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

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“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

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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

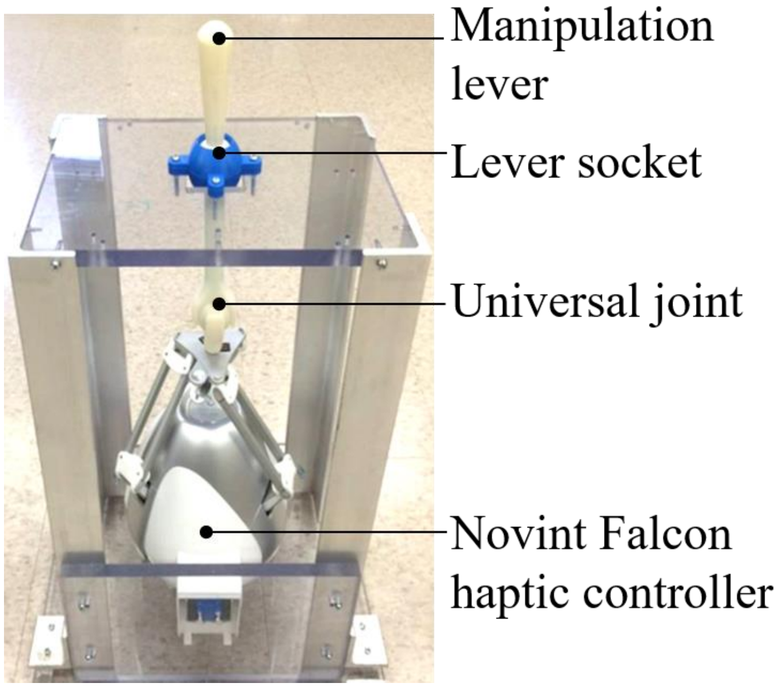
Force feedback + Visual cue

Fell short in the user's self esteem as per psychological test PIADS [*Wang et al. 2011*]

