].

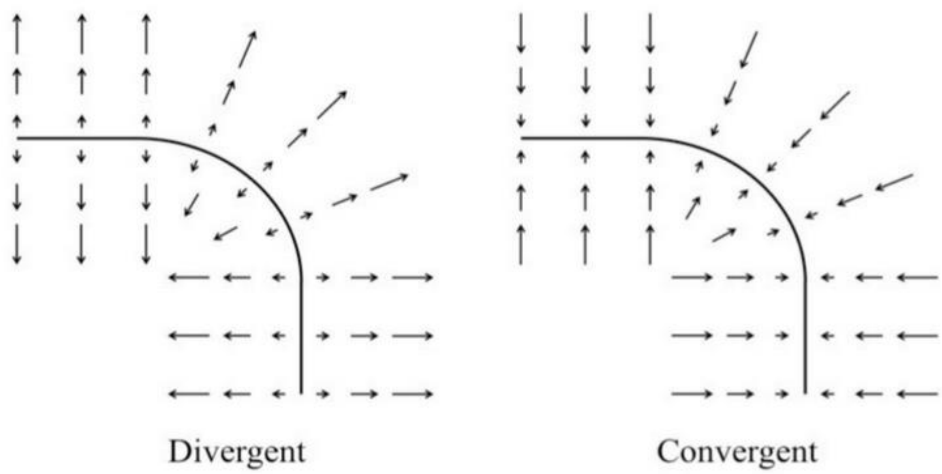

Figure 1: Figure from [1] showing 2-D representation of the divergent and convergent force fields that were applied in 3-D to the master gripper.

The experimental task is a peg transfer task. Subjects are shown a picture of the desired path and video of several good transfers. Every other trial, the subject alternates between moving the cylinder from lower right to upper left and moving the cylinder from upper left to lower right.

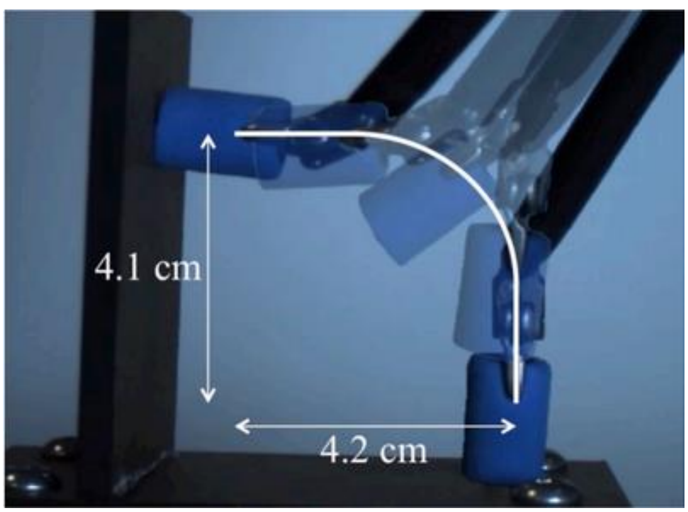

Figure 2: Figure from [1] showing the 6-DoF path that participants are asked to follow.

90 trials of transfers in 3 sets of 30 are performed. A control group completes all 90 trials with no force fields. For the divergent and convergent groups, force feedback is applied during the second session (trials 31-60) only.

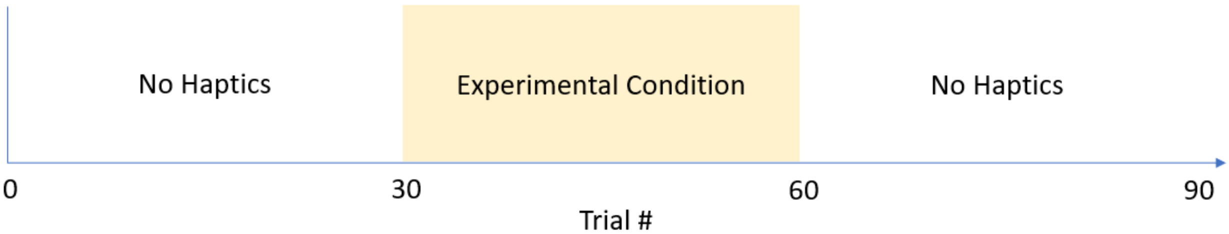

Figure 3: Which trials force feedback is applied on. There is a control group, a divergent force group, and a convergent force group.

