Enabling physical interaction through wrist-mounted haptic controller with force feedback

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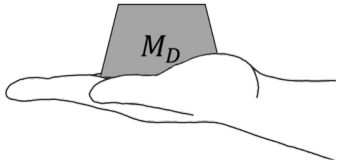
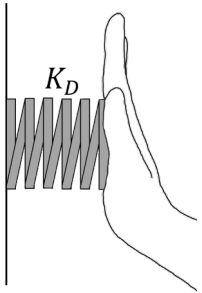
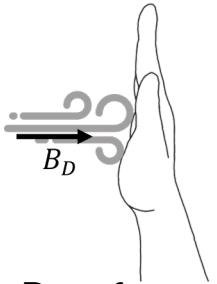
Research Motivation : Related Works



Weight
(Inertia)



Compliance
(Elasticity)



Drag force
(Viscosity)

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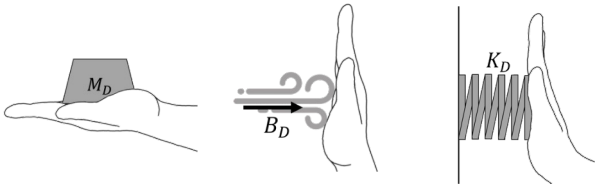
* Video from: Kovacs, Robert, et al. "Haptic PIVOT: On-demand handhelds in VR." Proceedings of the 33rd Annual ACM Symposium on User Interface Software and Technology. 2020.
** Video from: Ryu, Neung, et al. "GamesBond: Bimanual Haptic Illusion of Physically Connected Objects for Immersive VR Using Grip Deformation." Proceedings of the 2021 CHI Conference on Human Factors in Computing Systems. 2021.
*** Video from: Zenner, André, and Antonio Krüger. "Drag: on: A virtual reality controller providing haptic feedback based on drag and weight shift." Proceedings of the 2019 CHI Conference on Human Factors in Computing Systems. 2019.

Research Motivation : Hand - Object Haptic Interaction

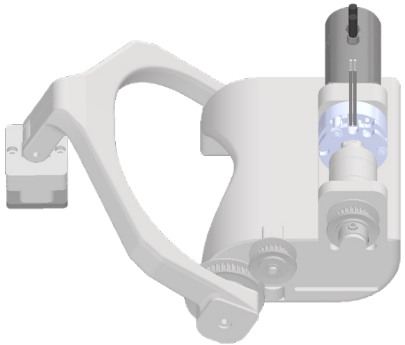
- Inertia, elasticity, and viscosity can be implemented as an **integrated force feedback system** because they **act independently of each other**
- **Motorized system** is one of the most suitable methods for dynamic force feedback formation



Inertia Viscosity Elasticity Mechanical Impedance

$$F = Ma + Bv + Kx = \mathrm{Z} \cdot \mathrm{v}$$

Force Acceleration Velocity Position Dynamic vector

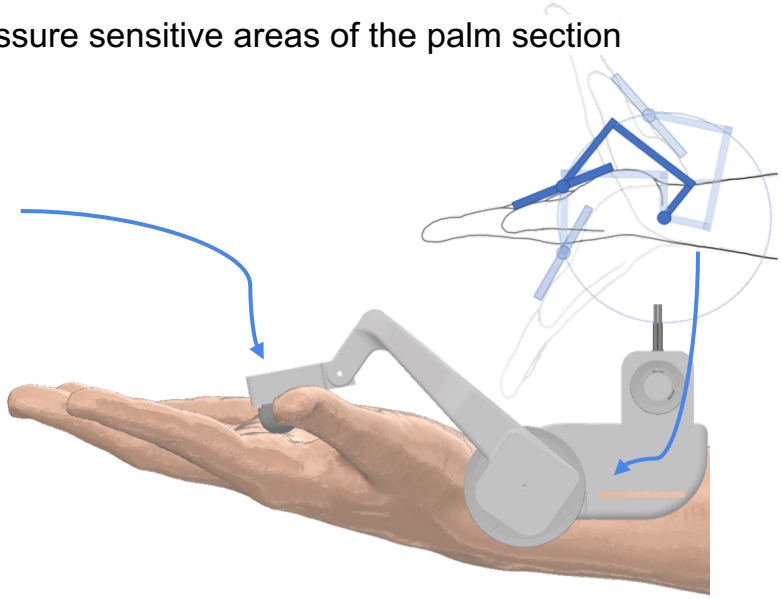


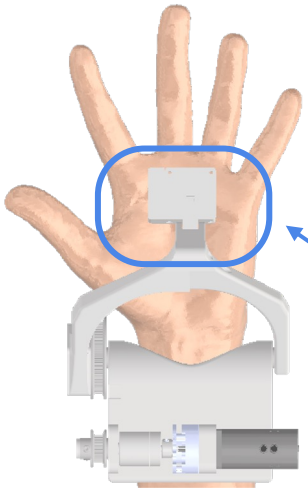
Motorized Controller able to simulate **All Physical Property**

