Visual versus Haptic Progressive Guidance for Training in a Virtual Dynamic Task

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Abstract

The objective of this work is to demonstrate that progressive haptic guidance can accelerate and improve motor task training outcomes over visual or practice-only methods in a training virtual environment (TVE). To that end, we design haptic and visual guidance schemes based on detailed analyses of performance differences between experts and novice trainees performing a dynamic motor control task in a TVE. Research shows that TVEs that include haptic interfaces produce significant short-term performance gains over audio visual TVEs. However, improved or accelerated long-term training outcomes for dynamic tasks have yet to be demonstrated due, at least in part, to the increasing dependence of the trainee on the assistance. To avoid this dependence, a progressive guidance controller can gradually remove the assistance as the performance of the trainee improves. However, the inputs to the guidance controller must be based on measurements of performance in the necessary kinematic and dynamic components of the task. Prior work introduced two such quantitative performance measures. We implement similar measures, trajectory error and input frequency, to identify and classify performance levels, thereby providing valid and robust inputs to the guidance controller. We demonstrate that progressive haptic guidance schemes can improve training in a dynamic task.

Index Terms: H.1.2 [Model and Principles]: User/Machine Systems, – human factors— [H.5.2]: Information Interfaces and Presentation—User Interfaces - Haptic I/O, theory and methods, evaluation/methodology K.4.2 [Computers and Society]: Social Issues – Assistive technologies for persons with disabilities—

1 Introduction

The implementation of training virtual environments (TVEs) is intended to reduce risk, improve and accelerate learning over traditional training methods, thereby transferring what is learned in the simulation to the targeted real world task. One type of TVE employs haptic guidance to assist the human trainee in performing the necessary kinematic and dynamic components of the task, however prior work suggests that these haptic guidance schemes perform best when the level of guidance is progressively adjusted based on the trainee's performance during training [2]. Our objective is to demonstrate that progressive haptic guidance can accelerate and improve training outcomes over visual or practice-only methods. To that end, we design haptic and visual guidance schemes that are based on detailed analyses of performance differences between experts and novice trainees. Participants trained in the TVE shown in Fig. 1 previously developed by O'Malley et al. and modified by Li et al. to study the efficacy of an error reducing guidance scheme [3, 4]. We analyzed the performance of experts and novice trainees during the execution of Li's experiment and discovered two independent components required to successfully complete the task. The kinematic component is to keep the input joystick, and therefore the output disc, on the trajectory axis as much as possible so as to ensure target acquisition. The dynamic component is to excite the input joystick slightly above the resonant frequency of the system dynamics so that the disc will oscillate rapidly and with sufficient amplitude between the targets. In order to measure how well the trainee is performing in these two components, we apply two measures: trajectory error (e_{traj}) and input frequency (f_{input}) similar to measures used by Li et al. and Huang et al. respectively [1,3]. The e_{traj} measure is the trial sum of the absolute errors in the off-axis position of the joystick. The f_{input} is computed via a fast Fourier transform of the position data along the target axis to determine the amplitude and frequency of the input motion being applied to the system. The e_{traj} and f_{input} measures are used as valid and robust inputs to the haptic guidance algorithm and a similar visual guidance algorithm for comparison. The guidance design is then tested with two trainees in the same target-hitting task experiment, thereby verifying the guidance functionality. The demonstration will show the visual and haptic progressive guidance schemes in operation.

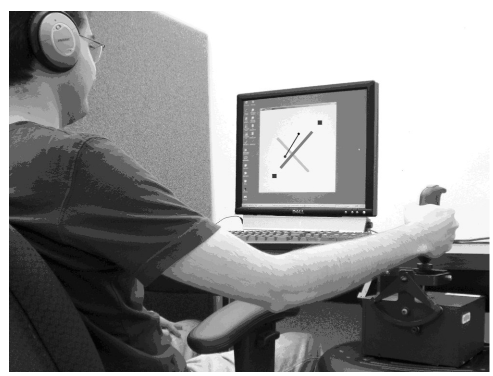

Figure 1: A participant is sitting at the training virtual environment. The interface includes a visual feedback display and a haptic joystick for force feedback, both of which provide feedback of the system dynamics to all trainees regardless of guidance scheme.

2 Demonstration Setup

The experimental setup for the demonstration is depicted in Fig. 1. The setup includes a two degree of freedom (DOF) force feedback joystick (Immersion IE2000) and a nineteen inch LCD display with a 60 Hz graphics software loop rate for visual feedback. The haptic control loop to display system dynamics and guidance forces runs at 1 kHz on a 2 GHz Pentium computer while position and velocity data is captured and stored at 20 Hz. A second order system is modeled as two point masses, connected by a spring and damper in parallel. This two-mass system has four degrees of freedom, namely the planar motion of each of the point masses. Therefore, it is under-actuated since the only control inputs are the planar motions of the user position mass attached to the joystick. All trainees wear noise canceling headphones displaying pink noise to avoid

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interference from audio cues such as the movement sounds of the joystick during the execution of the experimental task.

3 Task Description

The task is to manipulate the motion of the user position illustrated in Fig. 3 via the 2-DOF haptic joystick. Thus indirectly, through the system dynamics, the trainee controls the sprung mass to hit as many of the diagonally placed targets as possible during each 20-second long trial. Essentially, the participant needs to excite the system close to its resonant frequency and along the target axis to generate rhythmic oscillations of the sprung mass. For a detailed description of the task, refer to work by O'Malley et al. [4].