The 4 performance metrics used are 1) trial time, 2) translational path error, 3) rotational path error, and 4) combined path error times trial time. Trial time quantifies speed and is a classical measure of surgical skill [3]. Translational and rotation path errors quantify accuracy, and are related to the classical measure of economy of motion [3]. Combined path error times trial time is a combination of the first 3 metrics, and it provides an overall measure of performance.

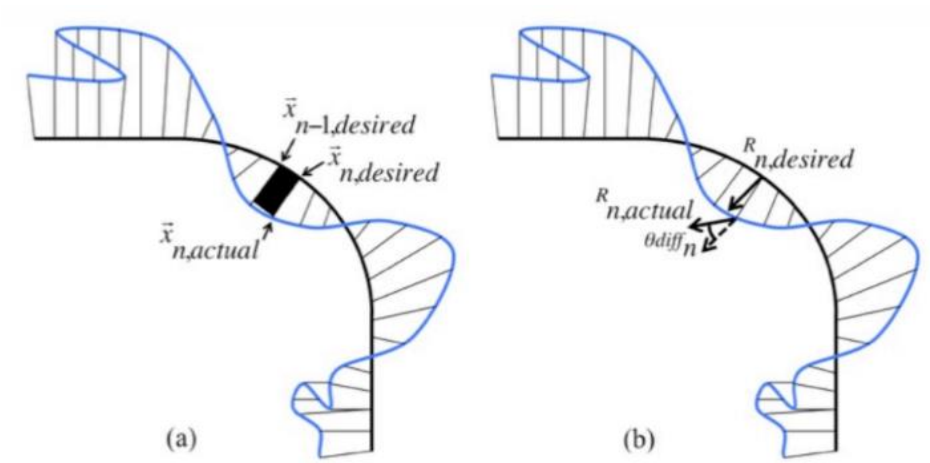

Figure 4: Figure from [1] showing translational path error (left) and rotational path error (right).

Main Result

There is no statistically significant difference between the performance of the groups on any metrics at the end of the experiment.

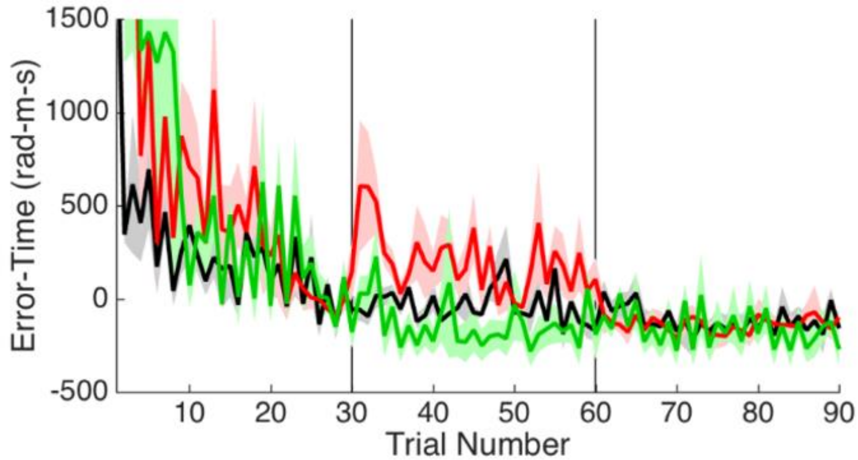

Figure 5: Figure from [1] showing evolution of combined path error times trials time (error-time). Green is convergent group. Red is divergent group. Black is control group.

Assessment

There are several positives about this paper. The paper provides a very clear description of the experimental task and of the experimental setup. If desired, the experiment could be replicated with very little guesswork. Explanations and citations of the performance metrics are provided, and it is clear that the metrics used make sense for this experiment.

There are 3 aspects I believe could be improved upon.

1) Task Oscillations

On odd numbered trials, subjects transfer the cylinder in one direction. On even numbered trials, subjects transfer the cylinder the in the reverse direction. These tasks are slightly different, and they may not be directly comparable. This results in the learning curves graphs showing a zigzag pattern. I would have liked to see separate graphs for the two directions separated into different graphs in order to better see more accurate variances for the individual directions.