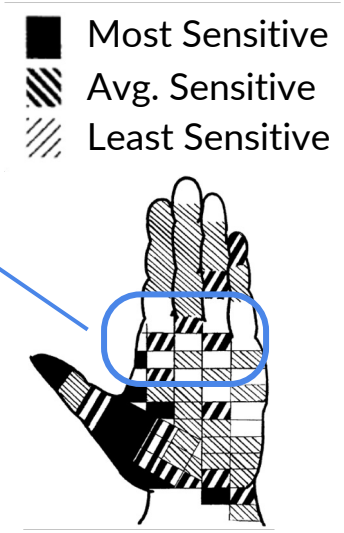
Hardware Ideation

- **Force Sensor Register** to use for measuring the force directly between controller & hand
- **1-Link & Wrist-Mounted design** for simple structure & lightweight & maximize range of motion
- Select the contact point **where the index, middle, and ring fingers begin** among the pressure sensitive areas of the palm section

RA9P	
Sensing Range	0.05N ~ 40N

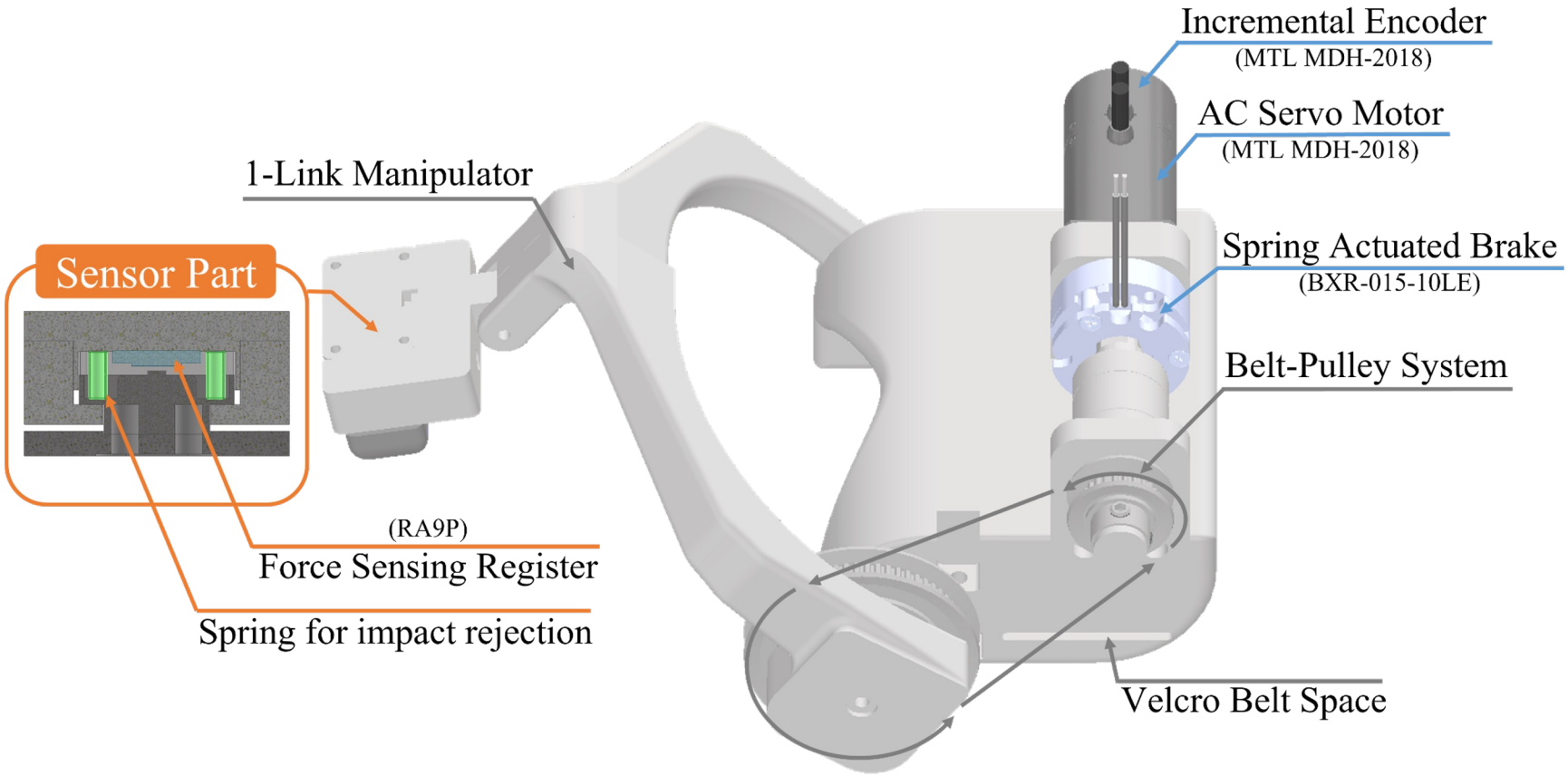




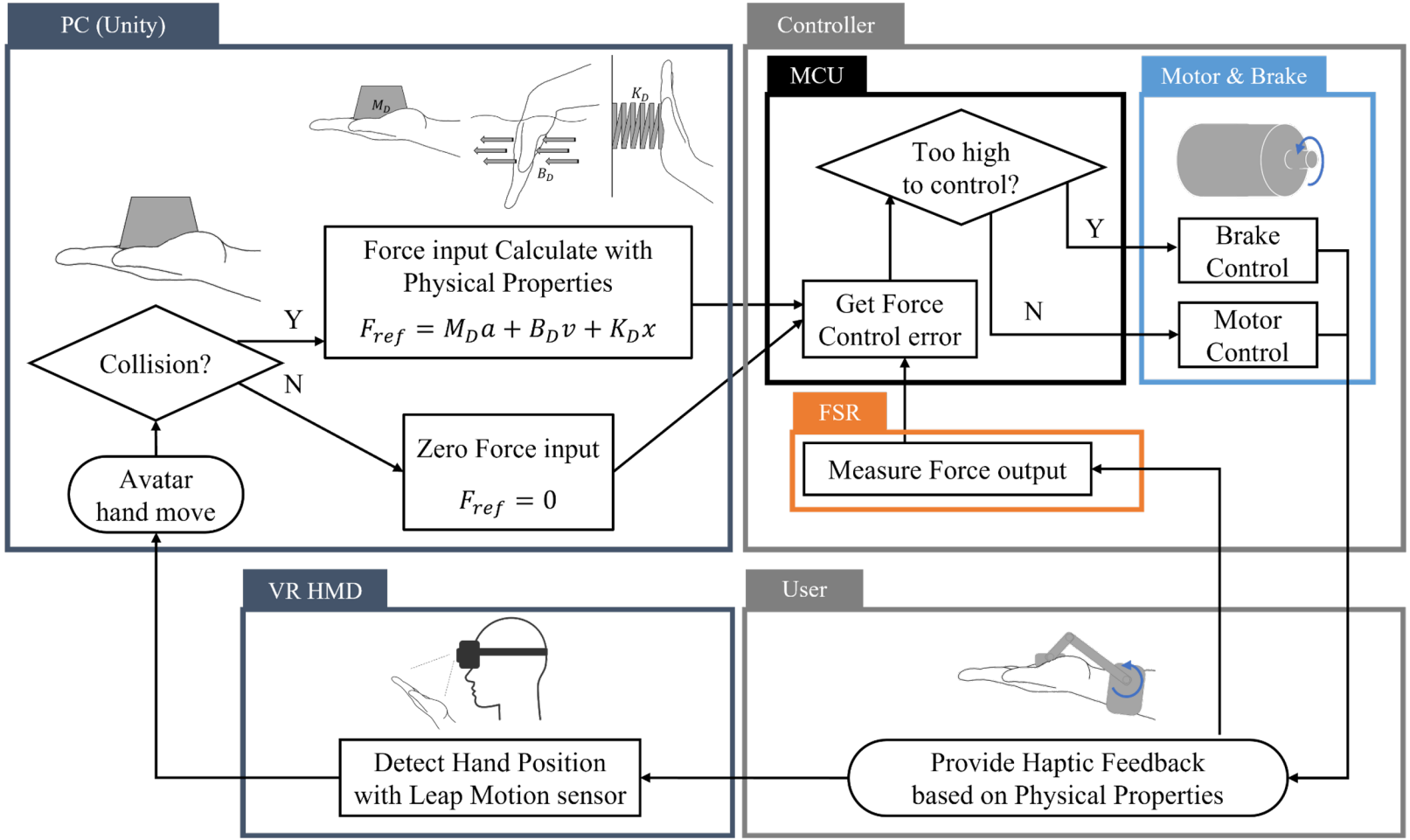


* Images from: Fransson-Hall, Charlotte, and Åsa Kilbom. "Sensitivity of the hand to surface pressure." Applied ergonomics 24.3 (1993): 181-189.