Proposition

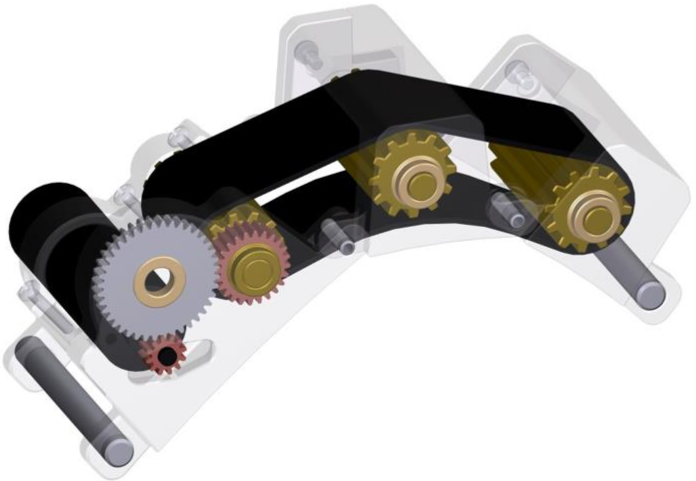
<u>Force feedback</u>

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



<u>Skin stretch feedback</u>

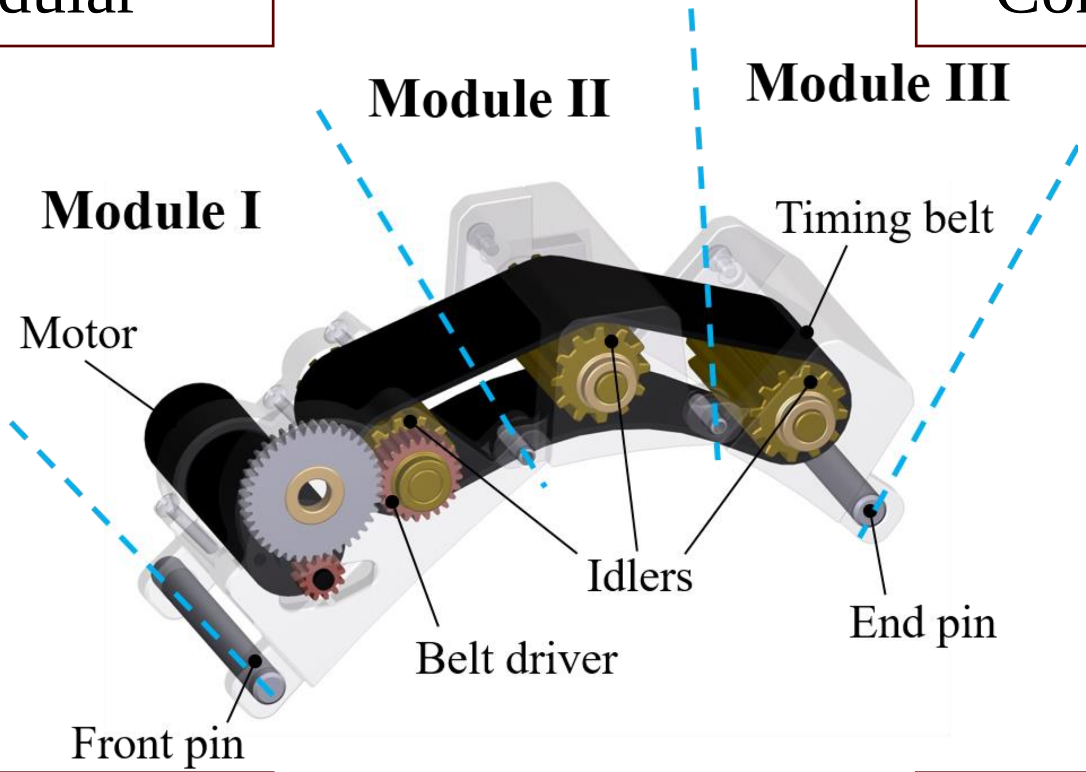
- Is intuitive in nature [*Yoon et al. 2016*]
- Can improve motor task performance [*Pan et al. 2016*]



