An Approach to Customize Haptic Guidance for the Aged Power-Wheelchair Riders
- Augmenting sensory feedbacks for better assistance

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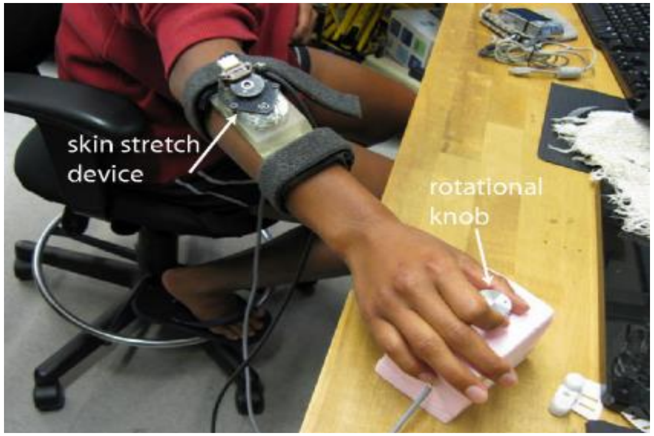
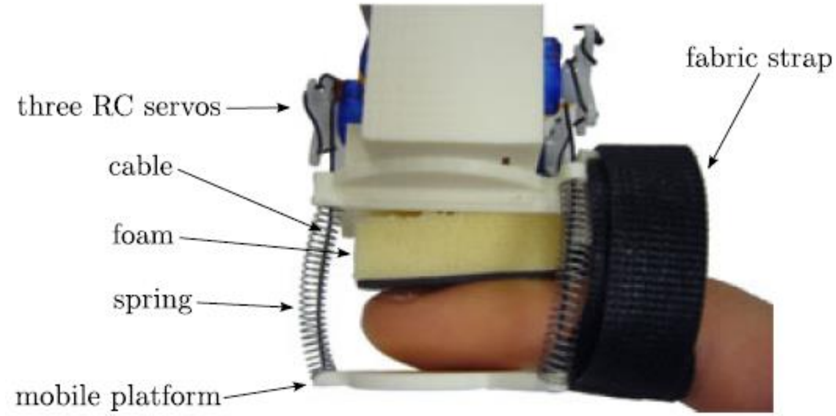
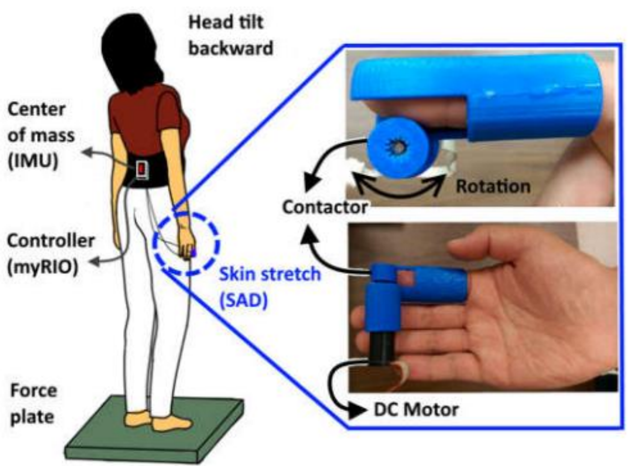
Wearable Devices for Sensory Feedback



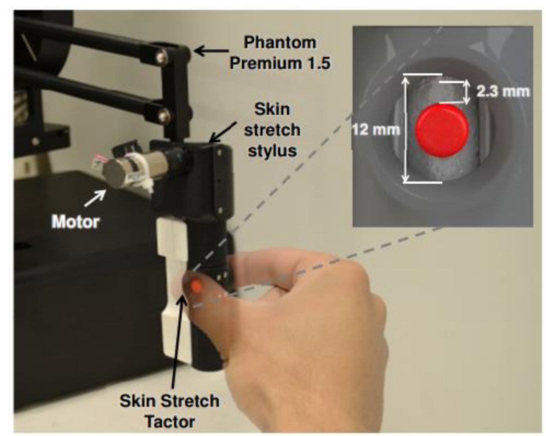
Bark et al, Stanford, USA



Pacchierotti et al, UPenn, USA



Pan and Hur, TAMU, USA



Quek et al, Stanford Univ. USA

Usages of Wearable Sensory Feedback

- **Sensory feedback substitution:** For example, substitute a finger perception into upper arm pinching for amputees.
- **Sensory feedback augmentation:** To Help people to perform better. EX) Quite balance, target pointing, collision avoidance, etc
- We employ **sensory augmentation** to **improve** power-wheelchair riders' task-performance.

Some research questions:

"Is sensory feedback augmentation always helpful?"

"Where will be the better place to mount this kinds of device?"

"Can they be combined with the other types?"

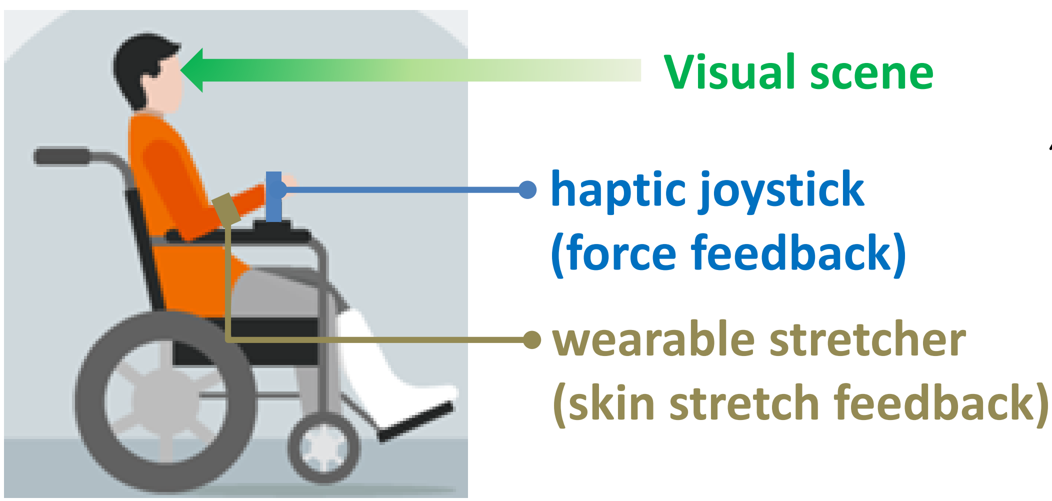
Assistance by Augmented Sensory Feedbacks