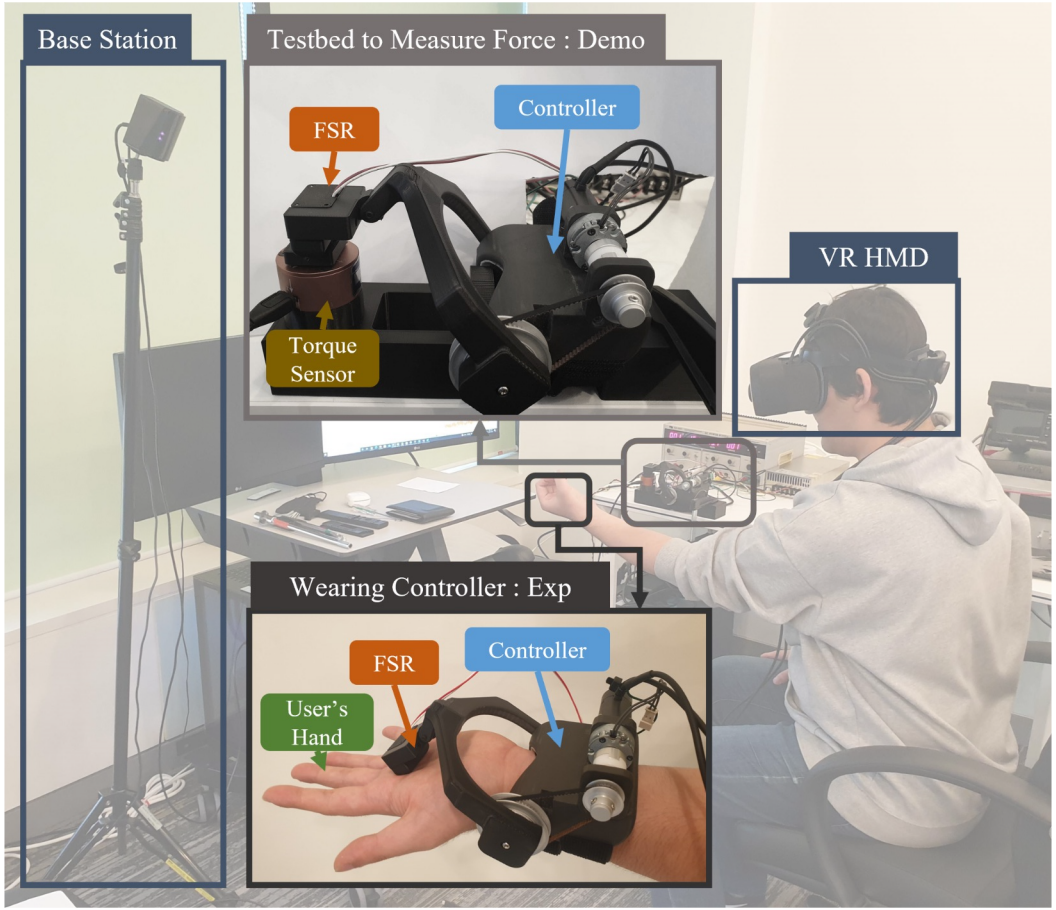
Hardware Implementation



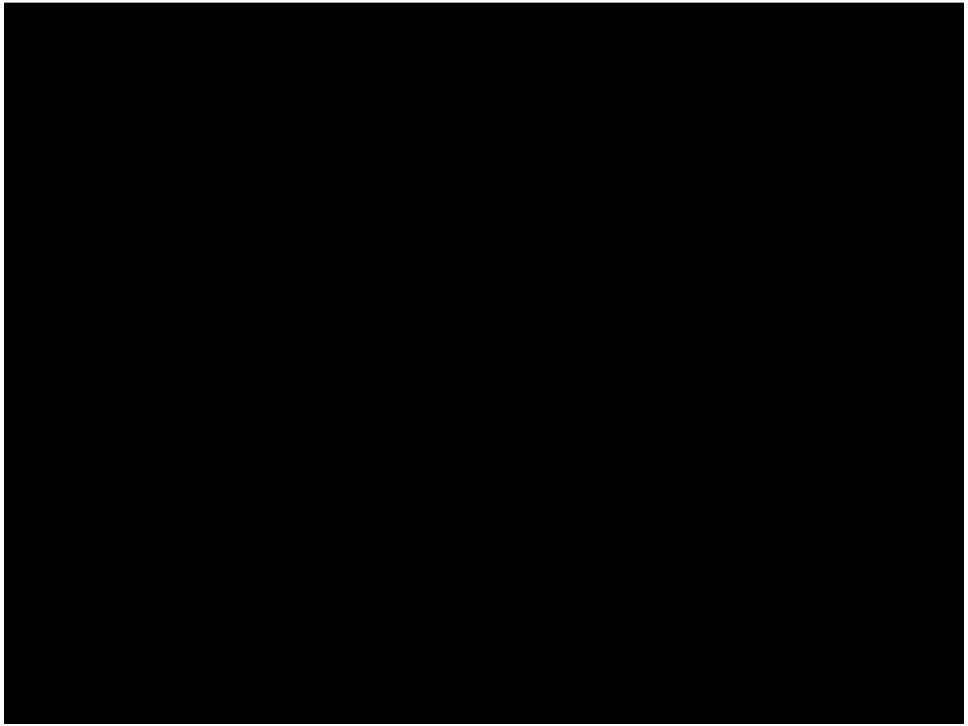
System Flow


PC (Unity)
Controller
MCU
Motor & Brake
M_D
K_D
B_D
Too high to control?
Y
N
Brake Control
Motor Control
Force input Calculate with Physical Properties
$F_{ref} = M_D a + B_D v + K_D x$
Collision?
Y
N
Get Force Control error
FSR
Measure Force output
Zero Force input
$F_{ref} = 0$
Avatar hand move
VR HMD
User