User centric design

Modular

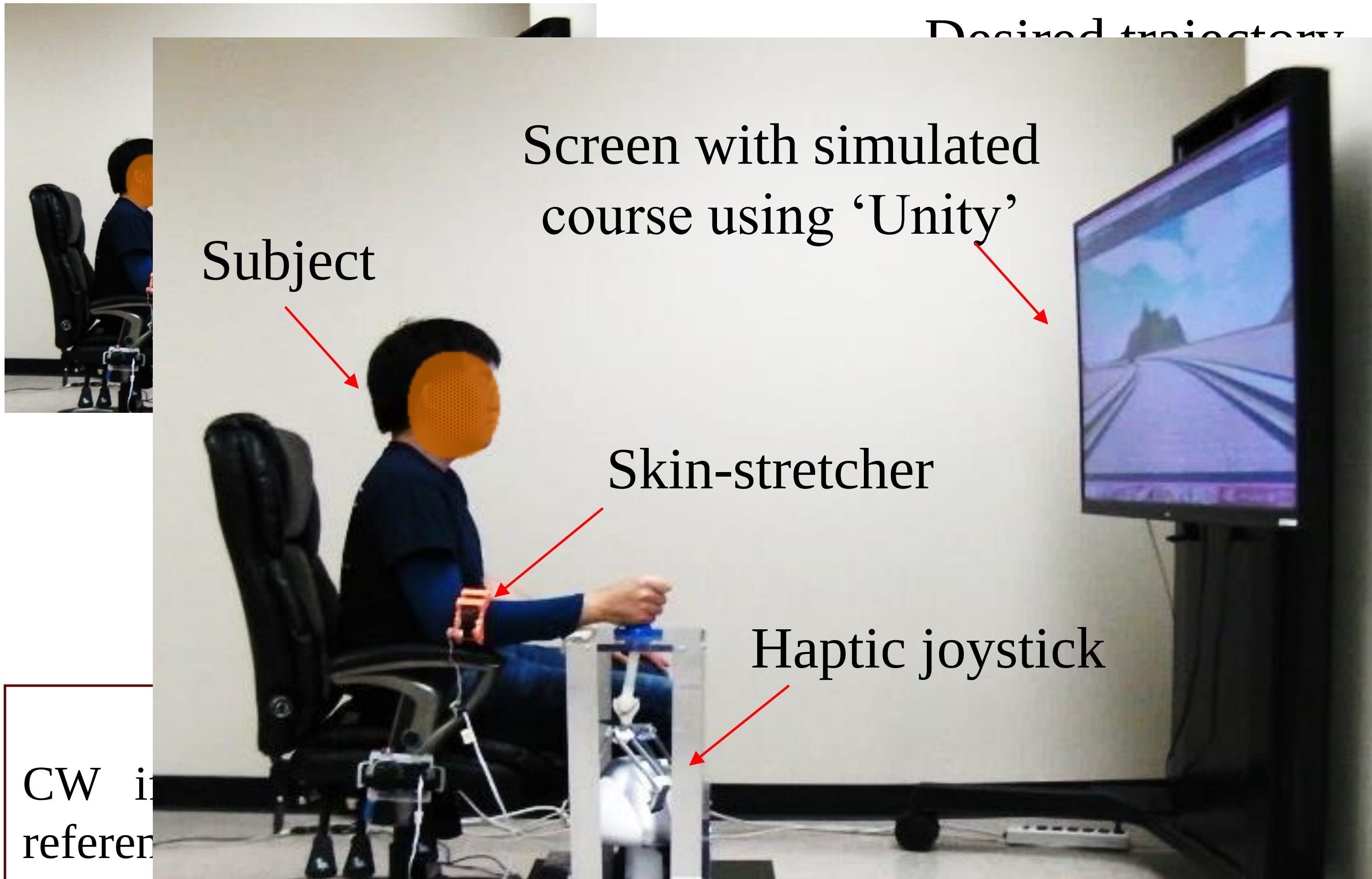
Comfortable



User acceptance

Economical

The workings



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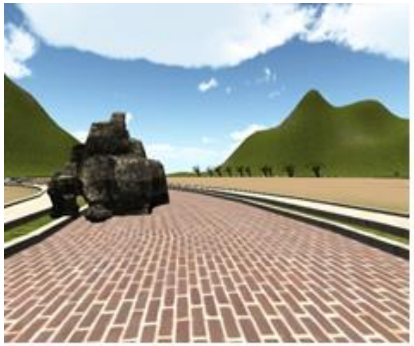
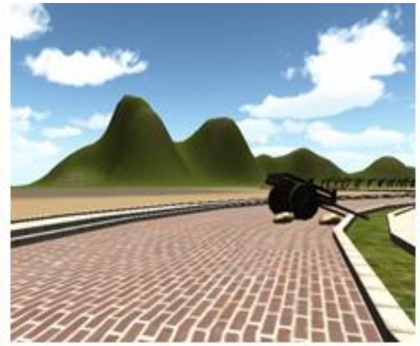
Performance evaluation

