A User-Centric Feedback Device for Powered Wheelchairs Comprising a Wearable Skin Stretch Device and a Haptic Joystick

Namita Anil Kumar, Han Ul Yoon and Pilwon Hur

MECHANICAL ENGINEERING
TEXAS A&M UNIVERSITY
“We spend a lot time designing the bridge, but not enough time thinking about the people who are crossing it.”

– Dr. Prabhjot Singh
Chair of Health System Design & Global Health
Mount Sinai Health System, NY, USA
Background

• About 3.5 million wheelchair users in US [US Census Bereau, 2010]

• The powered wheelchair can positively impact user’s mentality and lower social costs [Salatino et al. 2015]

But …

• It poses a learning challenge

• The failure to master maneuverability can lead to frustration, dissatisfaction and rejection of device [Salatino et al. 2015]
Attempted solutions

Implement feedback

PROBLEM
Force feedback with haptic joystick
[Yoon et al. 2017]
Elderly users have a weakened ability to process sensory signals
[Laurienti et al. 2005]

PROBLEM
Force feedback + Visual cue
Fell short in the user’s self esteem as per psychological test PIADS
[Wang et al. 2011]
Proposition

**Force feedback**

- Modified Novint Falcon haptic controller 
  [Yoon et al. 2017]

**Skin stretch feedback**

- Is intuitive in nature
  [Yoon et al. 2016]
- Can improve motor task performance [Pan et al. 2016]
User centric design

Modular

Comfortable

Module I
- Motor
- Front pin

Module II
- Idlers
- Belt driver

Module III
- Timing belt
- End pin

User acceptance

Economical
The workings

Desired trajectory

Screen with simulated course using ‘Unity’

Subject

Skin-stretcher

Haptic joystick

CW if user is on left side of reference and CCW if user is on the right side of reference

Yoon et al. 2017

The workings
Performance evaluation

Task 1: Smooth left
Task 2: Smooth right
Task 3: Sharp right
Task 4: Sharp left

Assist modes

- No assist (NA)
- Force feedback only (H)
- Skin stretch only (S)
- Force + Skin stretch feedback (HS)

With each combination repeated thrice, there were a total of 48 tests per subject
Performance evaluation

15 healthy elderly adults (7 male and 8 female, 72.8 ± 6.6 years)

Performance metrics
M1 – Quality of achievement
M2 – Minimum distance from obstacles
M3 – Mean deviation from reference
M4 – Total completion time

• A repeated measure ANOVA was performed with two factors: task and assistance mode (p<0.05)
• Significant differences among the assist modes were also studied via Bonferroni pairwise comparison with (p<0.05)
Results and inferences

M1 – Quality of achievement

M2 – Min distance from obstacles

M3 – Mean deviation from reference

M4 – Total completion time
Results and inferences

• Significant main effects were found for both task and assist mode in case of metrics M1, M2 and M3

• Bonferroni pairwise comparison revealed significant difference between
  • NA and HS for metrics M1, M2, M3
  • S and HS assist mode in case of metric M3

• Healthy elderly subjects’ performance improved when both force and skin-stretch feedback were applied

• Both force and skin-stretch feedback signals work synergistically to deliver a consolidated signal that is easy to interpret
Results and inferences

• Interaction effects were recorded between the task and assist mode in NA and S conditions

• The combined feedback HS signal is independent of the task’s nature

• The subject does not have to actively consider the task’s nature while interpreting the combined feedback signal. Thus the proposed device is more user-friendly.
In a nutshell

• Combining force and skin-stretch feedback provides an easy to interpret signal to the user

• The feedback channels were chosen such that they do not interfere with the audio and visual channels, which must be dedicated to surveying the road ahead

• We believe the focus on user comfort and acceptability makes the device attractive and user-friendly

• The socio-economic considerations implemented while designing the proposed device can be applied to any assistive device

Design not only for functionality but for usability!
Thank you!
Desired trajectory

Cost function based on:
Steering parameter, speed parameter, distance from boundaries (left and right)
System working

\[
\kappa_{\delta\perp}(\|e\|) = \begin{cases} 
\kappa_{\delta\perp} + \left(\frac{d/2 - \|e\|}{\nu}\right)(1 - \kappa_{\delta\perp}) & \text{if } \|e\| \leq \frac{d}{2} - \nu \\
\kappa_{\delta\perp} & \text{if } \frac{d}{2} - \nu \leq \|e\| \leq \frac{d}{2} \\
0 & \text{if } \|e\| \geq \frac{d}{2}
\end{cases}
\]

if \(d/2 - \nu \leq \|e\| \leq \frac{d}{2}\)
Feedback signals

- $e$ – vector to closest point on desired trajectory
- $\delta$ – preferred direction
- $f$ – input from users
- $h$ – tangential vector at closest point

$$f = f_\delta + f_{\delta \perp}$$

$$f_{\text{attracted}} = f_\delta + \kappa_{\delta \perp} f_{\delta \perp}$$

$$f_{\text{attracted}} = f + \underbrace{(1 - \kappa_{\delta \perp})(-f_{\delta \perp})}_{\text{original term}} + \underbrace{(1 - \kappa_{\delta \perp})(-f_{\delta \perp})}_{\text{guidance-related term}}$$

$$\|f_{\text{haptic}}\| = k_{\text{haptic}} (1 - \kappa_{\delta \perp}) \|f_{\delta \perp}\|$$

$$\|\omega_{\text{skin}}\| = k_{\text{skin}} (1 - \kappa_{\delta \perp})$$