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Wen-Jie Tseng
LTCI, Télécom Paris,
Institut Polytechnique de Paris
Paris, France
wen-jie.tseng@telecom-paris.fr

Samuel Huron
SES, CNRS i3, Télécom Paris,
Institut Polytechnique de Paris
Paris, France
samuel.huron@telecom-paristech.fr

Eric Lecolinet
LTCI, Télécom Paris,
Institut Polytechnique de Paris
Paris, France
eric.lecolinet@telecom-paris.fr

Jan Gugenheimer
LTCI, Télécom Paris,
Institut Polytechnique de Paris
Paris, France
jan.gugenheimer@telecom-paris.fr

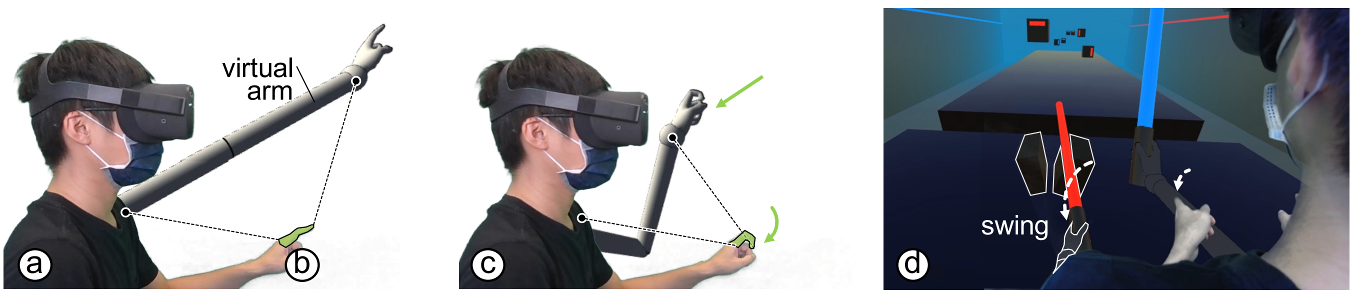

Figure 1: (a) Using VR in a confined space (e.g., commuting on a bus) with large gestures would cause obstructions. We present FingerMapper, a mapping technique leveraging (b) small and less physically demanding motions of fingers to control (c) VR arm interaction. (d) FingerMapper allows for larger swinging motions as shown in a slicing style game.

ABSTRACT

As Virtual Reality (VR) headsets become more mobile, people can interact in public spaces with applications often requiring large arm movements. However, using these open gestures is often uncomfortable and sometimes impossible in confined and public spaces (e.g., commuting in a bus). We present FingerMapper, a mapping technique that maps small and energy-efficient finger motions onto virtual arms so that users have less physical motions while maintaining presence and partially virtual body ownership. FingerMapper works as an alternative function while the environment is not allowed for full arm interaction and enables users to interact inside a small physical, but larger virtual space. We present one example application, FingerSaber that allows the user to perform the large arm swinging movement using FingerMapper.

CCS CONCEPTS

• **Human-centered computing** → **Virtual reality**.

KEYWORDS

Finger Mapping; Virtual Reality; Confined Space

ACM Reference Format:
Wen-Jie Tseng, Samuel Huron, Eric Lecolinet, and Jan Gugenheimer. 2021. FingerMapper: Enabling Arm Interaction in Confined Spaces for Virtual Reality through Finger Mappings. In *CHI Conference on Human Factors in Computing Systems Extended Abstracts (CHI '21 Extended Abstracts), May 8–13, 2021, Yokohama, Japan.* ACM, New York, NY, USA, 4 pages. https://doi.org/10.1145/3411763.3451573

1 INTRODUCTION

Current Virtual Reality (VR) interaction techniques are often based on an almost one-to-one mapping between the physical and virtual motion because it allows users to easily understand the correspondence between translations and rotations on the input device [14]. Although one-to-one mapping in VR is easy to comprehend and enables a form of natural interaction and embodiment, it also requires enough space to be able to perform these wide motions [9].

As VR Head-Mounted Displays (HMDs) are getting more mobile (e.g., Oculus Quest[1]), users are now able to immerse themselves wherever they wish. However, these new applications often happen inside of public and sometimes even confined spaces [5] such as planes [16], cars [6] and other means of transportation [10]. Using wide and open gestures is often times undesirable in these environments since users could accidentally hit bystanders or do not even have enough space for interaction (e.g., seat inside a bus).

