A visually realistic grasping system for object manipulation and interaction in virtual reality environments

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Introduction

A visually realistic, flexible and robust grasping system for real-time interaction in Virtual Reality environments

- VR objects extracted from the YCB dataset [Çalli 2017].
- Hands are controlled using handheld devices (e.g. Oculus Touch).
- Implemented in Unreal Engine 4.
- Qualitative analysis:
  - motor control.
  - finger movement realism.
  - interaction realism.
- Quantitative analysis:
  - novel metric quantifying hand-object overlapping.
  - time needed to grasp each object.

Motivation

- Lack of realism of existing interactions in VR applications using handheld controllers.
    - Distance-based grasping.
    - Predefined grasp animations.
- Lack of open-source approaches.
- Extract data from visually realistic interactions with everyday objects.

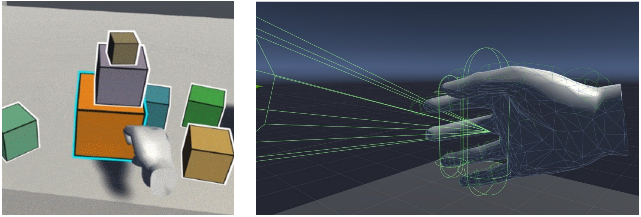


Figure: Distance grab example from Oculus Sample Framework [ocu]

Grasping System

The essence of our grasping system is how the hand is automatically fitted to the object shape. Our methodology consists of two main stages:

- Virtual hand configuration:
    - Choose the grasp animation according to a grasp taxonomy proposed by Feix et al. [Feix 2016].
    - Experimentally place the capsule triggers on the phalanges.
- Grasping pipeline design and implementation.

Grasping System- vr hand configuration

Choose the grasp animation

- We analyzed 33 different grasp types from the taxonomy.
- The cylindrical grasp:
  - Power grasp.
  - Palm opposition.

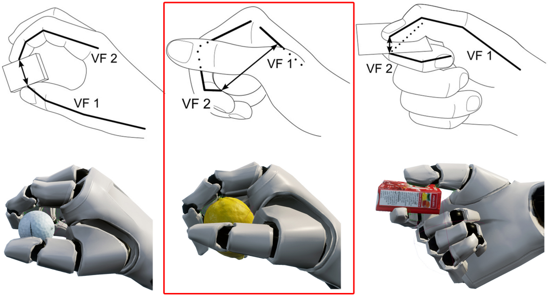


Figure: From left to right: pad, palm and side opposition.

Triggers placement

- Progressively increase the number of capsules maintaining performance.
- Interact with small and different shaped objects using capsules only on the distal phalanges.
  - Slippery behavior because of the collision with middle phalanges.
  - **Solution:** put capsule triggers on the middle phalanges.
- Put a sphere trigger on the hand palm to enable palm opposition.

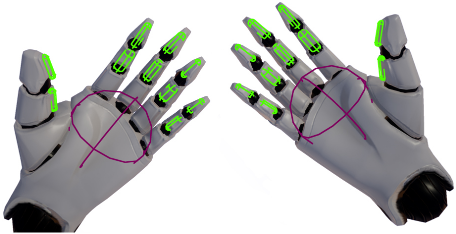
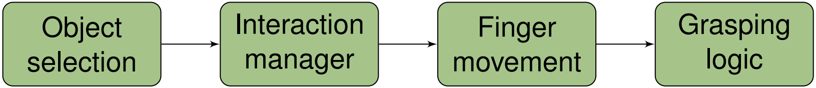


Figure: In green, capsule triggers of the middle and distal phalanges. In purple, sphere triggers used to detect the nearest object the the hand palm.



- Object selection:
  - selects the nearest object to the hand palm.
- Interaction manager:
  - manages the capsule triggers placed on finger phalanges.
  - determines phalanx state (blocked/released).
- Finger movement:
  - controls individual finger movement during interaction.
- Grasping logic:
  - decides when to grab or release an object.