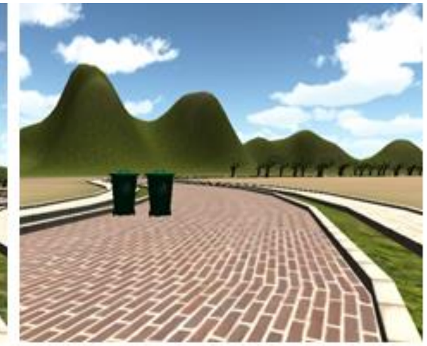


Task1:
Smooth left

Task2:
Smooth right



Task3:
Sharp right



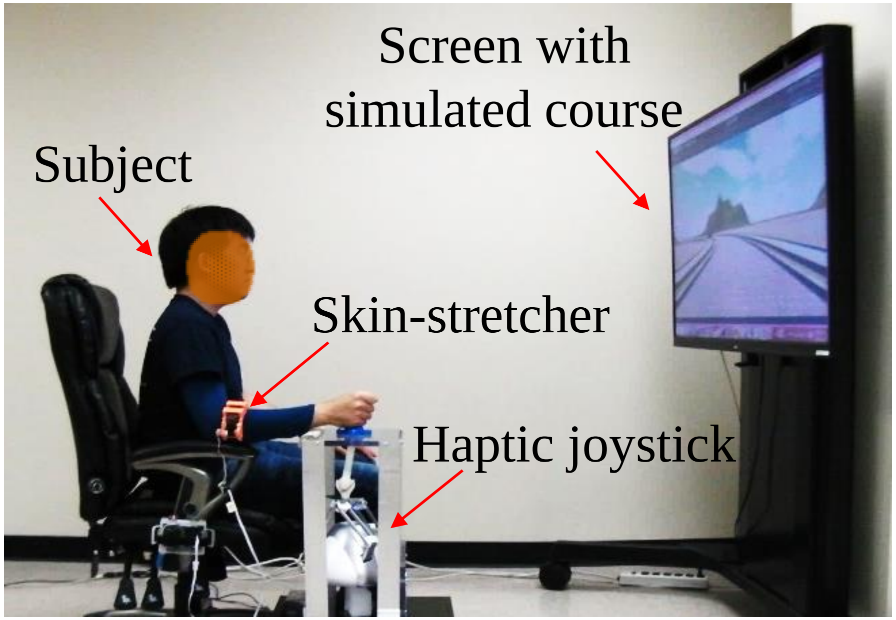
Task4:
Sharp left

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)

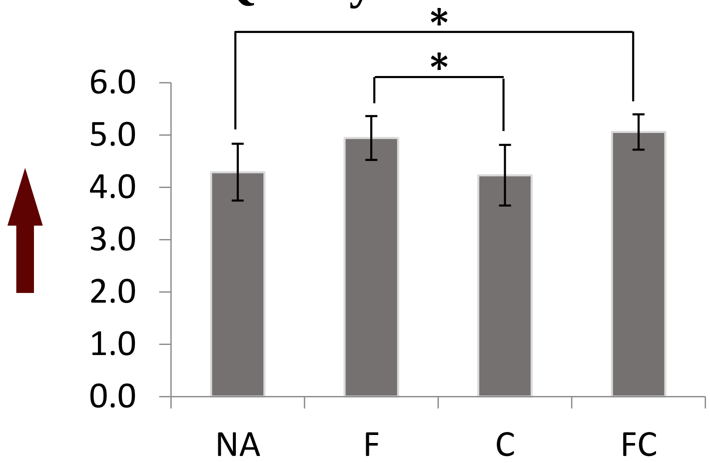
Performance metrics

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

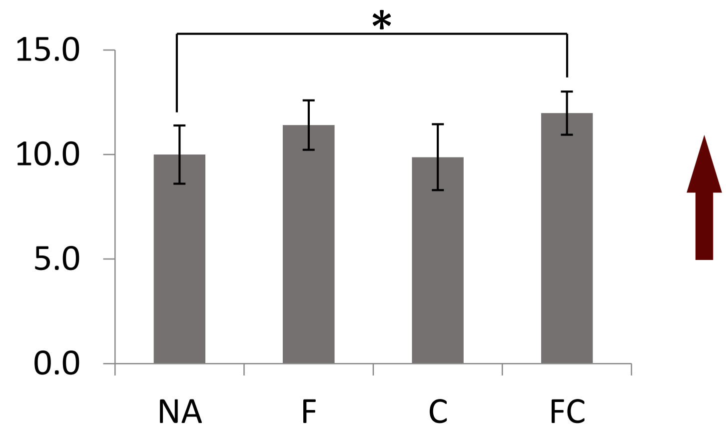
- A repeated measure ANOVA was performed with two factors: task and assistance mode ($p<0.05$)
- Significant differences among the assist modes were also studied via Bonferroni pairwise comparison with ($p<0.05$)

