MECHANICAL ENGINEERING
TEXAS A&M UNIVERSITY

PREDICTING PERFORMANCE IMPROVEMENT UNDER CUSTOMIZED HAPTIC ASSISTANCE

HUR (Human Rehabilitation) Group http://hurgroup.net

HAN UL YOON, Ph.D. and PILWON HUR, Ph.D.

hanulyoon@tamu.edu, pilwonhur@tamu.edu

INTRODUCTION

Motivation

- For haptic assistive control, various approaches to adapting the assistance level to the user's skill level have been presented.
- Although there have been ample considerations about adjusting the assistance levels, the efficacy of these methods on user's performance has still remained inconclusive.

Objectives

- To predict the potential improvement of user's performance under a customized haptic assistance for each user.

Approach

- Represent the temporospatial characteristics of a controlled path demonstrated by a user under no-assistance with two metrics: *variability* and *Hurst exponent*.
- With the user's data under customized assistance, we will train a classifier function to distinguish the improved users and unimproved users by using machine learning techniques.

METHODS

Subjects

- 39 healthy young adults (31 male, 8 female, age=20-35) participated in this study.

Procedures (For more information see [1])

- Subjects were seated at 1.5m away from a 105cm-by-81cm screen
- A modified version of Novint Falcon was used as 2D haptic interface (Fig. 1).
- Experiments consisted of two separate sessions: the first session for obtaining the baseline data and the second session 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.
- Subjects were instructed to drive the vehicle as fast and safe as possible.

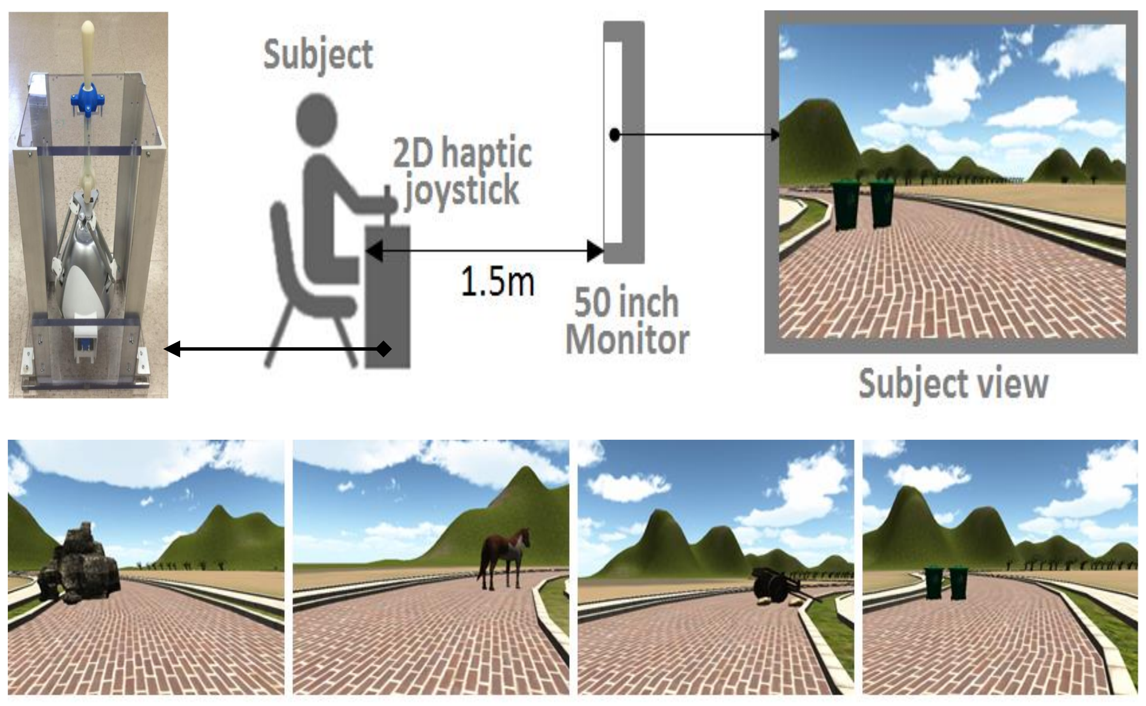

Fig. 1 A virtual power-wheelchair simulator for the experiment (top) and four different scenarios (bottom).