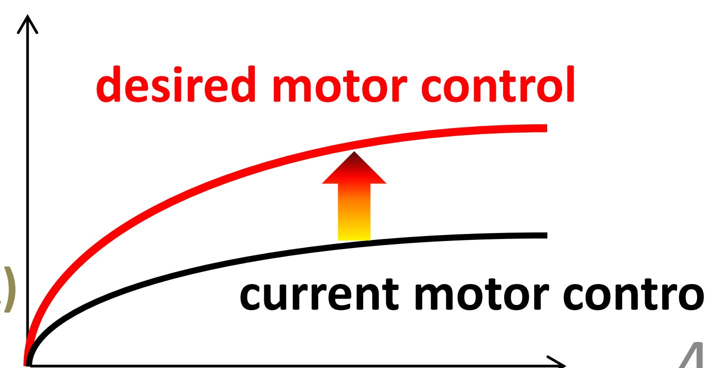
Goal

- **Develop** a **user-customized assistive system** to guide power wheelchair riders and protect their safety.

Objectives

- **Employ** **force feedback** and **skin-stretch feedback** to guide power wheelchair riders.
- **Identify** **the effect of provided feedbacks** on the rider's performance, especially in terms of safety-related metrics.





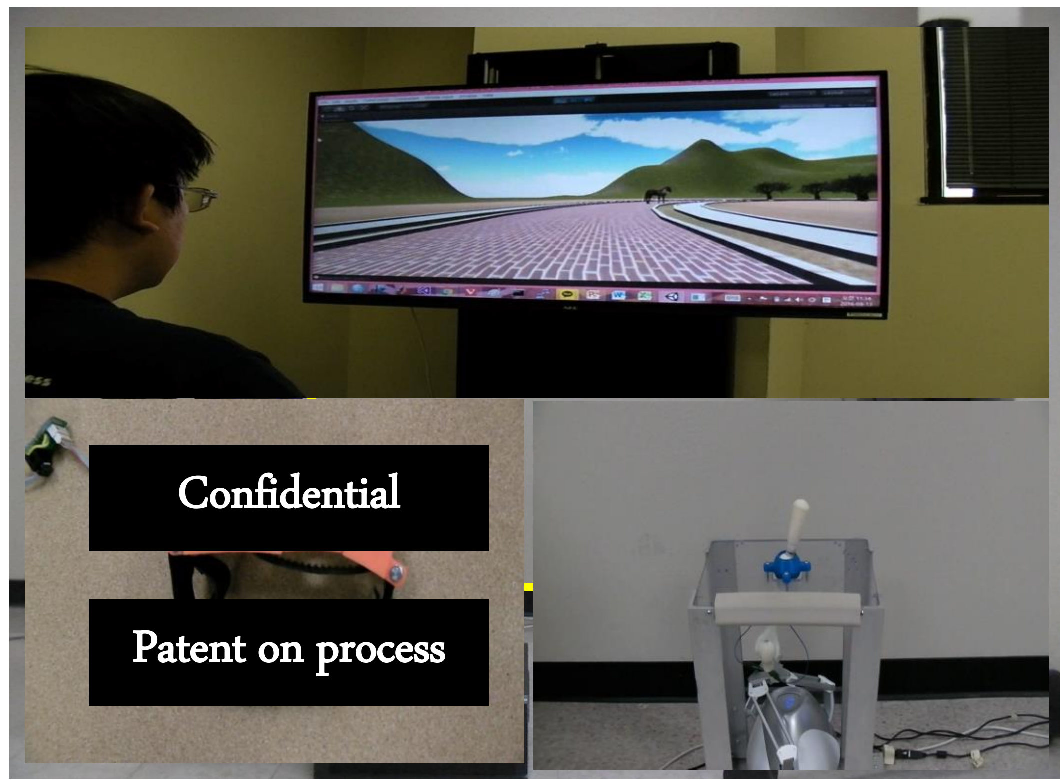
Assistive Power-Wheelchair Simulator Platform

Overview

- Subjects drive power-wheelchair by joystick handle in a virtual reality (VR) environment (implemented by Unity 3D)
- The subjects receive force feedback and skin-stretch feedback

Components

- 55 inch LED screen displaying VR task
- Novint Falcon haptic joystick
- Custom-designed wearable skin-stretcher
- Sabertooth motor driver (controlled remotely via XBee communication)



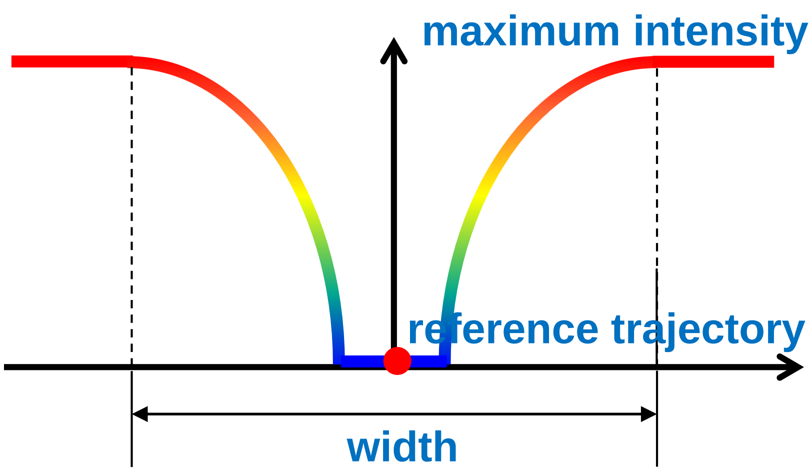
Machine Assistance in VR Environment Task