Results and inferences

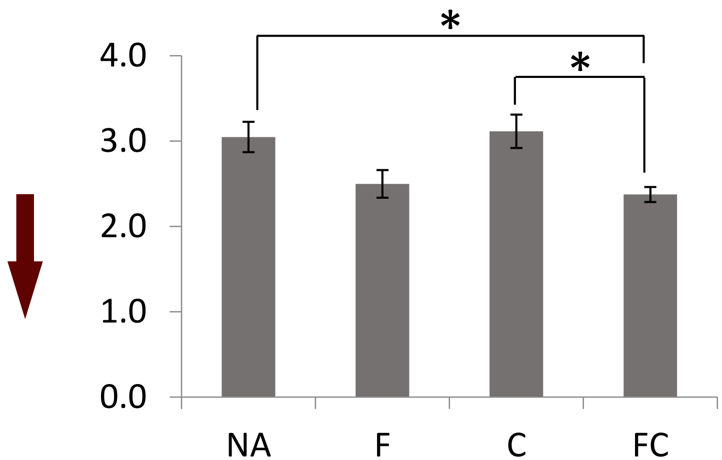
M1 – Quality of achievement



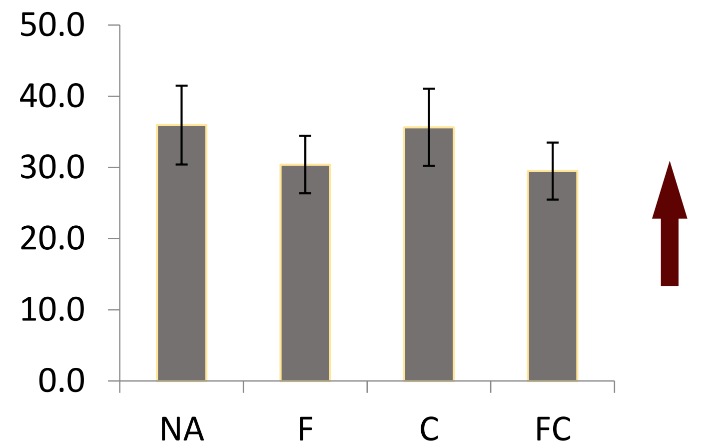
M2 – Min distance from obstacles



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