Performance analysis

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A qualitative evaluation:

- based on: user experience interaction in a photorealistic environment.
- to assess: interaction realism, immersion, hand movement naturalness, etc.

A novel quantitative evaluation:

- novel error metric.
- time needed to grasp the objects.

Two groups of users: experienced and inexperienced.

Performance analysis- dataset

(a)

(b)

(c)

(d)

(e)

(f)

(g)

(h)

(i)

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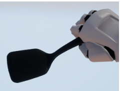


(u)

Performance analysis- dataset

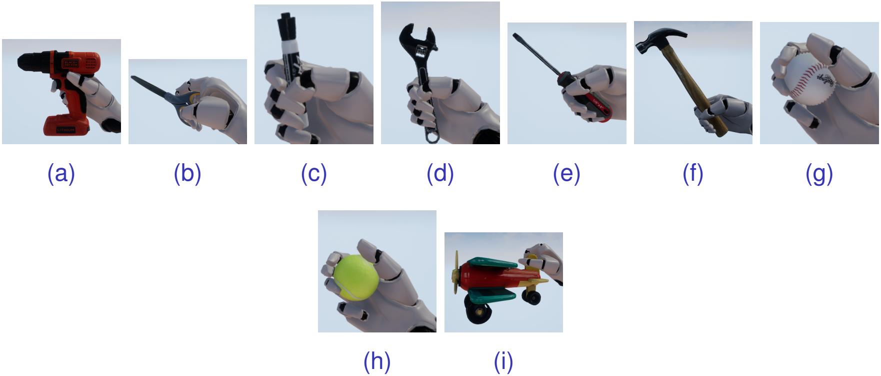


Figure: Grasping performed on objects from the YCB dataset.

Performance analysis- qualitative

ID	Question
	Aspect 1: Motor Control
Q1	I felt like I could control the virtual hands as if it were my own hands
Q2	The movements of the virtual hands were caused by my movements
Q3	I felt as if the movements of the virtual hands were influencing my own movements
Q4	I felt as if the virtual hands were moving by themselves
	Aspect 2: Finger Movement Realism
Q5	It seemed that finger movements were smooth and plausible
Q6	I felt fingers open and close in a natural way
Q7	Fingers react adequately to my intentions
	Aspect 3: Interaction Realism
Q8	I felt like I could grab objects wherever I wanted to
Q9	It seemed as if the virtual fingers were mine when grabbing an object
Q10	I felt that grabbing objects was clumsy and hard to achieve
Q11	It seemed as if finger movement were guided and unnatural
Q12	I felt that grasps were visually correct and natural
Q13	I felt that grasps were physically correct and natural
Q14	It seemed that fingers were adapting properly to the different geometries

Table: User evaluation questionnaire.

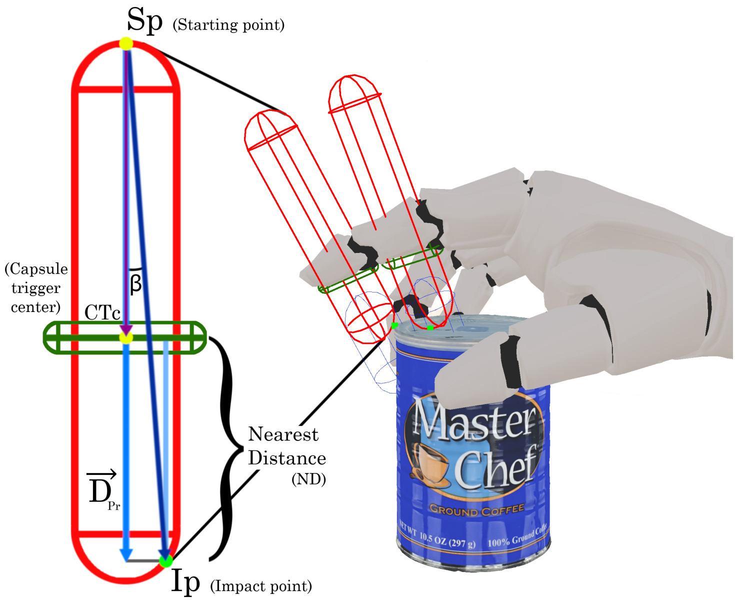
Performance analysis- qualitative

	Score	
Evaluation Aspects	Experienced users	Inexperienced users
(1) Motor Control	1.85	2.34
(2) Finger Movement Realism	2.33	2.51
(3) Interaction Realism	1.84	1.95
Embodiment score	1.97	2.19