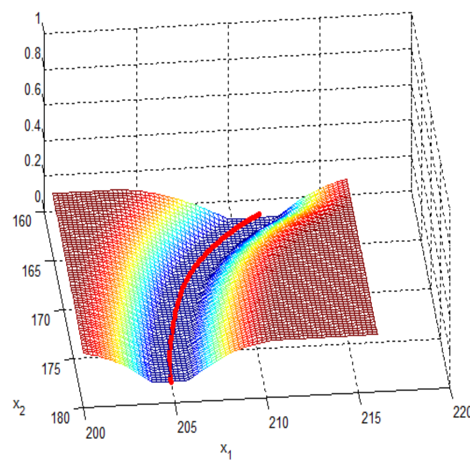
Functional block diagram

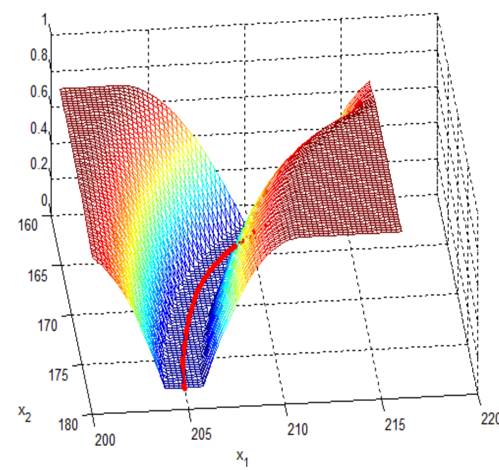
Environment sensing and **Data processing** (detecting road, obstacle, etc)

Machine algorithm to set an **assistance policy** (**Reference path** and **Feedback Intensity**)

Virtual fixture to set an assistance policy



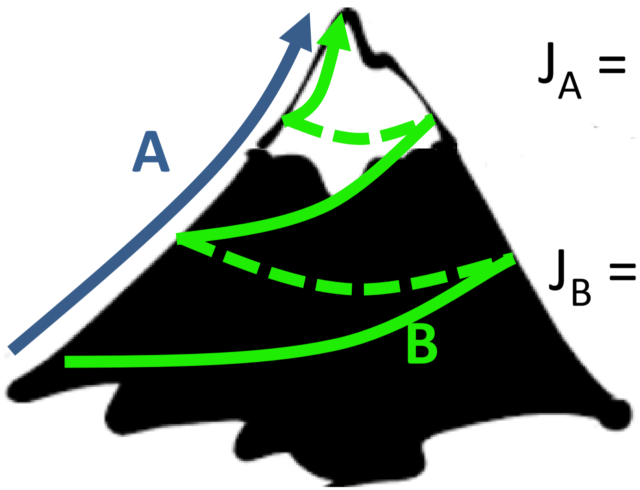




Assistance Policy Customization

Two Different Cost Functions and Corresponding Paths

- Utilizing Inverse optimal control to represent human strategy



$$J_A = \int w_1(\text{fuel consumption})^2 + w_2(\text{dist. to top})^2 \, dt$$

$$w_1 \ll w_2$$

$$J_B = \int w_1(\text{fuel consumption})^2 + w_2(\text{dist. to top})^2 \, dt$$

$$w_1 \gg w_2$$

(Direct) optimal control and inverse optimal control.

J

cost

optimal control →

← inverse optimal control

Fuel consumption

Dist. to top

Path

Employed basis functions to define a (penalty) cost

- To represent human strategy

$$J = \int w_1(b_1)^2 + w_2(b_2)^2 + w_3(b_3)^2 + w_4(b_4)^2 \, dt$$

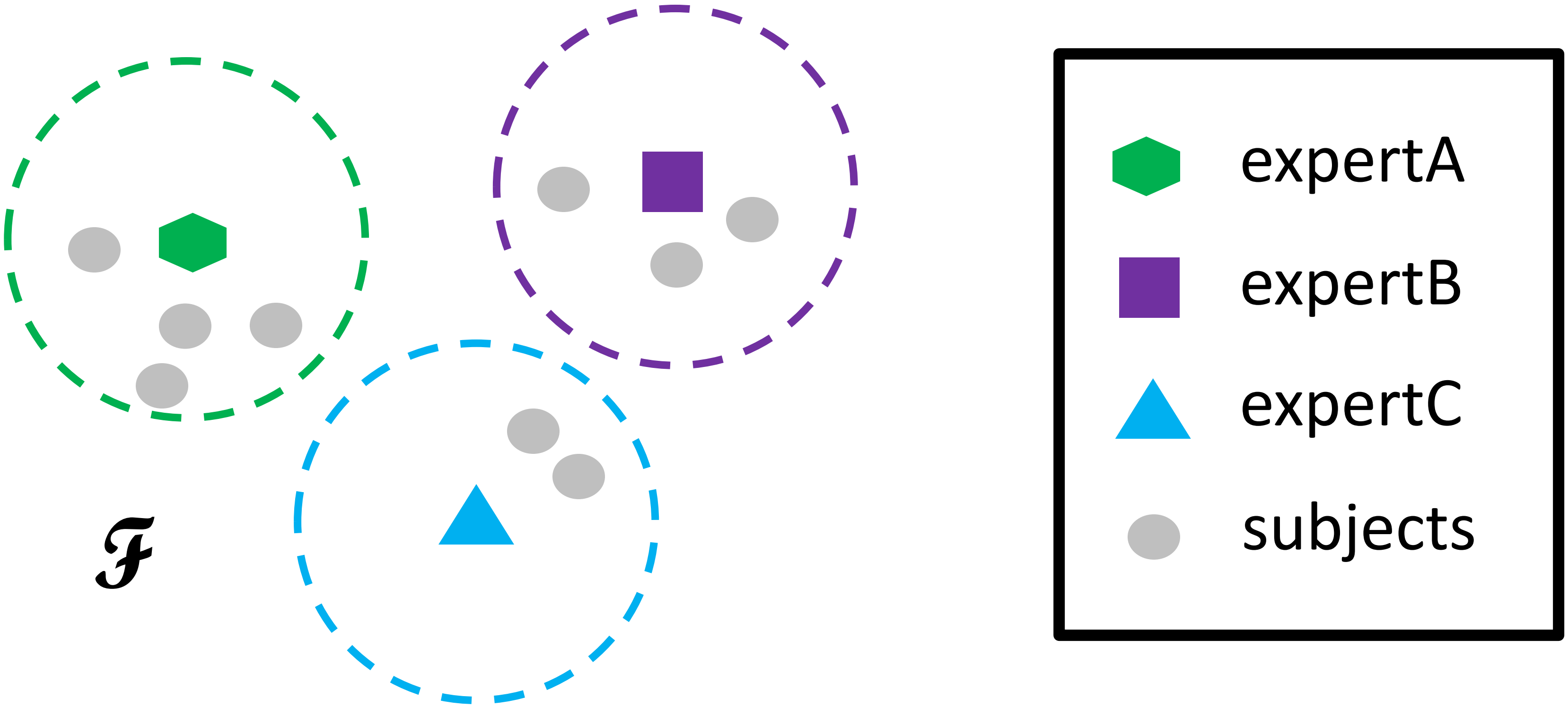
where
b_1 : effort to change speed
b_2 : effort to change steering
b_3 : distance to obstacle free road boundary
b_4 : distance to obstacle side road boundary