Detect Hand Position with Leap Motion sensor
Provide Haptic Feedback based on Physical Properties

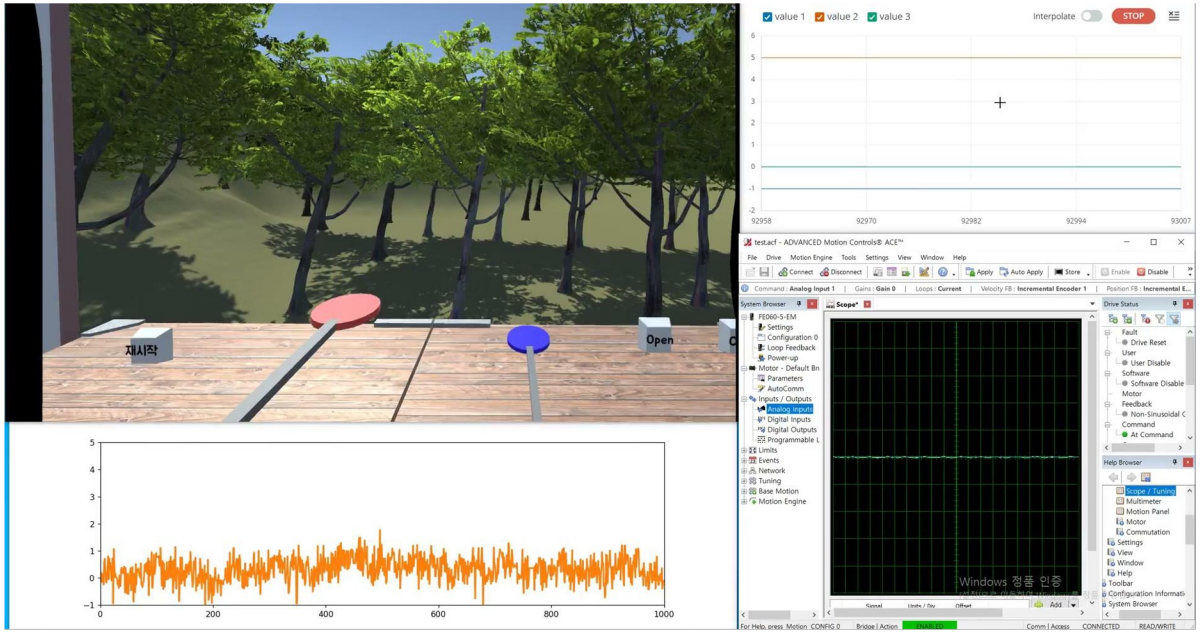
Device : Demo & Experimental Implementation



Device : Demo Example



Device : Demo Example



Device : Demo Example

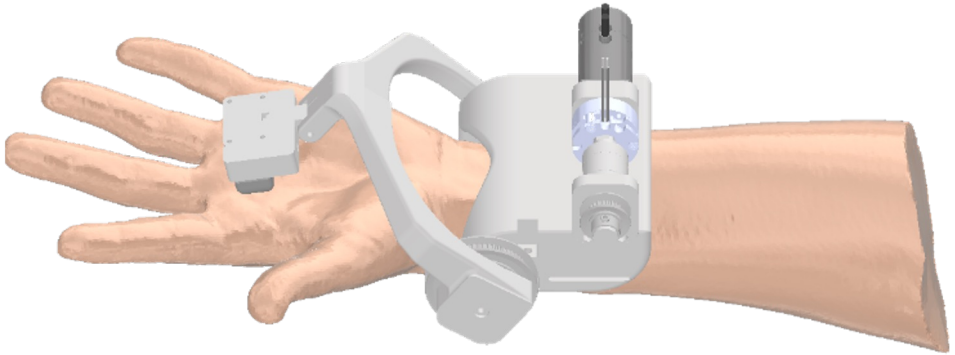
Device Evaluation : Experiment Example

- **Hand method**
  - Users can feel the weight
  - However, there is a limit to vibration alone

  ⇒ So we use force feedback.

