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CIS II
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Seminar Presentation Paper Critical Review

My Project Summary

My work for this semester focuses on augmenting existing Virtual-Reality Surgical Simulators (Figure 1) with Haptic Guidance in order to provide real time feedback during practice tasks consisting of complex trajectories, such as suturing. The goal of this project is to develop two methods of haptics, (1.) active guidance forces encouraging user's along an optimal 3D path and (2.) passive forbidden regions in which the forces are applied only upon navigating into that region. After implementation, these methods are to be evaluated in a user study for their efficacy in improving performance and/or learning on the surgical task using the metrics of task completion time, mean task space error, total time spent deviated from optimal path, and levels of forces applied throughout.

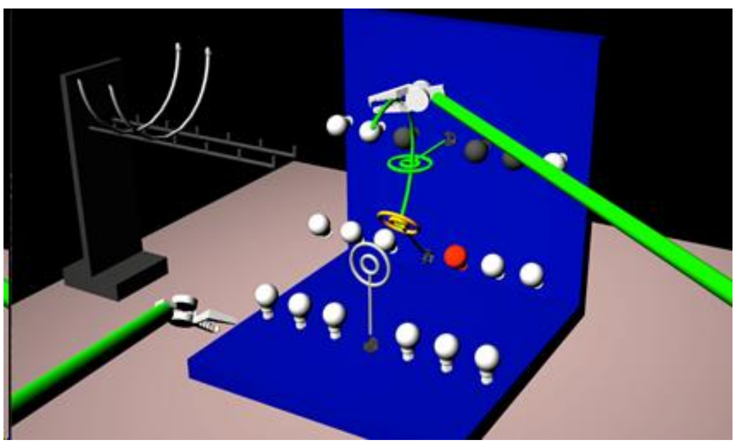


Figure 1: Exisiting Virtual-Reality Surgical Simulator for Suturing that we will be using as our platform for implementing Haptic feedback

Paper Selection

The paper selected for this review and critique is:

R. J. Kuiper, D. J. F. Heck, I. A. Kuling and D. A. Abbink, "Evaluation of Haptic and Visual Cues for Repulsive or Attractive Guidance in Nonholonomic Steering Tasks," in *IEEE Transactions on Human-Machine Systems*, vol. 46, no. 5, pp. 672-683, Oct. 2016.
doi: 10.1109/THMS.2016.2561625

This paper was selected as it formed the basis of much of the discussion surrounding our approach to this project early on. We drew from their implementations of attractive and repulsive haptic guidance while designing our implementation as well as from their study setup to help direct what metrics it is important for us to consider. Additionally, I find it interesting to see an application and approach so similar to ours in a different setting (virtual vehicle steering vs. virtual surgical task simulator) and it is refreshing after having spent a large portion of my education working in the surgical space.

Summary of Goal, Key Results, and Significance

Teleoperation is more difficult than direct manipulation due to delays and limited sensory feedback of the task as a result of taking the user out of manipulation. In order to restore a sense of natural feedback, artificial task-related feedback can be added such as visual and haptic cues. This paper implements repulsive haptic and visual guidance as well as attractive haptic and visual guidance in order to evaluate the efficacy of these support systems in assisting the task.

The authors found that providing predicted trajectory of the vehicle and suggested path information improved task performance, but no difference was found between haptically or visually reflected information. Additionally, it was found that reflection of predicted trajectory resulted in improved performance visually but not haptically. Finally, the hypothesis that more difficult environments resulted in larger benefits for all support systems was confirmed.

These results were significant because they indicate that both haptic and visual feedback can improve performance, especially when difficulty is high. When available, it is beneficial to reflect both haptic and visual information to best recreate a natural environment. The paper specifically notes that the authors are not making recommendations on what type of feedback to use and that choice must be made with careful consideration by the developers of the task.

Necessary Background

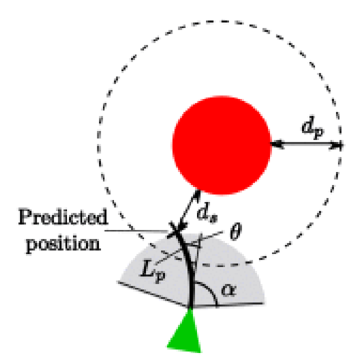
This paper has a relatively low barrier to entry. The topics and approaches are well explained, but a basic understanding of forbidden regions, forces, and torques will help the reader quickly understand the haptic guidance support systems. When analyzing the results of the paper, comfortability with statistics and RM-ANOVA is helpful as the authors often present results in dense tables. There are summarizing graphs for the important features of the results which allows for a starting point.