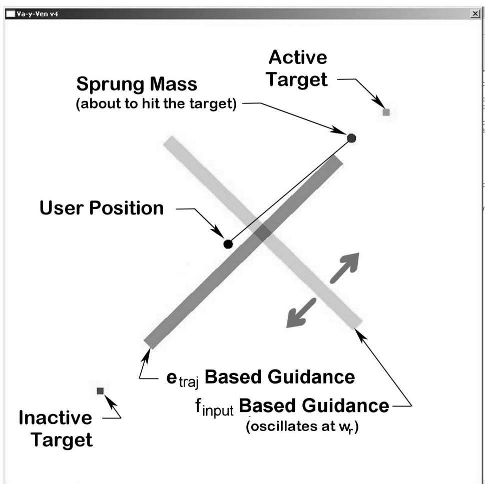

Figure 2: Guidance schemes designed from expert performance in the dynamic task show kinematic and dynamic task components to the guidance trainees. In addition to a control group, one group receives progressive guidance only through the visual display while a third group receives equivalent progressive guidance only through the haptic joystick display.

4 Visual and Haptic Guidance Schemes

In order to provide progressive guidance to the trainees throughout the protocol, the assistance proposed in this work is comprised of two orthogonal regions as shown in Fig. 3 to demonstrate the best performance in the two task components. The first bar (shown in dark gray) indicates the maximum allowable deviation from the target axis that will still result in a target acquisition, thereby reducing e_{traj}. The second region (shown in light gray) oscillates at the resonant frequency of the system and with an amplitude that will, if tracked, ensure sufficient output amplitude to acquire the targets. For the visual scheme, these two regions are represented by colored bars whose intensities diminish independently as performance improves in each of the two measures. Similarly, in the haptic scheme, the edges of the regions are represented by stiff virtual walls (see Rosenberg, et al. [5]). The minimum force required to penetrate the walls is progressively reduced as performance improves thus gradually shifting primary control from the robot to the trainee as the training protocol progresses. Both the visual and haptic guidance employ exponentially decaying gains that are controlled by the performance measures e_{traj} and f_{input}. When three successive trials show improvement in performance in one of the two measures, the corresponding gain decreases. In contrast, when three trials show degrading performance, the gain increases. Fluctuating performance trends cause the gain to remain unchanged.

A pilot study was administered to two trainees to verify the functionality of both the visual and haptic guidance schemes and the

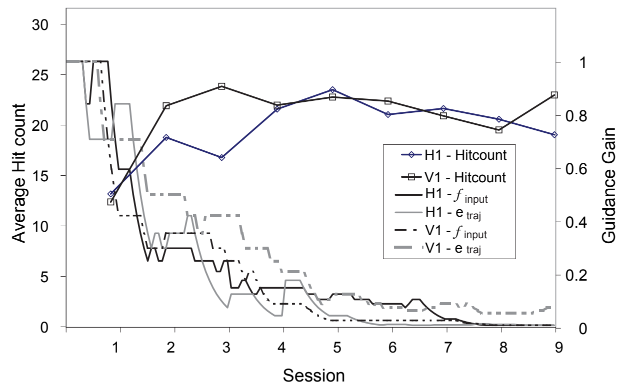

Figure 3: Both visual and haptic guidance gains based on the performance measures e_{traj} and f_{input} decay through training in a dynamic task while the objective measure of the task, average hit count, gradually increases for both haptic (H1) and visual (V1) guidance trainees. This suggests that the designed guidance schemes are functional.

study is presented in this demonstration. The changes of both gains for both trainees (H1 received haptic guidance, V1 received visual guidance) are illustrated in Fig. 4 and show exponentially decaying trends with some occasions where the gains remained the same or increased. The averages of five evaluation trials after each training session are also shown in Fig. 4 and display increasing trends in hit count, thereby verifying the functionality of the guidance schemes.

5 Conclusions

We propose that haptic guidance schemes for TVEs must be based on measurements of the task components. We identified minimization of trajectory error and excitation of the system near resonance as key kinematic and dynamic components for this task. The current demonstration will show that our guidance design allows a comparison of the haptic guidance scheme to traditional visual and practice-only schemes. While pilot results indicate that the progressive guidance design is functional, future work will include a long-term training study to compare the success of haptic and visual forms of progressive guidance.

Acknowledgements

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References

[1] F. C. Huang, R. B. Gillespie, and A. D. Kuo. Visual and haptic feedback contribute to tuning and online control during object manipulation. *Journal of Motor Behavior*, 39(3):179–193, May 2007.

[2] Y. Li, J. C. Huegel, V. Patoglu, and M. K. O'Malley. Progressive shared control for training in virtual environments. In *In Proc. IEEE Second Joint Eurohaptics Conference and Symposium on Haptic Interfaces for Virtual Environments and Teleoperator Systems, (WHC '09)*, 2009.

[3] Y. Li, V. Patoglu, and M. K. O'Malley. Negative efficacy of fixed gain error reducing shared control for training in virtual environments. *Transactions on Applied Perception*, 6(1), 2009.

[4] M. K. O'Malley, A. Gupta, M. Gen, and Y. Li. Shared control in haptic systems for performance enhancement and training. *Journal of Dynamic Systems, Measurement, and Control*, 128(1):75–85, 2006.

[5] L. B. Rosenberg. Virtual fixtures: Perceptual tools for telerobotic manipulation. In *Proc. of the IEEE Annual Int. Symposium on Virtual Reality*, pages 76–82. IEEE, 1993.