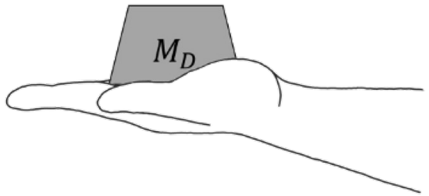
- **Requirement**
  - Noticable difference when interacting with virtual object
  - Destruction to the sense of experience should be minimized

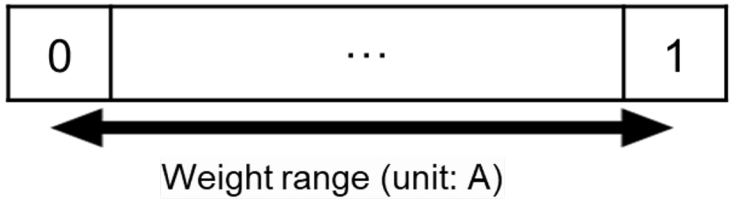
Device Evaluation : Experiment Example



- **Advantage of device**
  - Rotatable handle
  - Force applied to the palm of the hand can change the user's perception of the object.
  - Can simulate lifting a heavier object in a virtual scene
  - Can simulate the weight of the object or the inertial change during picking or pushing

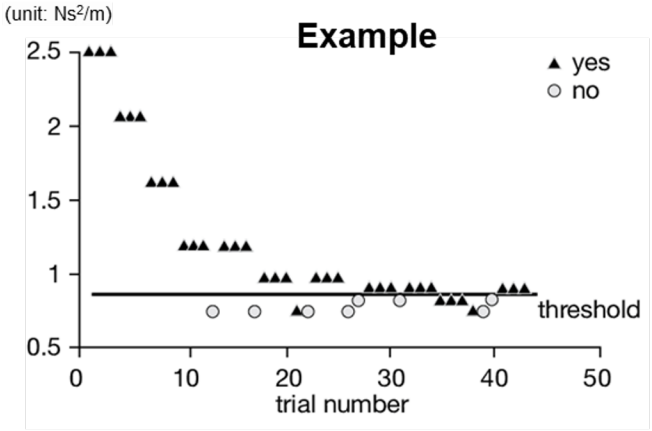
User study 1

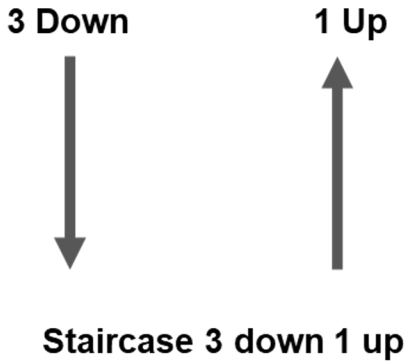




- **Absolute Threshold Of Weight**
  - Participants were asked to move while wearing the device. Participants responded whether they perceived the forcefeedback or not, as compared to the default value that the device presses on the palm.
  - If participants perceived forcefeedback, they answered “Yes”, otherwise they answered “No”.

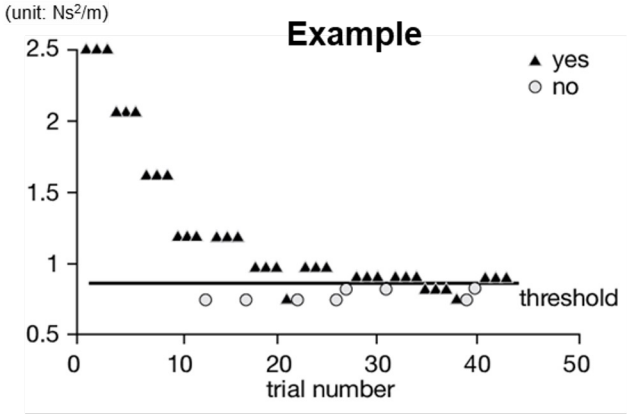
User study 1

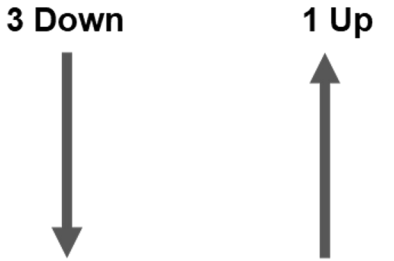




- **2AFC**
  - A particularly useful method for measuring sensory thresholds is the so-called two-alternative forced-choice(2AFC) procedure
  - 2AFC procedure discourages response biases and also produces an especially high level of performance.

