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Encountered-Type Tabletop Haptic Display for Objects On-Demand in Virtual Environments

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Technical Aspects of Multimodal Systems

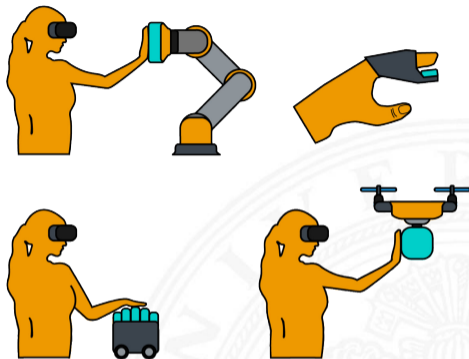
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Multimodal haptic feedback in VR:

- ▶ Visual
- ▶ Audio
- ▶ Vibration
- ▶ Flat surface
- ▶ Shape changing surface
- ▶ Single individual shape

What about augmented reality?



Variants of haptic feedback [2]

Main goal

Development of an Encountered-Type Haptic Display for Virtual and Augmented Reality, as well as other human-computer interaction scenarios.

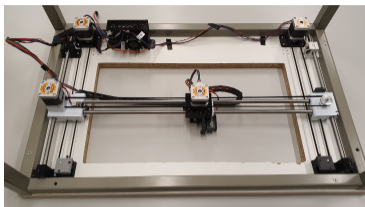
- ▶ The device should be inconspicuous
- ▶ Interaction with physical objects
- ▶ Arbitrary objects and shapes
- ▶ Haptic feedback on-demand within workspace



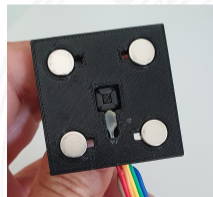
ETHD with VR

Encountered-Type Haptic Display - Hardware Design

- ▶ 4-DoF below tabletop
- ▶ 3-DoF of objects on top of the table
- ▶ Belt driven
- ▶ Controlled with Marlin and ROS
- ▶ Workspace: 47.2×26 cm
- ▶ Reliable speed of 66.6 cm/s
- ▶ Positioning accuracy of 0.5 mm with compensated friction



Hardware setup below the table



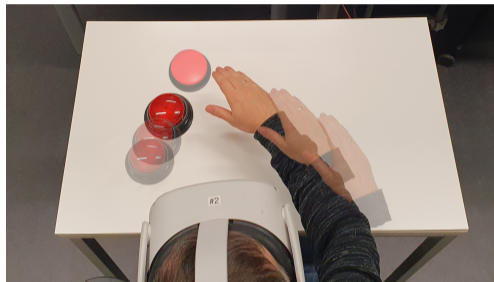
Hall sensors for friction compensation and object position detection

Research Question 1

At what moment can a virtual object be presented to the user to ensure it arrives at the target position before the user reaches it?

Research Question 2

Can our haptic display provide a satisfying user experience and usability?



User approaches virtual button



Setup:

- ▶ Meta Quest 2 (with Unity)
- ▶ Hand tracking by Oculus Integration SDK
- ▶ 15 virtual buttons substituted by 1 real one





Setup:

- ▶ Meta Quest 2 (with Unity)
- ▶ Hand tracking by Oculus Integration SDK
- ▶ 1 physical button and 15 virtual ones

User Study:

- ▶ "Whac-A-Mole"
- ▶ 100 presses (50 flat hand, 50 fingertip)
- ▶ Hands need to be returned to home pose between presses

Whack-A-Mole experiment

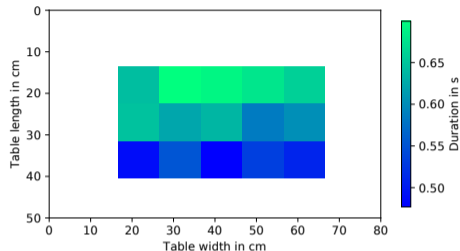


Results: Research Question 1 - Object positioning

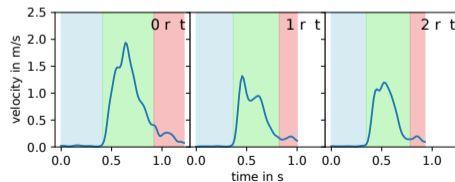
- ▶ 996 arm movements (759 right-, 237 left-handed, 503 fingertip, 493 flat hand)
- ▶ Quickest movements between **477 to 690 ms**
- ▶ Resulting in **31.7 to 45.9 cm** traveling distance (~half of the workspace)