Featuring human strategy by utilizing weights $w_1 \ldots w_4$

$f_1 = w_1/w_2$: ratio to penalize a speed over a steering (path curvature).
$f_2 = w_3/w_4$: boundary preference (lane preference)
$f_3 = \rho(w_1,w_2,w_3,w_4)$: control effort over collision avoidance effort

Now, we can represent the human strategy as a sample point in the defined feature space $\mathcal{F}$.

To assign a coach to subject group, we use experts as centroids for K-Nearest Neighbor classification



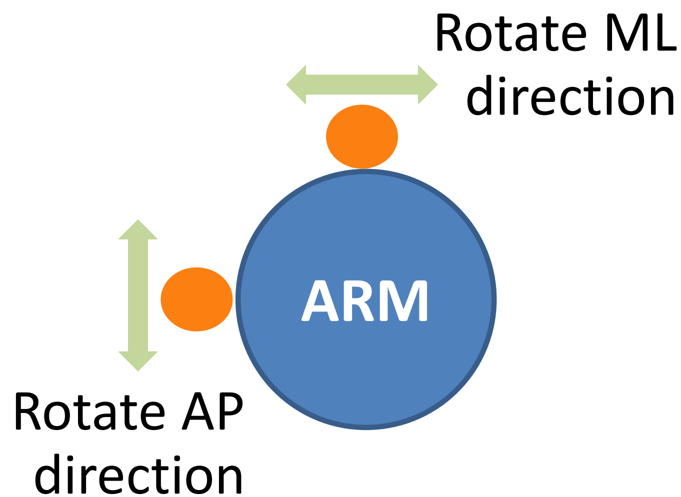
From preliminary study, we already selected an expert who can assist the aged subject group at best.

For subjects in the same group, we determine virtual fixture parameters as a function of feature values.

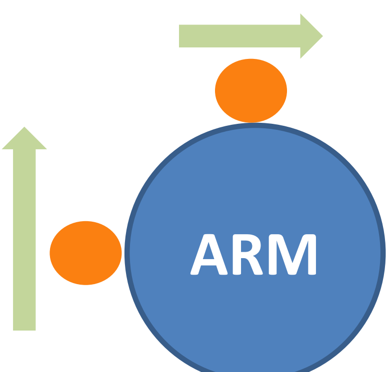
Position, Intensity, Direction of Skin-Stretch

Applying bi-directional skin stretch with two actuators

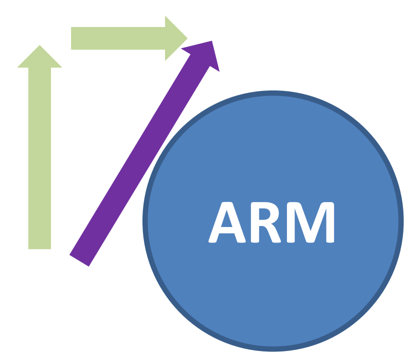
- Two actuators stimulate skin surface in AP and MP direction.



Question: "Can two skin stretches be decomposed?"



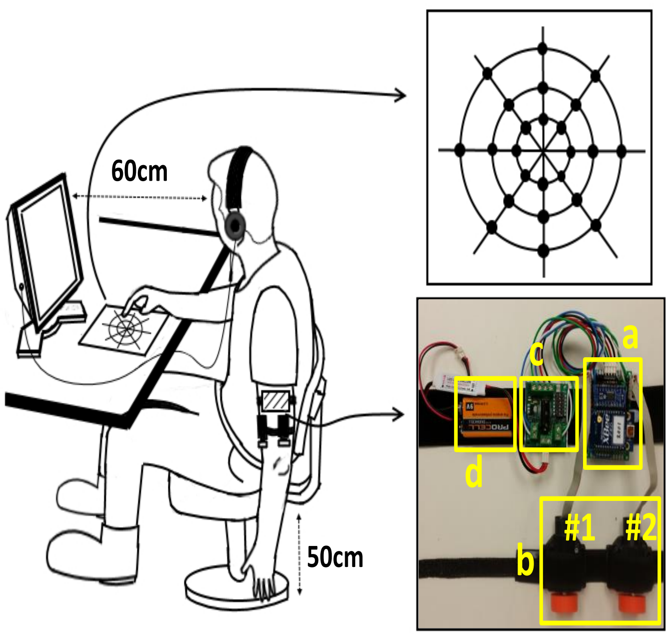
subject will perceive this stretch pattern as

