EFFECT OF CUSTOMIZED HAPTIC FEEDBACK ON NAVIGATION CHRACTERISTICS AND PERFORMANCE

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INTRODUCTION

Assistive technologies for driving and navigation have been engaged for the past two decades. However, the effectiveness of the outcome of assistive technologies using haptic devices is still debatable. Specifically, determining the level of haptic assistance, e.g., the magnitude and direction of haptic force, is a challenging problem [1]. For instance, an excessive assistance level may degrade user's performance and cause discomfort, whereas a lack of enough assistance may yield task failure.

Previous studies have shown possibilities to enhance human task-performance by adopting control characteristics [2] and to design a controller by mimicking human's driving style via inverse optimal control (IOC) [3]. In this study, subject's control strategy for given tasks was parameterized by IOC. Also, the obtained parameters will serve as metrics to customize haptic feedback for each subject by i) assigning a *coach* whose task-performing characteristics are the desired characteristics for the rest of the subjects, ii) defining a *spine* (guiding path) which guides subjects based on the coach's strategy, and iii) determining the level of assistance. Therefore, the objective of this study is to identify the effect of customized haptic guidance on subjects' task-performance and performing-characteristics.

METHODS

Sixteen healthy young adults (14 male and 2 female, age=20-35 yrs) participated in this study. Subjects were seated at 1.5m from a 105cm-by-81cm (width-by-height) screen as shown in Fig.1. The modified version of Novint Falcon (Novint Technologies, Albuquerque, NM) was used to provide 2D haptic interface [4]. All subjects gave informed consent prior to their participation and this research was proved by the University Institutional Review Board.

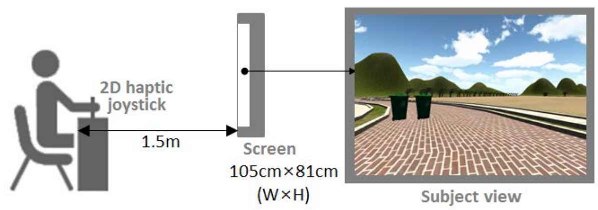

Figure 1: The experimental environment.

The experiment consisted of two separate sessions: the first session for obtaining the baseline data and the second session (one week apart) for identifying the effect of customized haptic feedback based on the baseline data. For both sessions, the subjects were asked to drive a virtual vehicle along four roads each of which had a difference radius of curvature and obstacles. The subjects were instructed to drive the vehicle as fast and safe as possible. Completion time, sampling time, task#, trial#, successes, fails, vehicle's positions and heading direction were recorded from the start line to the finish line. Each task was repeated 3 trials. The sequence of the tasks was randomized. Sampling frequency was 60Hz. This virtual task environment was developed by Unity3D (Unity Technologies, San Francisco, CA).

After the first session, the subjects' strategy for each task was analyzed. A cost function that each subject may have minimized during each task was assumed to be in the following form: $cost = \sum_{i=0}^{N} c_v v(i)^2 + c_\omega \omega(i)^2 + c_{d_o} d_o(i)^2 + c_{d_f} d_f(i)^2$ where v: linear velocity, ω: angular velocity, d_o: distance from the vehicle to road boundary on obstacle side, and d_f: distance from the vehicle to road boundary on obstacle-free side. As these four variables at each discrete time step $i \in [0,N]$ corresponded to the baseline data, positive coefficients, c_v, c_ω, c_{d_o}, and c_{d_f}, could be estimated by solving an IOC problem [2][3].

Subject's *performing-characteristics* vector q was defined from the estimated coefficients as $q = [c_v, c_\omega, c_{d_o}, c_{d_f}] \times 100 / (c_v + c_\omega + c_{d_o} + c_{d_f})$ where each element represents subject's efforts for *speed control*, *steering* *control*, and *lane selections for routing and obstacle avoidance* as percent, respectively. By clustering the *q* vectors in $\mathbb{R}_+^4$ via k-means clustering algorithm, the subjects were classified into 3 groups. As a result, subjects in the same group have similar driving patterns. A subject whose task-completion time was fastest in each group was designated as a *coach* in each group. The *coach*'s baseline vehicle trajectory in the first session was used as a *spine* to guide the rest of subjects in the same group. The level of haptic guidance for each subject was determined proportional to L_1-norm distance from his/her to the *coach*'s performing-characteristics vector. The resulted guidance is called *customized haptic guidance* (CH). For the second session, CH was applied to assist the subjects. To compare the effect of CH to typical guiding method, another type of haptic guidance that enforced the vehicle to a road center (RH) was applied.