Technical Approach

Repulsive Haptic Guidance around Obstacles

In each environment, there were 4 obstacles and a single goal at the end of the task. Virtual potential fields were developed around these 5 landmarks (repulsive for obstacles and attractive for the goal) in order to provide repulsive haptic guidance (HR). The field as generated based on the predicted position of the slave after a translation of L_p = .01m. They were calculated using the equation

Repulsive Haptic guidance (HR)



(a)

below with the following variables. Additionally, the forces were only reflected when the angle α with the obstacle was less than or equal to 90°. the parameters were tuned in such a way so that the forces were over-rulable by the user if so desired. The additional image depicts the implementation of this force

- Gain k_p = 6 N/m,
- penetration depth d_p,
- slave distance d_s

$$\tau_{\mathrm{HR},i} = \begin{cases} k_p L_p \left(d_p - d_{\mathrm{si}}\right), & \text{if } d_{\mathrm{si}} \le d_p \text{ and } |\theta_i| \le \alpha \\ 0, & \text{else.} \end{cases}$$

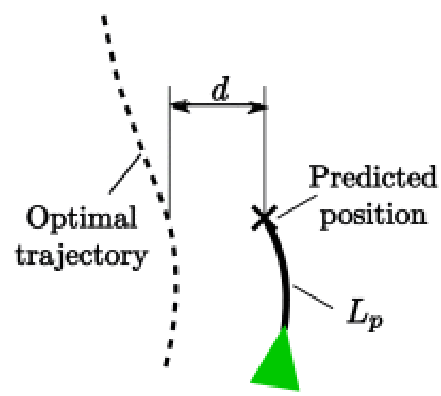
<u>Attractive Haptic Guidance to a Suggested Path</u>

The second approach to haptic guidance involved defining a suggested path through the environment. At each step of the robot, torques are computed from a virtual guidance force acting on the predicted motion arm of length L_p = .01m. The distance d between the suggested path and the predicted position of the slave is then calculated via the following formula and used to present a torque onto the robot. This torque comes in the form of torsion stiffness on the master. This process is visualized below.

- Gain k = 5 N/m

$$\tau_{\mathrm{HA}} = k L_p d.$$

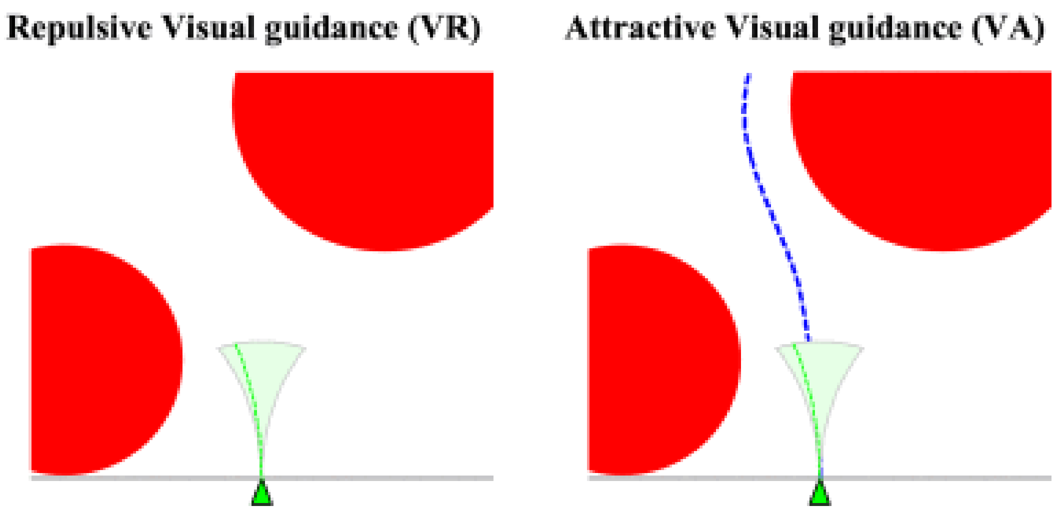
Attractive Haptic guidance (HA)



(b)

<u>Visual Equivalent Support Systems</u>

The visual systems were designed to be similar to the corresponding haptic systems. On one hand, the repulsive haptic force is based on the predicted path, so in repulsive visual, only the predicted path is shown. On the other hand, the attractive haptic force is based on predicted location and optimal path, so both are shown to the user in attractive visual feedback. Both of these are visualized below.