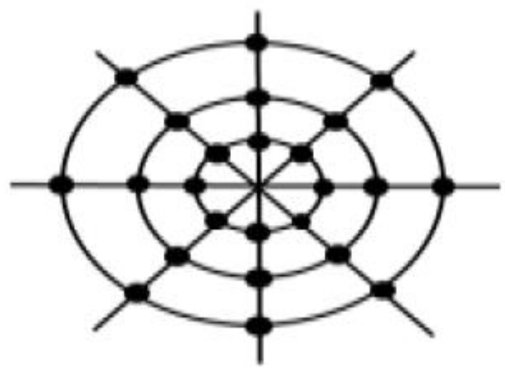


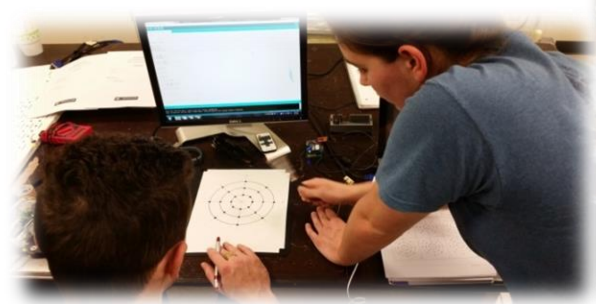
?

Identify a perceptual mapping from stretch pattern to work space perception

- Generate skin stretch patterns by a combination of 8 directions and 3 intensities of two actuators (total 24 stretch patterns).
- Subjects were instructed point out a discrete point on the provided chart within a short interval.

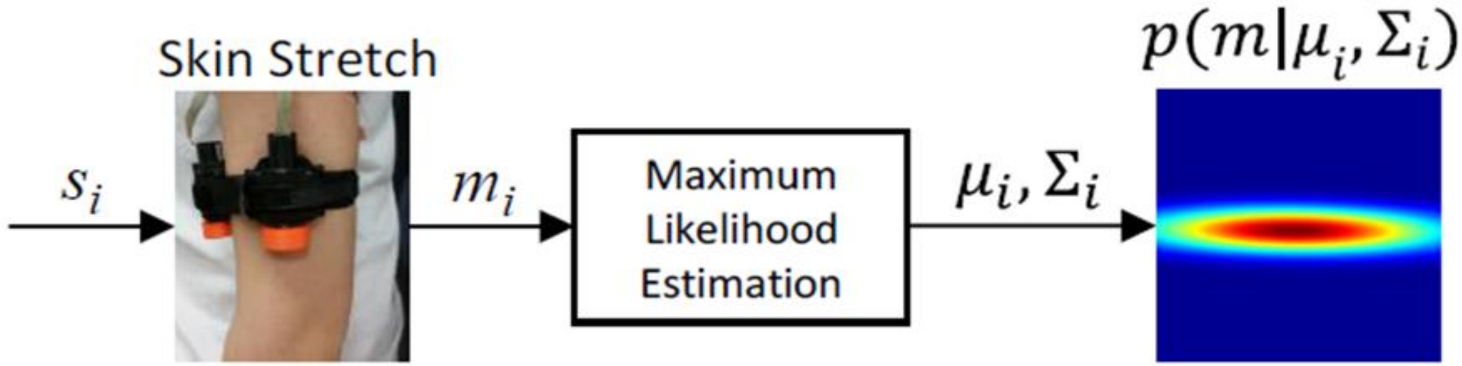




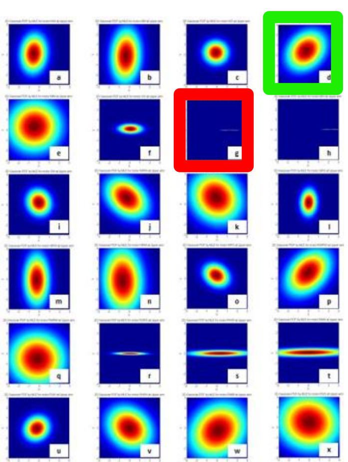


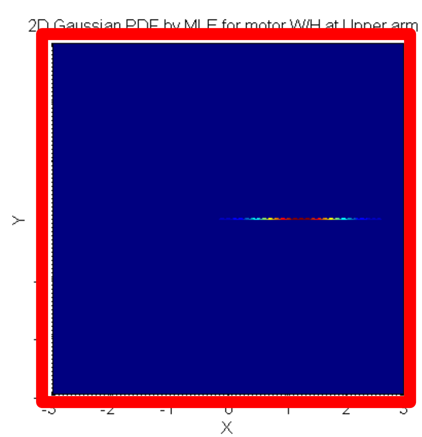
Skin stretch to provide a direction information