	Tip	Flat	Overall
Latency phase	381 ms	389 ms	385 ms
Ballistic phase	440 ms	417 ms	429 ms
Correction phase	98 ms	42 ms	70 ms
Total	920 ms	848 ms	884 ms

Average Duration of Movement Phases



Minimum duration distribution



Movement velocity plots

User Experience (with User Experience Questionnaire - Short (UEQ-S) [4]):

- ▶ Pragmatic quality: $M = 1.917$ ($SD = 0.779$)
- ▶ Hedonic quality: $M = 1.354$ ($SD = 1.105$)

Usability (with System Usability Scale (SUS) [1])

- ▶ 84.167 ($SD = 9.673$)

Haptic Experience (matching between virtual and real button):

- ▶ Pressing behavior: 4.417 ($SD = 0.900$)
- ▶ Shape: 4.833 ($SD = 0.389$)
- ▶ Position: 4.167 ($SD = 0.937$)



- ▶ Build a 3-DoF ETHD
- ▶ Arbitrary shaped objects on-demand in VR
- ▶ Half of the workspace is on-demand accessible
- ▶ Positioning accuracy of 0.5 mm
- ▶ Good user experience and usability

Future Work:

- ▶ Increase on-demand region with hand redirection
- ▶ Rehabilitation
- ▶ Collision detection
- ▶ Shape reconstruction





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Thank you for your attention!

Any questions?

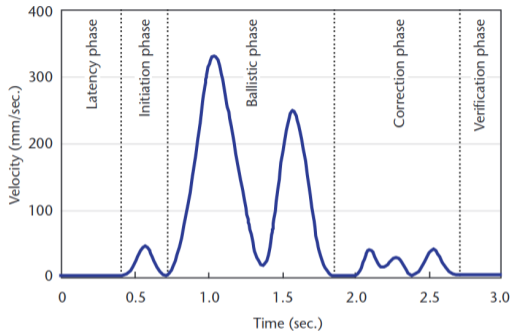




- [1] Aaron Bangor, Philip T. Kortum, and James T. Miller. An Empirical Evaluation of the System Usability Scale. *International Journal of Human–Computer Interaction*, 24:574 – 594, 2008.
- [2] Víctor Rodrigo Mercado, Maud Marchal, and Anatole Lécuyer. “haptics on-demand”: A survey on encountered-type haptic displays. *IEEE Transactions on Haptics*, 14(3):449–464, 2021.
- [3] Karin Nieuwenhuizen, Lei Liu, Robert van Liere, and Jean-Bernard Martens. Insights from dividing 3d goal-directed movements into meaningful phases. *IEEE computer graphics and applications*, 29(6):44–53, 2009.
- [4] Martin Schrepp, Andreas Hinderks, and Jörg Thomaschewski. Design and Evaluation of a Short Version of the User Experience Questionnaire (UEQ-S). *International Journal of Interactive Multimedia and Artificial Intelligence*, 4 (6), 103-108., 2017.

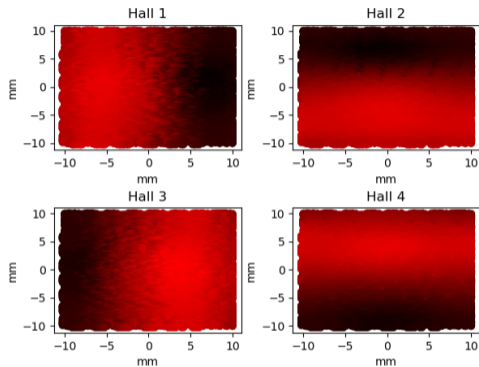
Movement Phases [3]

1. **Latency phase:** between start of the task and start of the movement
2. **Initiation phase:** small motions before the ballistic phase
3. **Ballistic phase:** a faster movement to reach the target (>75 % of the full motion)
4. **Correction phase:** a slower movement to correct unintended errors
5. **Verification phase:** between the end of the motion and the end of the task



A velocity profile of a goal-directed movement. [3]

Position tracking



Collected samples for position tracking





The user study took around half an hour over all, with approximately 10 minutes in VR
Participants:

- ▶ 12 participants
- ▶ 9 male, 2 female, and 1 not disclosed
- ▶ 10 between 25 and 34 years, 1 between 35 and 44, and one between 55 and 64
- ▶ One uses VR once a week, the rest once a quarter or less
- ▶ Only participants without any visual impairments