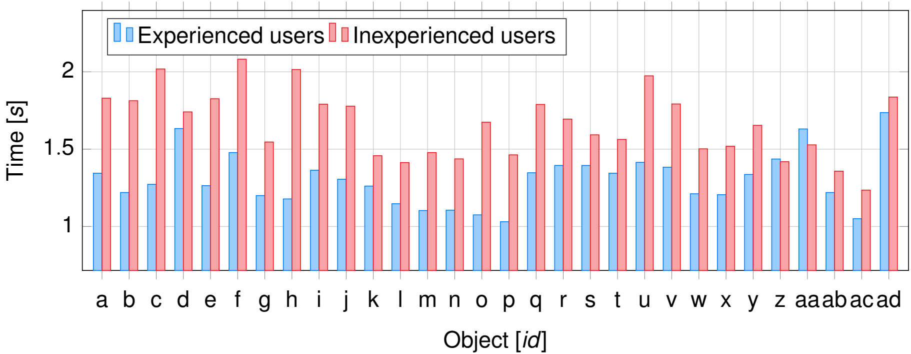
Table: Score for each qualitative aspect of the evaluation and group of participants.

- 7-point Likert-scale [-3,3].
- Average result of 2.08.

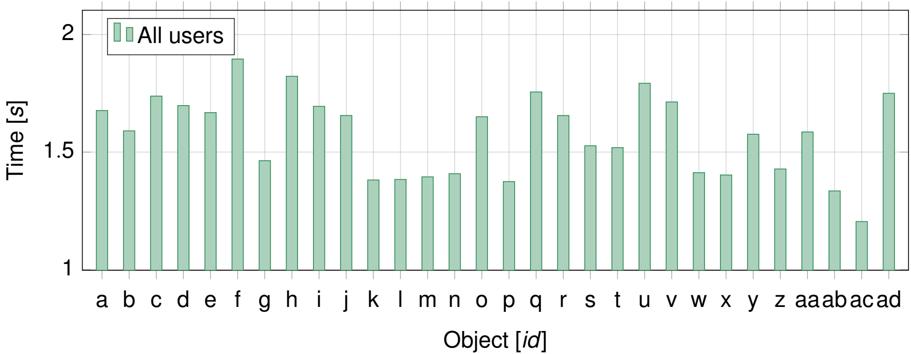
Performance analysis- quantitative



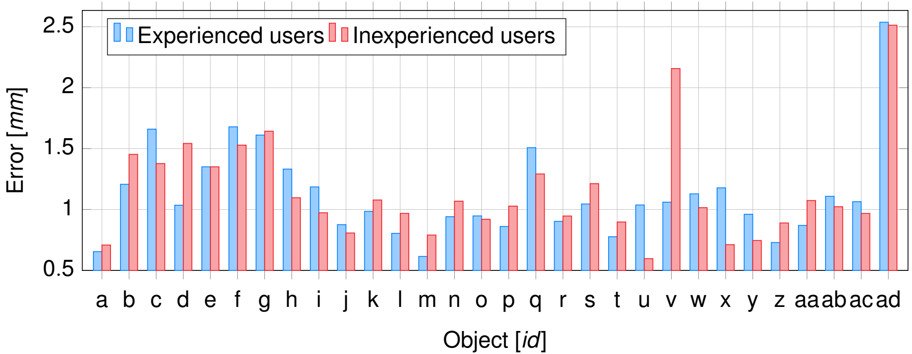
Performance analysis- quantitative



- Inexperienced users have taken longer to grasp the objects.
- More time is needed because of random spawn.