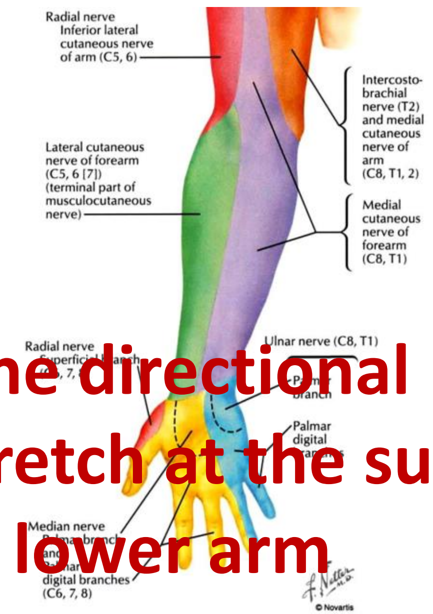
Estimate distribution by using MLE



Interpretation of outcomes







One directional stretch at the surface of lower arm

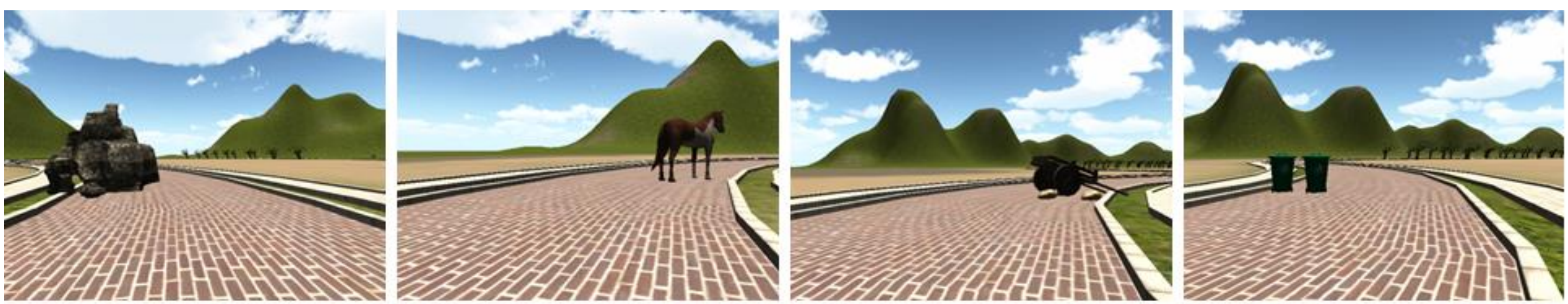
Experiments

Subjects

- 15 healthy **elderly subjects** were participated (7 male, 8 female, **age 72.8±6.6 yrs**).

Task

- Four scenarios w.r.t. different road curvatures and obstacle types.
- Subject was instructed to pass around the obstacle and reach to a goal.



Four different scenarios were given to subjects for a virtual power-wheelchair simulator experiment.

Protocol

- Subjects were instructed about the VR simulator platform and experimental procedures.
- Practice time was given, but not exceed to 5 min to prevent a learning effect.
- Four different assistance modes were applied to the subjects

  NA: no-assist, **H**: haptic force feedback only,

  S: skin-stretch only, **HS**: both force feedback and skin-stretch.

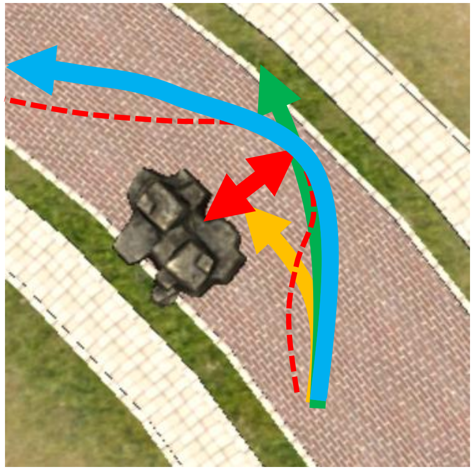
- Trial scenarios were given by a combination of

  four different scenarios
  four assistance modes
  three repetitions

  Thus, there were 4x4x3=48 trials.

- The trial scenario sequence was randomized.

Performance metrics to evaluate subject's performance

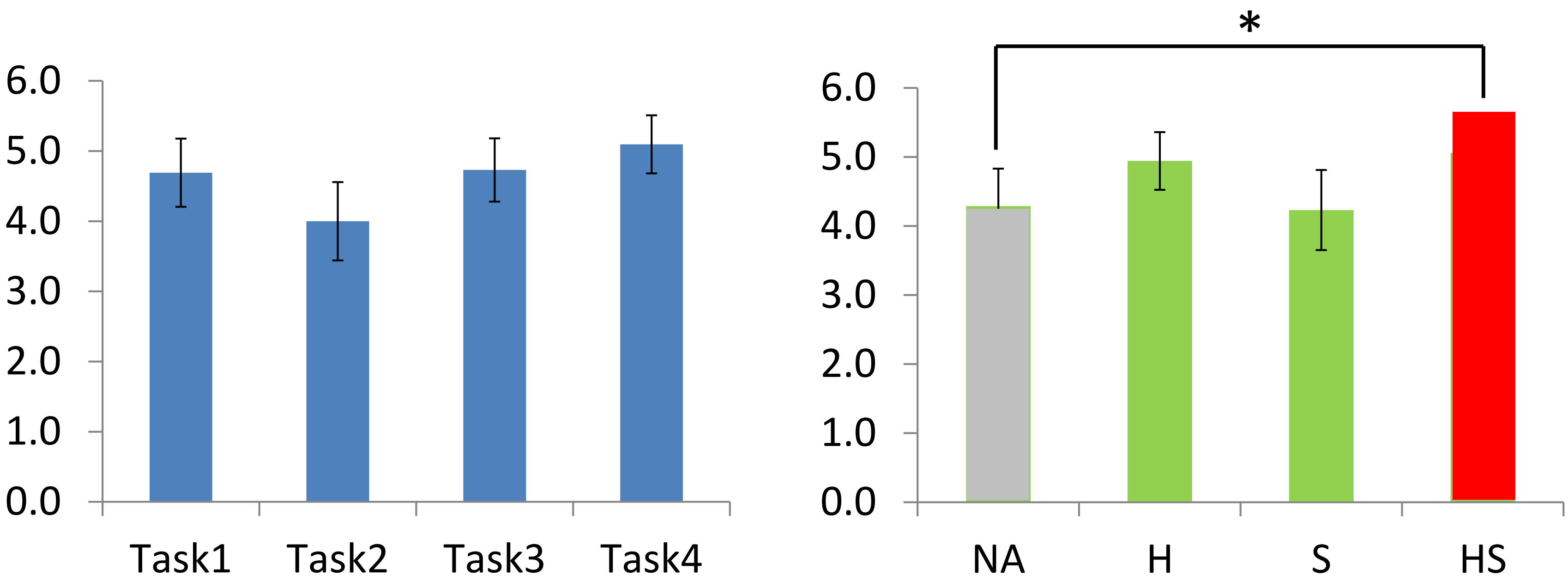


- **Quality of achievement**
  - **2**: reach to goal
  - **1**: pass an obstacle, but collide to road boundary
  - **0**: failed before obstacle or hit it.
- **Minimum distance to obstacles**
  A nice clue to check safety while passing through the obstacle.
- **Mean deviation from the reference trajectory**
  A metric to tell whether the given reference trajectory helps or work against.
- Completion time and variability
  Not safety-related, but worthy of checking these two metrics as driving task.