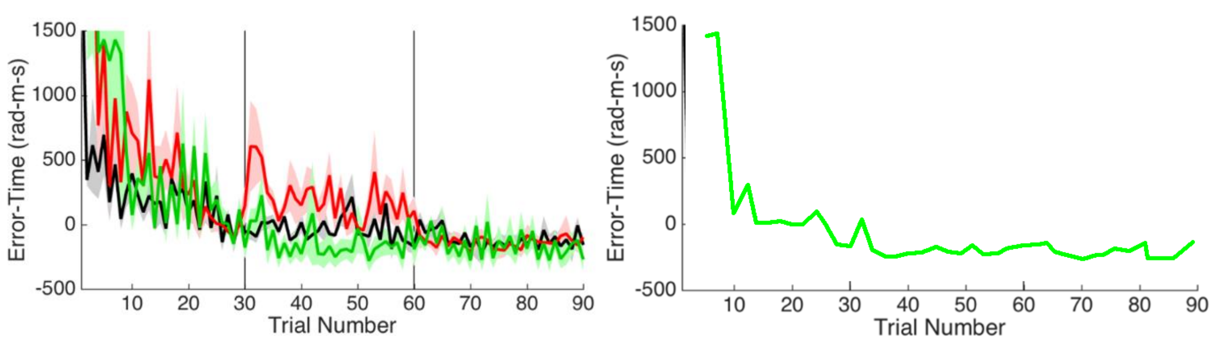

Figure 6: Hand drawn approximation of a separated error-time convergent learning curve.

2) No visual feedback

Subjects are shown a picture of the desired path and video of several good transfers. During the actual trials, however, there is no visual feedback about the desired path. Therefore, it may be unclear during the trials where the desired path actually is. Subjects rely solely on memory of the desired path, especially during trials with no haptic feedback. It may be useful to add a visual cue to show the location of the desired path.

Lack of visual feedback also somewhat limits the experiment. Since the goal is to train the subjects' RMIS skills, it may be useful to move the starting and ending locations and change the desired path between trials. This may prevent the subjects learning just a path instead of truly developing RMIS skill. Without visual feedback, however, moving the desired path without interrupting the experiment to reshow another picture/video is impossible.

3) Trial Lengths

The task chosen for this experiment is relatively simple. Subjects are able to reach a high level of proficiency during the first session of trials, before training with begins. All groups improve dramatically on all metrics within the first session of trials and less dramatically throughout the rest of the experiment. Future work will include work on more complicated surgical training tasks.

An interesting aspect of this paper's analysis is a normalization by subject baseline ability. In order to account for small variation between subjects, each subject has their own baseline ability subtracted from all of their data. Baseline ability is defined as the average of each metric at the end of the first session (trials 25-30). This is a tool that I will keep in mind during future analyses of my own work.

Conclusions

This paper has very clear descriptions of the experiment task and of the experimental setup, and it is very useful for my project because of these descriptions. The user study is well designed and serves as a starting point for the design of our own user study. The analysis tools and statistical tests used give insight into how we may want to analyze our own data.

There are four main lessons learned from this paper:

1) Keep all trials as similar as possible. If non-similar trials are desired, account for differences between trials during analysis and data visualization.
2) Consider using haptic feedback in conjunction with other types of feedback, i.e. visual.
3) Find a suitable number of trials for the difficulty of the experimental task.
4) Consider normalizing each subject by baseline ability.

This paper is very well written. I believe that its clear descriptions have helped me think about other experiments more clearly and have helped me become a better researcher.

References

[1] M. M. Coad et al., “Training in divergent and convergent force fields during 6-dof teleoperation with a robot-assisted surgical system,” IEEE World Haptics Conf., 2017, pp. 195–200.

[2] H. Abboudi, M. S. Khan, O. Aboumarzouk, K. A. Guru, B. Challacombe, P. Dasgupta, and K. Ahmed, “Current status of validation for robotic surgery simulators–a systematic review,” British Journal of Urology International, vol. 111, no. 2, pp. 194-205, 2013.

[3] Y. Sharon, T. Lendvay, and I. Nisky, “Instrument tip angular kinematics in teleoperated needle-driving,” Proc. Hamlyn Symposium on Medical Robotics, pp. 96-97, 2016.