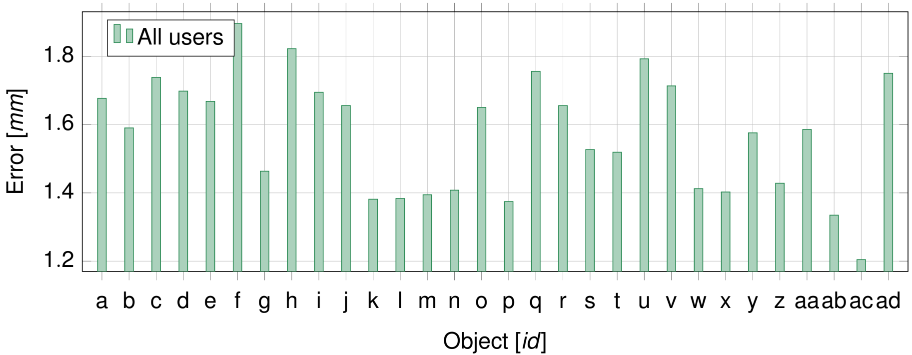


- Larger objects are more time consuming.
- Less time is needed as the user gains experience.



- Similar results regardless of previous VR experience.
- Most differences: power drill (u) and spatula (v).

Performance analysis- quantitative



- Large objects are the most error-prone.
- Overall error is decreasing progressively.

Applications

- Robotics: human-robot knowledge transfer.
- Rehabilitation: patients with hand motor difficulties.
- Data generation.

Limitations and future works

- Single animation for hand closing.
- Cannot grasp one object with both hands at the same time.
- Interaction with large objects require VR skills.

- We proposed a grasping system for interaction in VR where hand is automatically fitted to the object geometry.
- We analyzed our proposal both qualitatively and quantitatively.
- For the quantitative evaluation we proposed a novel metric quantifying the hand-object overlapping at the distal and middle phalanges.
- Performance analysis results indicate that previous experience with our grasping system is not a prerequisite for an enjoyable VR interaction experience.

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- Berk Çalli, Arjun Singh, James Bruce, Aaron Walsman, Kurt Konolige, Siddhartha S. Srinivasa, Pieter Abbeel et Aaron M. Dollar.
  Yale-CMU-Berkeley dataset for robotic manipulation research.
  I. J. Robotics Res., vol. 36, pages 261–268, 2017.
- Thomas Feix, Javier Romero, Heinz-Bodo Schmiedmayer, Aaron M Dollar et Danica Kragic.
  The grasp taxonomy of human grasp types.
  IEEE Transactions on Human-Machine Systems, vol. 46, no. 1, pages 66–77, 2016.
- *Distance Grab Sample Now Available in Oculus Unity Sample Framework*, Septembre.

Grasping logic

$$f(th_{ph}, in_{ph}, mi_{ph}, palm) = \begin{cases} true, & \text{if } (th_{ph} \lor palm) \\ & \land (in_{ph} \lor mi_{ph}) \\ false, & \text{otherwise} \end{cases} \tag{1}$$

, where th_{ph}, in_{ph}, and mi_{ph} are defined as

$$\begin{aligned} th_{ph} &= thumb_{mid} \lor thumb_{dist} \\ in_{ph} &= index_{mid} \lor index_{dist} \\ mi_{ph} &= middle_{mid} \lor middle_{dist} \end{aligned} \tag{2}$$

$$\begin{aligned}\text{Motor Control} &= ((Q1+Q2)-(Q3+Q4))/4 \\ \text{Finger Movement Realism} &= (Q5+Q6+Q7)/3 \\ \text{Interaction Realism} &= ((Q8+Q9)-(Q10+Q11) \\ &\quad +Q12+Q13+Q14)/7\end{aligned} \tag{3}$$

, using the results of each individual aspect, we obtain the total embodiment score as follows:

$$\begin{aligned}\text{Score} = (&\text{Motor Control} + \text{Finger Movement Realism} \\ &+ \text{Interaction Realism} * 2)/4\end{aligned} \tag{4}$$