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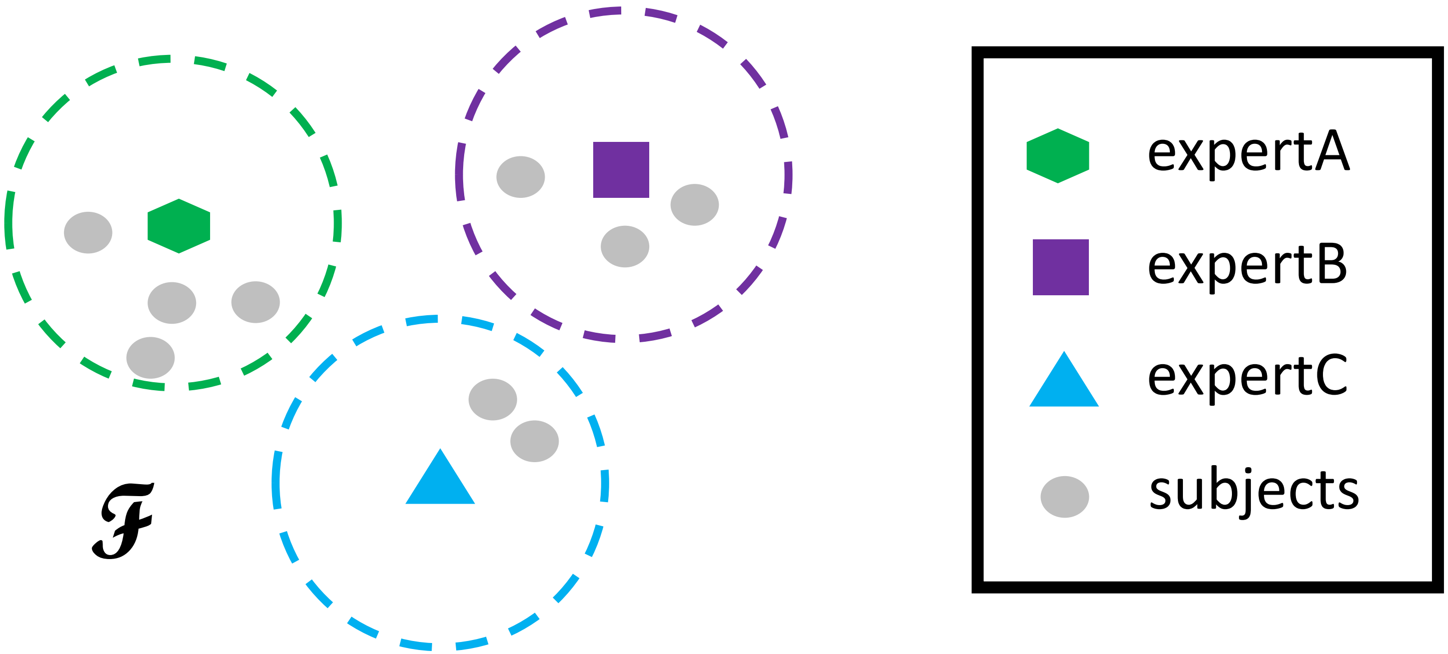
Design not only for functionality but for usability!

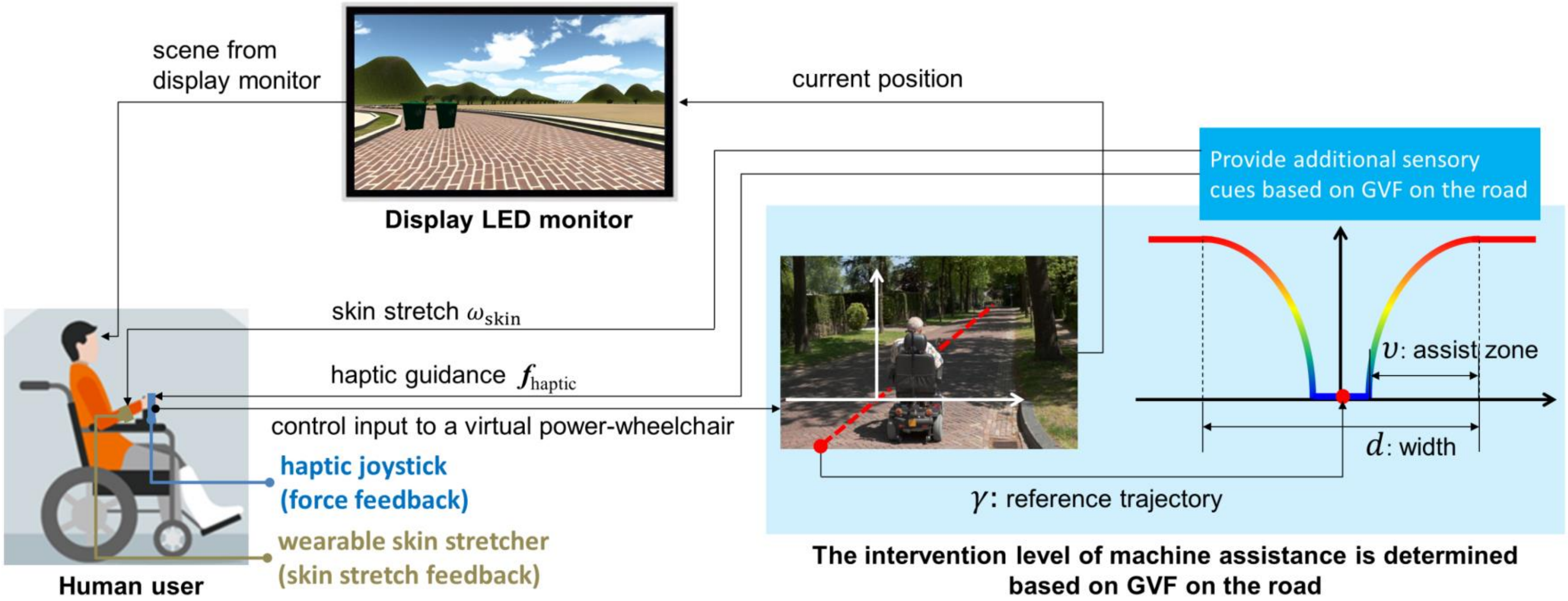
Thank you!