Experimental Design

A user study involving 15 subjects was completed wherein each subject controlled a three DOF planar parallel master device (Figure). The forward translation coupled to translation of the slave and the rotation of the master was coupled to steering in order to provide control. The subjects steered a virtual vehicle through a virtual environment in 5 blocks (one each experimental condition) of 8 trials. Amongst these 8 trials, 4 different environments of varying difficulty (Figure) were shown twice (regular once and mirrored). There was an additional catch trial on the difficult environment to investigate the dependency on the support systems - totaling 45 trials per subject.

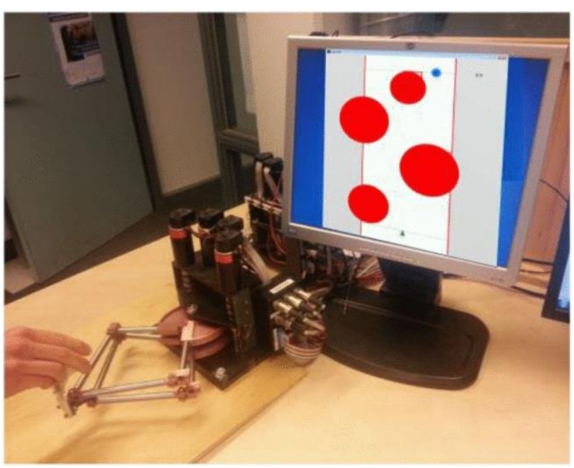


Figure 2 left: Experimental setup showing master controller and slave presentation on screen.

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Figure 3 below: One subjects completion of the task illustrating the different environments.

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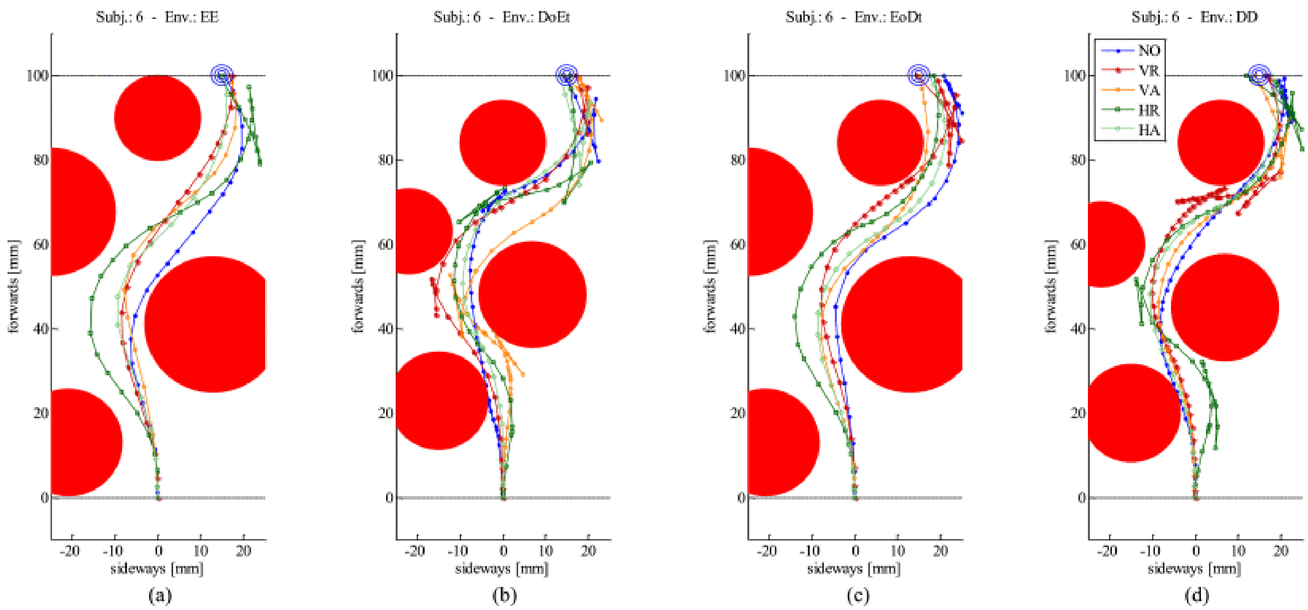

The metrics collected were task completion Time, targeting accuracy (accuracy of driving the vehicle into the target), number of slave retractions (changes in forward motion), total duration of retractions, number of collisions, minimum time to obstacle collision, distance to obstacles (averaged over the trial).