Data Collection

- Completion time, sampling time, task#, trial#, # of successes, # of fails, vehicle's positions and heading direction were recorded from the start line to the finish line.
- Each condition was repeated 3 times. The sequence of the tasks was randomized.
- Sampling frequency was 60Hz.

Representing the Temporospatial Characteristics of a Controlled Path

- After completing all sessions, subjects' performances under no assistance and customized haptics were examine in terms of variability (temporal) and Hurst exponent (spatial).
- First, the variability was computed as a summed standard deviation of mean completion time for all scenarios

$$V = \sum_{i=1}^{4} std\left(mean\left(\sum_{j=1}^{3} T_{i,j}\right)\right)$$

where i and j are indices for scenario and repetition, respectively.

- Next, Hurst exponent, H, was obtained from detrended fluctuation analysis (DFA) which tells us the slow/fast varying characteristics of time course data (see Fig. 2) [2]. H is the estimated power-law exponent of a scale invariant structure of a signal $X(t)$, which is

$$X(ct) = c^H X(t)$$

- Consequently, each subject was associated with two metrics as either *subject#*:$\{V, H, 1\}$ or *subject#*:$\{V, H, 0\}$ for improved or non-improved subjects, respectively.

Define a Performance Improvement Predictor (PIP) Function

- From the associated data above, we randomly selected 80 percent of improved subjects (label: 1) and non-improved subjects (label: 0) and set them as a training set.
- A logistic sigmoid function, $\sigma(V)$, was trained to yield 1 for the improved subjects and 0 for the non-improved subjects:

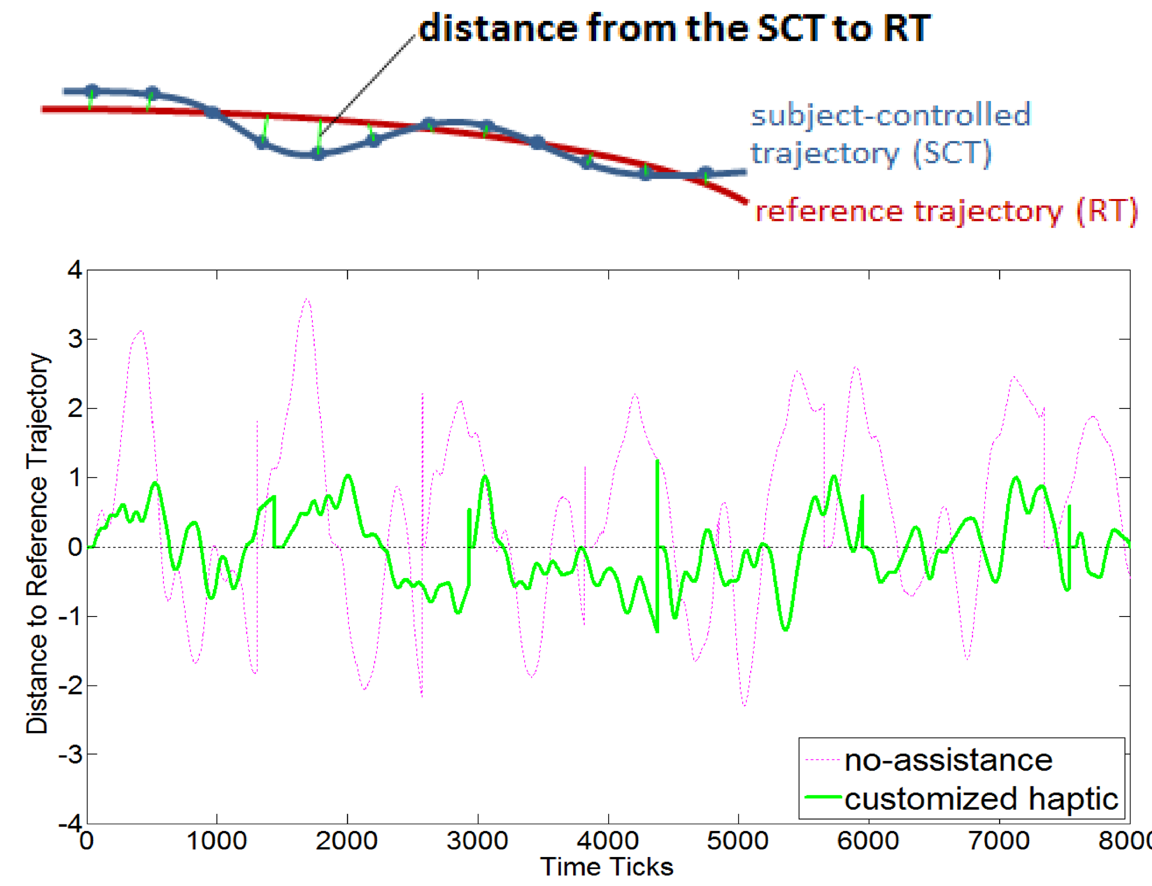

Fig. 2 The reference path is employed as a baseline, and the distances from the reference path under no-assistance (magenta-dotted-thin) and the customized haptic (green-solid-thick) are depicted (bottom).

$$\sigma(V) = \left(1 + e^{-k(V-V_0)}\right)^{-1}$$ where V_0 is a bias

and $\varphi(H)$ was estimated by using a kernel density estimation (see Fig. 3).

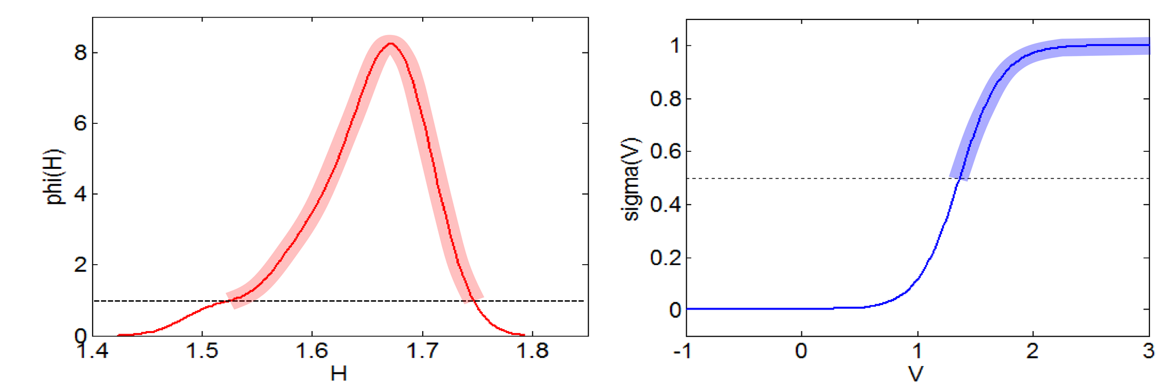

Fig. 4 The example of the estimated $\varphi(H)$ and the trained $\sigma(V)$.

- Finally, from the trained $\sigma(V)$ and the estimated $\varphi(H)$, the performance improvement predictor function, f_{PIP}, could be defined as

$$f_{\mathrm{PIP}}(\sigma(V), \varphi(H)) = \begin{cases} \text{yes}, & \text{if } \sigma(V) \geq 0.5 \wedge \varphi(H) \geq 1 \\ \text{no}, & \text{otherwise} \end{cases}$$