User study 1

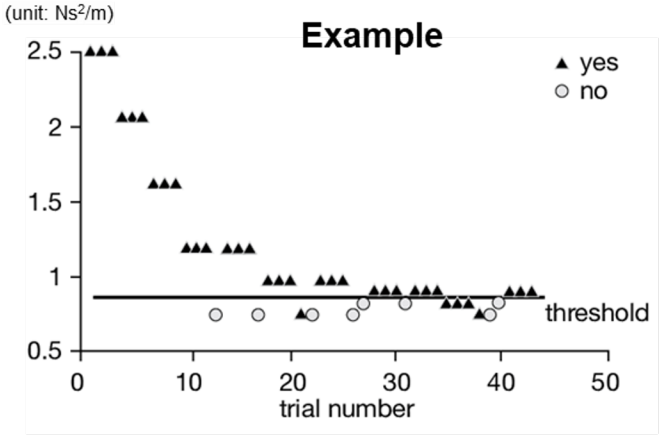


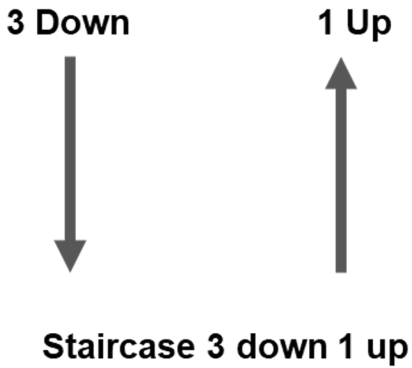


Staircase 3 down 1 up

- **Staircase 3 down 1 up**
  - The staircase converges on a target stimulus level by decreasing stimulus amplitude when a number (N) of responses are correct, and increasing stimulus amplitude when one response is incorrect.
  - In a three-down, one-up staircase (3D1U) the stimulus amplitude decreases after three correct responses and increases when one response was incorrect.
  - It is 1 down until the first reverse occurs.

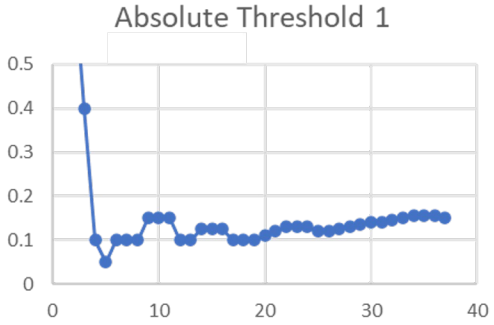
User study 1

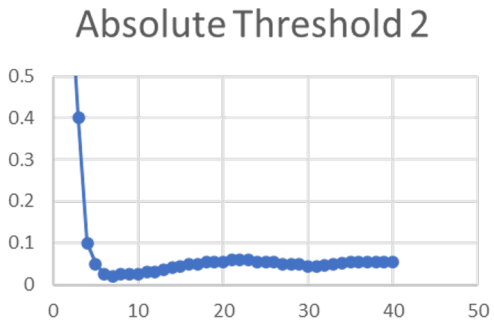


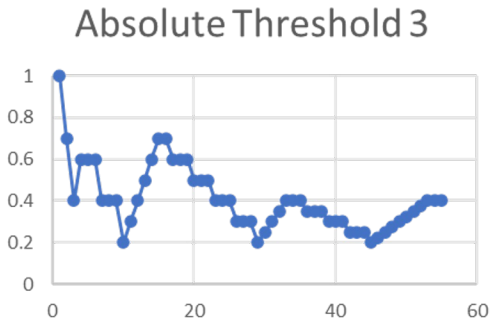


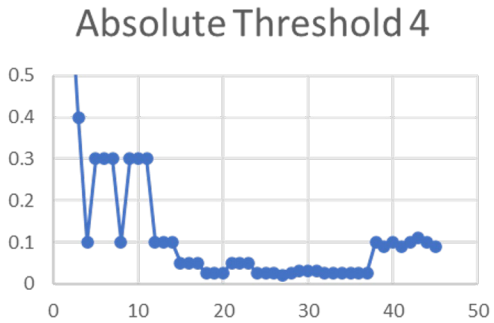
- **Staircase 3 down 1 up**
  - "Reversal" occurs when a decrease in signal level is followed by an increase (lower turning point) or an increase in signal level is followed by a decrease (upper turning point).
  - When two reverses occur, the step size changes.
  - Do up to 10 reverses to find the absolute threshold. The 8th reversal value is set as the threshold.