Results

A depiction of the significant comparisons between key performance data is given below in Figure 4. Shown in the results, giving the predicted trajectory of the vehicle and suggested path information in the HA and VA approaches improved task performance. No difference was found between haptically or visually reflected information, as the HA and VA generally correspond to each other, also the same with VR and HR. When comparing VR with HR, reflecting the predicted trajectory in these ways resulted in improved performance visually but not haptically. Finally, the delta between the NO group on the most difficult environment (DD) and the other support systems was large, indicated that more difficult environments resulted in larger benefits for all support systems.

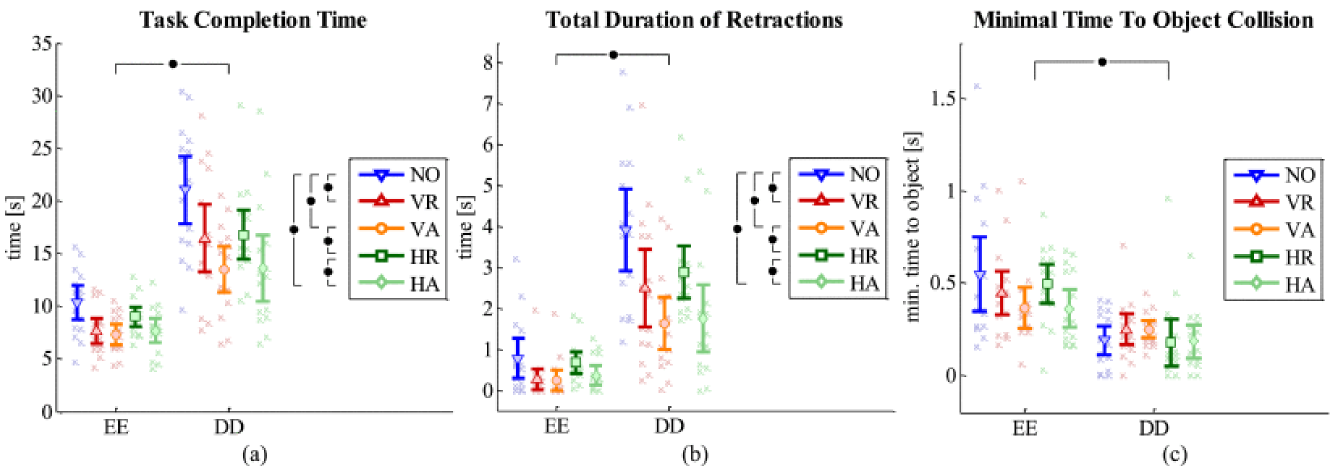

Figure 4: Graphical representation of the results recorded for the 5 groups as shown across the easiest and most difficult environment.

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Assessment

This paper was important because it provides support that the coupling of haptic and visual feedback can be beneficial to completing teleoperative tasks, especially as the tasks become more difficult. On a more negative note, this paper fails to convince me that haptics alone is helpful in teaching or improving performance. Both of these remarks are relevant to my project as we seek to evaluate the effects of haptic cues in a simulated surgical task. In summary, this paper provides a basis that we started from when approaching our project.

There are several good and bad points to this paper. On the positive, this paper gives a very thorough explanation of its approach and experimental design – defining all of its metrics in depth and reasoning for choosing to run different environments for example. In the same vein, it gives a very complete look at haptics and visual cues from both the repulsive and attractive angles. The changing environment helped to teach the user a skill and not memorize a path which is a significant consideration when building a task like this. Negatively, the paper tested for a lot of different things and changed many variables so that every user experienced every possibility. I wonder if this may have affected their results in any way. The presentation of these metrics was often dense as well.

A suggestion for further work would be to attempt to model the operator (ie through brain stimulation) to try and generalize the results to other tasks. The authors made note that it was hard to know how these cues would translate to other tasks as a result of lacking this piece.

Conclusion

This paper presented a refreshing application on haptic and visual cues in a different simulated environment application, granting a much need respite from surgical simulators. The major result of the paper is rather obvious, indicating that providing additional information (haptically and visually) to the user is beneficial – especially in tasks with greater difficulty. However, the results (or rather non-results) cast more doubt on my personal belief in the efficacy of haptics as a sole provider of feedback. In many of the papers I have read, haptics alone as not been enough to significantly impact performance on different training tasks.