Analysis

- We wanted to check the (main and interaction) effect of task and assistance mode.
- Therefore, **rANOVA** was performed with two factors: **task** and **assistance mode**. Significance level was set to <.05.

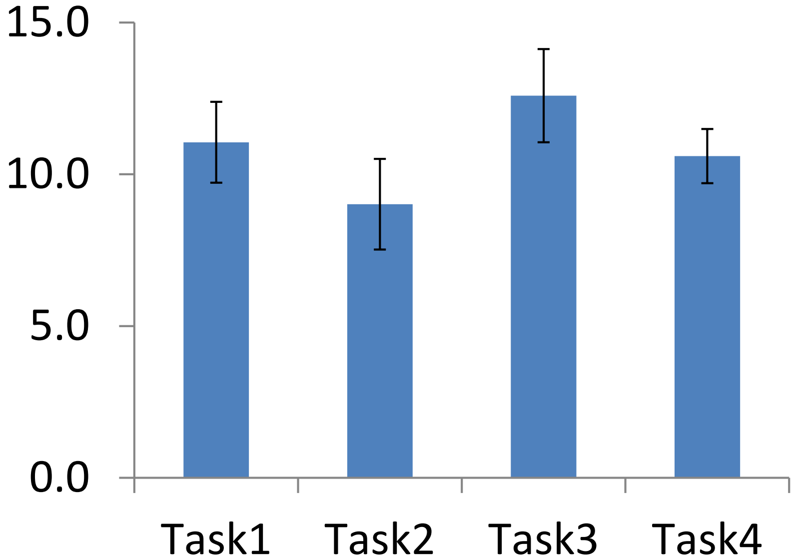
Result - Quality of achievement

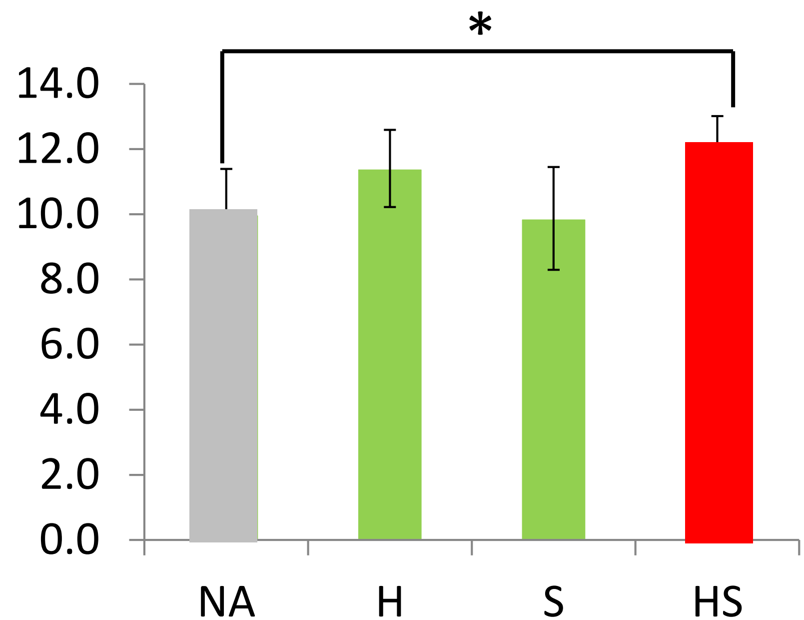


STAT result

- **Significant main effects** found both for **task** and **assistance mode**.
- Bonferroni pairwise comparison for **NA and HS** yielded significant difference (p<.048).
- **No significant interaction effect** was found.