The following 3 parameters were investigated: i) summed average task-completion time, $\sum T_{avg}$, ii) summed standard deviation (std) of T_{avg}, denoted by $\sum T_{std}$, and iii) guided driving characteristics under three assistance modes, NA(no assist), CH, and RH. A repeated measures analysis of variance (rANOVA) was used to identify the effect of haptic guidance on subject's task-performance and performing-characteristics. Significance level was set to 0.05 (SPSS v21, Chicago, IL)

RESULTS AND DISCUSSION

Based on the baseline data during the first session, subjects were grouped into 3 groups (bold is a coach): {**s4**, s2, s5, s7, s8, s13, s14, s15}, {**s9**, s10, s16}, and {**s12**, s1, s3, s6, s11}. The coach data were excluded from statistical analysis since coach data were used as references. First, rANOVA found that $\sum T_{avg}$ was not significantly affected by haptic assistance. Some improvements of $\sum T_{avg}$ could only be observed in slower subjects, e.g., s10, s7, s16, as shown in Fig. 2.

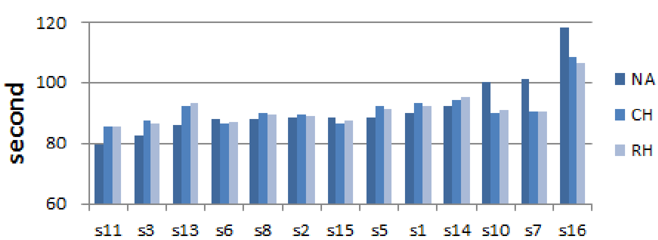

Figure 2: $\sum T_{avg}$ with respect to NA, CH, and RH (From left to right, ordered by $\sum T_{avg}$ under NA).

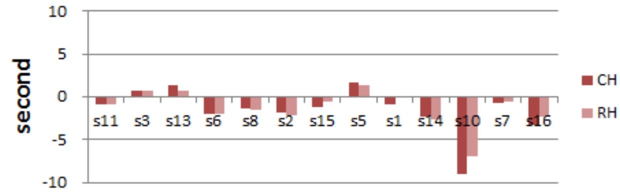

Figure 3: The difference of $\sum T_{std}$ under CH and RH compared with NA.

Next, rANOVA on $\sum T_{std}$ showed tendency for reduction of $\sum T_{std}$ when haptic assistance was provided (F(2,24)=4.168, *p*=0.061, with mean of 3.929, 2.430, and 2.658 for NA, CH, and RH, respectively). The mean of variability of subjects' performance reduced the most when CH was provided. Figure 3 depicts the difference of $\sum T_{std}$ for CH and RH compared with NA. However, rANOVA on the guided driving characteristics, which was represented by L_1-norm distance from the coach under three assistance modes, showed no significant difference.

By direct data observation, several interesting aspects were found. From Table 1, both mean and std decreased in **s12** group for CH. For **s4** group, most subjects' performing-characteristics were already close enough to **s4** as the smallest mean for NA indicated. Hence, applying haptic feedback to **s4** group might work as disturbance. Increased mean in **s9** group might be caused due to small number of subject, but std was reduced under CH. For further statistical analysis on L_1-norm distance, more data will be collected. Also, task-difficulty will be elevated to investigate the broader range of subjects' performance.

Table 1: Mean(std) of subjects' L_1-norm distance from the group coach under three assistance modes.

	NA	CH	RH
s4 group	11.95(13.39)	31.34(45.00)	16.44(22.89)
s9 group	27.12(18.38)	67.49(7.53)	37.20(39.58)
s12 group	16.44(6.84)	6.67(3.80)	10.66(9.54)

REFERENCES

1. Feygin D, et al. *Proceedings of IEEE Symp. on HAPTICS*, Orlando, FL, USA, 2002.
2. Suzuki S and Furuta K, *J Control Science and Engineering* **2012**, 1-10, 2012.
3. Lavine S and Koltun V, *Proceedings of ICML*, Edinburgh, Scotland, 2012.
4. Kim Y. et al., *Proceedings of IEEE World Haptic Conf.*, Chicago, IL, USA, 2015.