User study 1





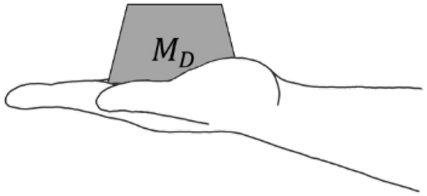


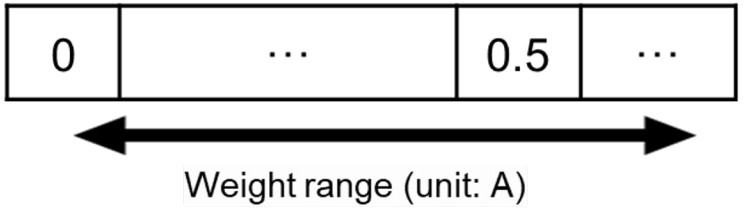


Absolute Threshold (unit: A)

No.1 : 0.15
No.2 : 0.053
No.3 : 0.4
No.4 : 0.1

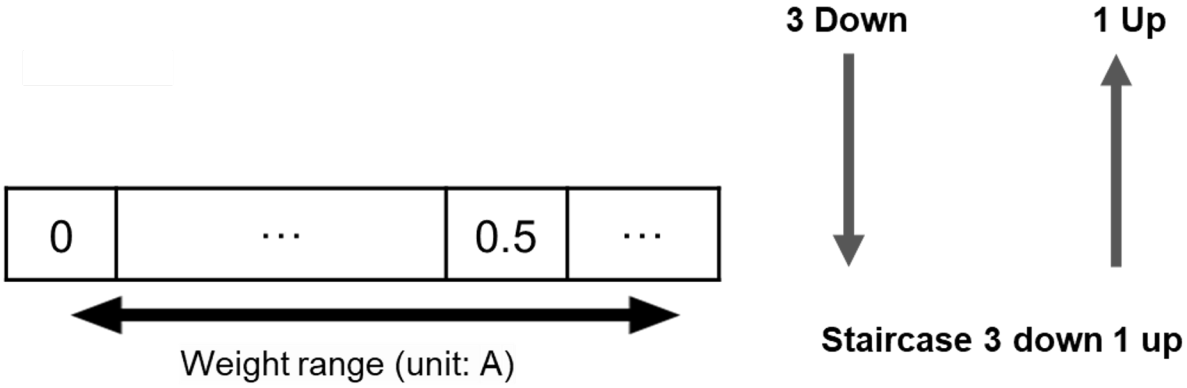
User study 2





- **Difference Threshold Of Weight**
  - Participants were asked to move while wearing the device. Participants responded whether they perceived the difference of forcefeedback or not, as compared to the previous value that the device presses on the palm.
  - If it can be distinguished from previous stimuli, they answered “Yes”, otherwise they answered “No”.

User study 2



- **Difference Threshold Of Weight**
  - In a three-down, one-up staircase (3D1U) the stimulus amplitude decreases after three correct responses and increases when one response was incorrect.
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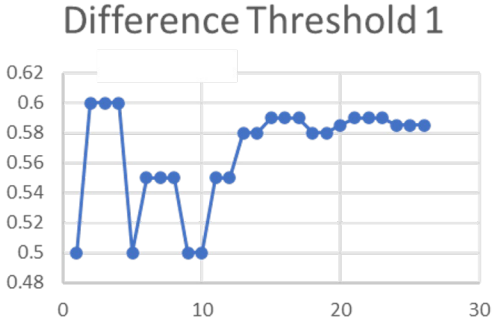
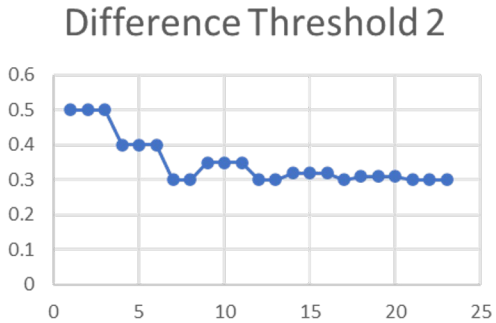
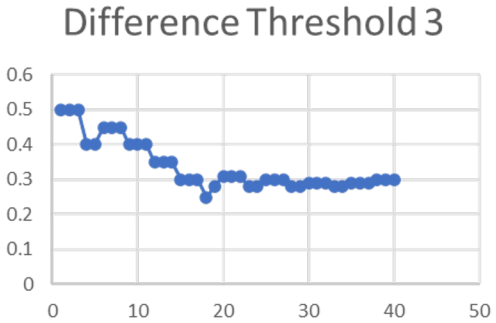
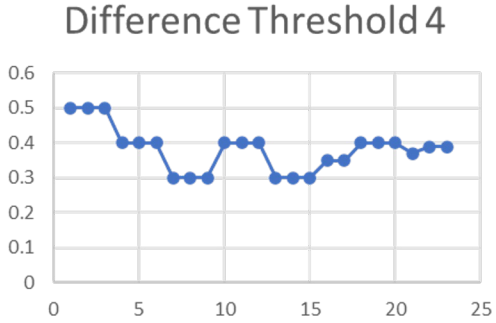
User study 2









Difference Threshold

No.1 : 0.585
No.2 : 0.3
No.3 : 0.28
No.4 : 0.37