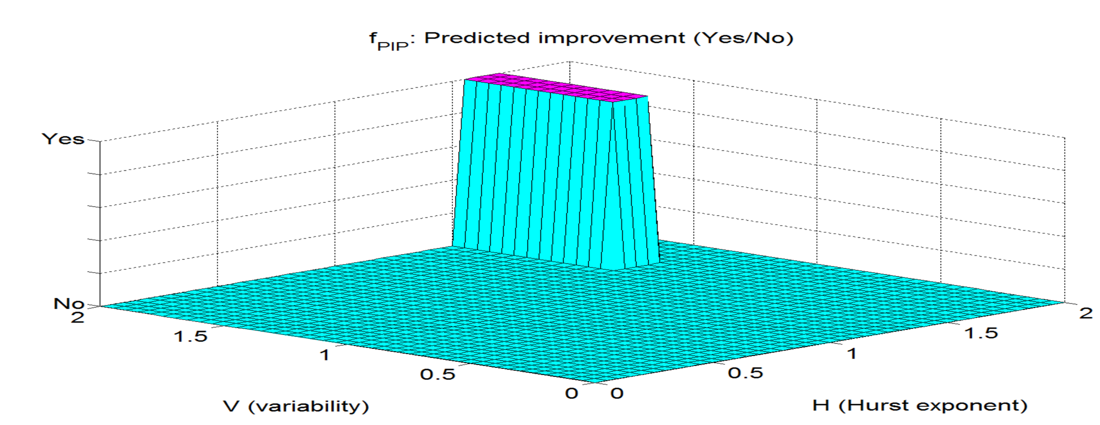

Fig. 4 The example of f_{PIP} from $\varphi(H)$ and $\sigma(V)$.

RESULTS AND DISCUSSION

- First, f_{PIP} was generated 100 times from the randomly selected a training set, then it was validated by a test set.
- To show the accuracy of f_{PIP}, Youden's index J was used [3]

$$\mathrm{J = sensitivity + specificity - 1}$$

- The average of J from the 100 f_{PIP} was 0.803.

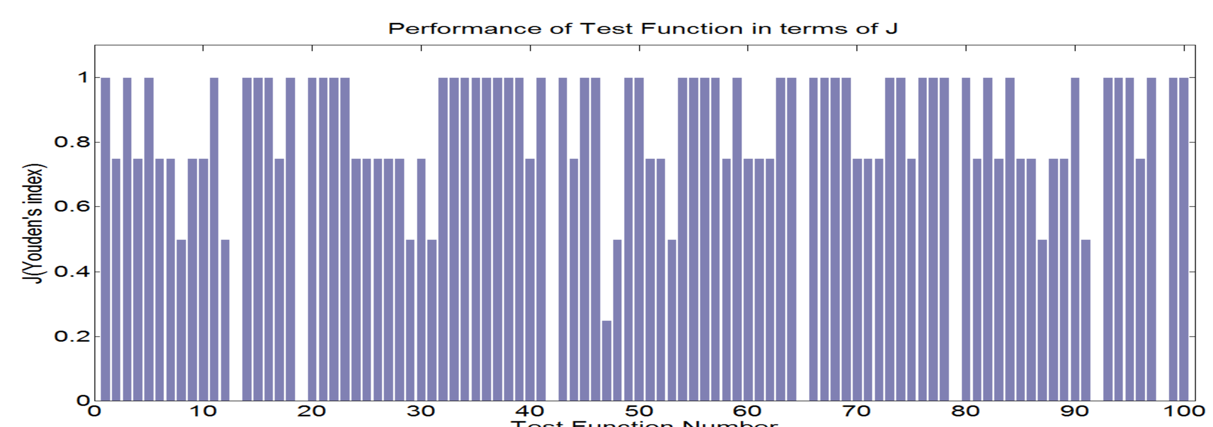

Fig. 5 J of 100 f_{PIP}. The average J is 0.803.

CONCLUSION

- The temporospatial characteristics of a wheelchair path controlled by subjects were expressed in terms of variability and Hurst exponent.
- The defined f_{PIP} can be used to predict the performance improvement with the subject-specific customized haptic feedback.

References

[1] Yoon H. and Hur P., American Society of Biomechanics, 2015.

[2] Kantelhardt J. W. et al., Physica A: Statistical Mechanics and its Application, vol. 316, no. 1, pp. 87-114, 2002.

[3] Bewick V. et al., Critical care, vol. 8, no. 6, p. 508, 2004.