Result - Minimum distance to obstacles

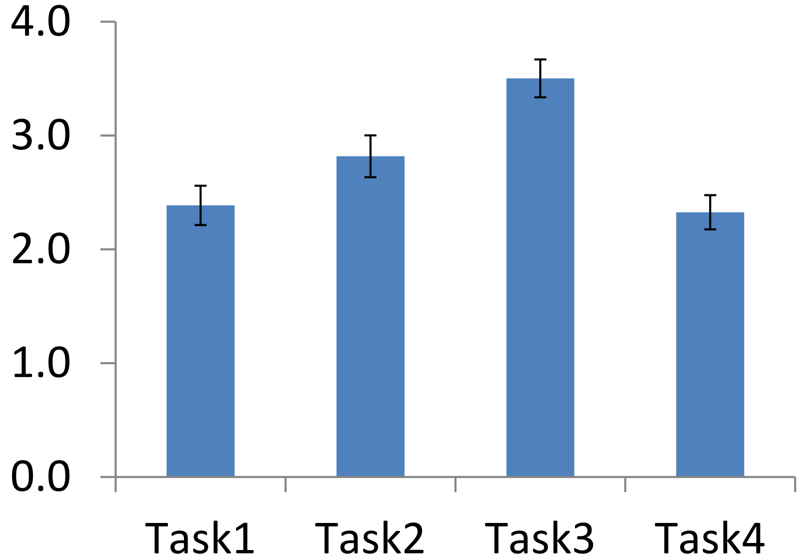


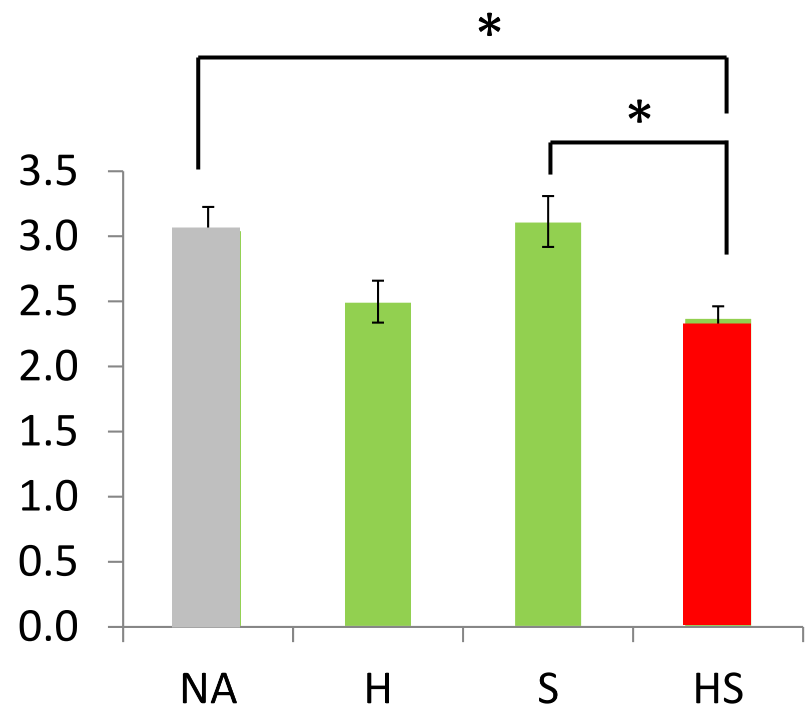


STAT result

- **Significant main effects** found both for **task** and **assistance mode**.
- Bonferroni pairwise comparison for **NA and HS** yielded significant difference (p<.015).
- **No significant interaction effect** was found.

Result - Mean deviation from the reference trajectory



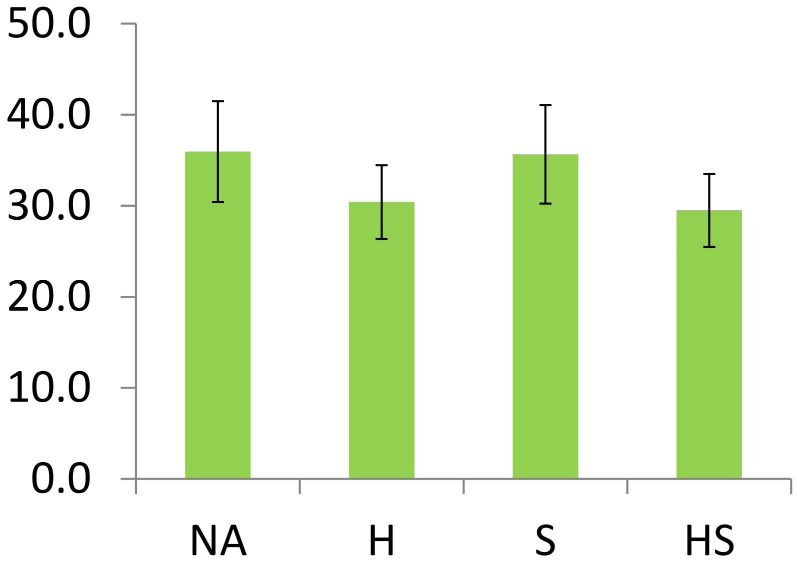


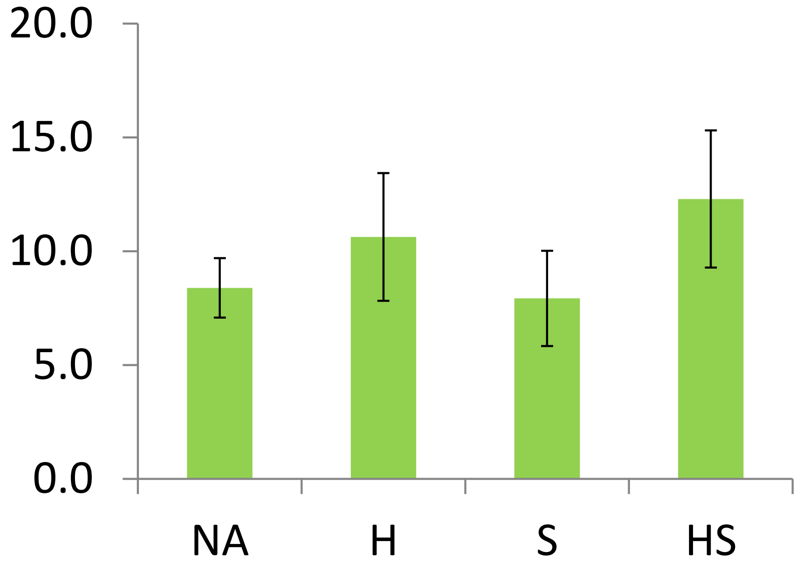
STAT result

- **Significant main effects** found both for **task** and **assistance mode**.
- Bonferroni pairwise comparison for **NA and HS** yielded significant difference (p<.039), and **S and HS** (p<.026).
- **No significant interaction effect** was found.

Result - Completion time and variability

(assistant mode only)





STAT result

- **No significant main effects** found either for task or assistance mode.
- **No significant interaction effect** was found.

Conclusion

Summary

- We employed haptic force feedback and skin-stretch to improve subject’s performance.
- Compared to baseline NA, significant improvements in quality of achievement, minimum distance to obstacles, and mean deviation from the reference trajectory were found under HS.



Future work

- Apply to a steering wheel control task with the two of one-directional skin stretcher at contralateral sides.
- Consider various types of sensory augmentation which can generate synergetic improvement.

"It doesn't matter how beautiful your theory is, it doesn't matter how smart you are. If it doesn't agree with experiment, it's wrong."

- Richard P. Feynman

Thank you so much ☺

Any question will be welcomed