Desired trajectory

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

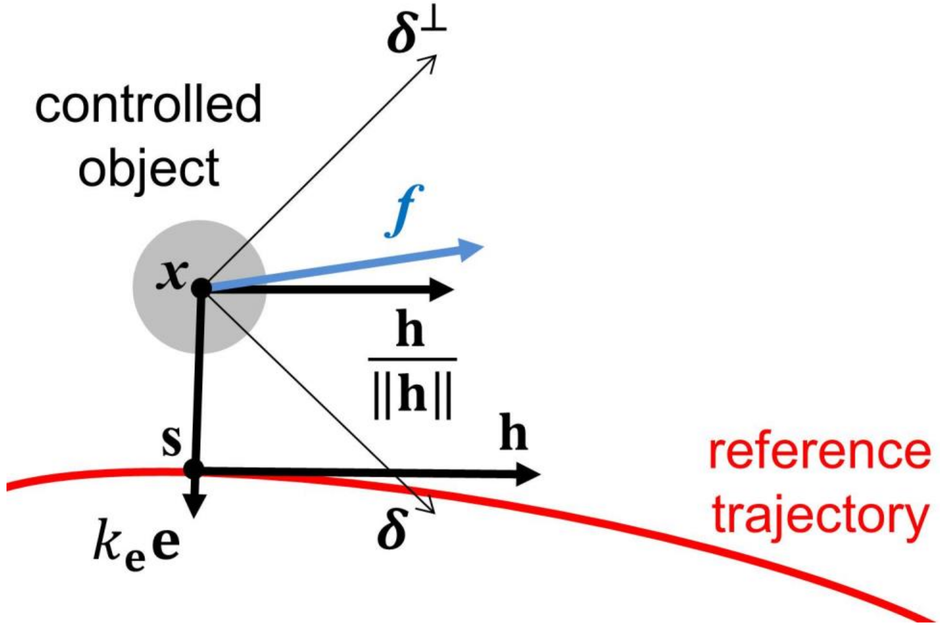


System working



$$\kappa_{\delta\perp}(\|\mathbf{e}\|) = \begin{cases} 1.0 & \text{if } \|\mathbf{e}\| \le \frac{d}{2} - \nu \\ \kappa_{\delta\perp} + \left[\frac{d/2 - \|\mathbf{e}\|}{\nu}\right](1 - \kappa_{\delta\perp}) & \text{if } \frac{d}{2} - \nu \le \|\mathbf{e}\| \le \frac{d}{2} \\ \kappa_{\delta\perp} & \text{if } \|\mathbf{e}\| \ge \frac{d}{2} \end{cases}$$

Feedback signals



e – vector to closest point on desired trajectory

δ – preferred direction

f – input from users

h – tangential vector at closest point

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

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

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

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