Prior work has started to explore these scenarios, focusing on reducing motion, fatigue, and overall improving ergonomics of VR interaction. For instance, redirecting the user's arm to a comfortable resting position during overhead interaction [3], reducing the physical path length and fatigue by manipulating the visual location of targets in VR [11], and creating an offset to the user's virtual hand [15]. One of the big challenges for all these approaches is trying to not negatively impact the overall user experience or reduce the level of functionality the interaction provides.

We propose *FingerMapper* (Figure 1a), a finger mapping technique that maps small energy-efficient finger motions (Figure 1bc) onto large scale virtual arm motions, enabling embodied VR interaction in public and confined spaces. Our approach enables hand and arm interaction in VR with less physical motions while maintaining presence and partially virtual body ownership (VBO). FingerMapper is grounded in homuncular flexibility [17] that shows users could learn to control an avatar body that changes the relationship between tracked and rendered motion in VR. Recent research has investigated body re-association [7] and found that re-associating body parts with visuomotor synchrony can still induce VBO in VR.

Our goal with FingerMapper is not to create a novel interaction technique for a specific application but to actually present an alternative way to generate input stimuli for arm-based interactions that can be used across all current application relying on full scale hand-tracking. Our envisioned scenario is that users can switch to FingerMapper as they find out the environment is constrained and not allowed for large motions. *"A user started playing BeatSaber in their home but had to meet a friend. On the bus, the user still wanted to continue their game and started another session while seated in a confined public space. On the system level, the user changed the tracking boundaries to be stationary and also selected to have 'confined' input. The VR HMD was now applying the FingerMapper to map the user's hand to the virtual arm in the game."* Here, FingerMapper is not yet another interaction technique that has to be implemented to every application, but an abstract mapping that can be applied to any application working with hand tracking.

In the following sections, we present the related work and introduce a mapping metaphor (Attach) to map the users' fingers and the virtual arms. Next, we demonstrate an application (FingerSaber, Figure 1d) to show FingerMapper can support large swinging motions in a smaller physical space. Finally, we discuss the potential scenarios of using FingerMapper as a situational alternative for the regular input techniques such as hand tracking and ray-casting.

2 RELATED WORK

VR interaction requires selection and manipulation. Although the human hand has a direct metaphor for interacting with objects, the reaching distance is limited to our length of the arm. Prior work has proposed the arm-extension technique [13] to extend the virtual arm while preserving the manipulation. Frees et al. [4] introduce PRISM technique that allows for switching between coarse reaching and fine manipulation by computing an offset based on the user's hand speed dynamically. However, these techniques did not consider preserving VBO in the design.

Besides the extension of the arm, another line of previous works improves the ergonomics of VR interaction by exploiting visual dominance over proprioceptive cues [1]. By controlling the visual content, these techniques can redirect the user's arm motions [3, 11] to reduce the physical path length and fatigue while preserving the VR experience (e.g., VBO). Other approaches create an offset for 3D selection in VR [8, 15] to the range of the user's maximum arm reach, where users can reach at a further distance with less movement but does not break the VR experience.

FingerMapper is inspired by these approaches but differs on three essential premises: 1) Most of the prior techniques tried to extend the existing arm span in the real world further to reach more in VR. However, FingerMapper allows user to conduct small finger motions for mapping more physically demanding interactions within the maximum arm's reach of a human; 2) FingerMapper was designed to imitate tracked arm and hand interaction in VR (no controller input as in [15]); 3) FingerMapper aims to be a situational alternative to techniques such as full arm tracking or ray-casting without changing the interaction paradigm. Therefore, the technique is designed to work across different types of environments and interaction styles without having to actually change or adapt the virtual experience to input.

3 FINGERMAPPER IMPLEMENTATION

Attach Mapping. We introduce Attach mapping that maps finger motions to virtual arms. The Attach mapping design is based on homuncular flexibility and the idea that humans are flexible at learning a different relationship between tracked and rendered motion [17]. We see the virtual wrist position as a point within the user's maximum arm reach. The maximum arm reach is represented by a sphere that has an origin (P_s) at the shoulder and a radius of the user's arm length (Figure 2a). To determine the virtual position of the wrist, we cast a ray from the metacarpophalangeal (MCP) joint on the index finger and along the direction of proximal phalanx (i.e., the segment from the MCP joint to the proximal interphalangeal (PIP) joint) hitting a point on the sphere (P_c in Figure 2a). We choose the proximal phalanx since it is less intervened when bending the finger inwards. Users can either move their proximal phalanx of the index finger or rotate their wrist to cast their virtual wrist on the surface of the maximum arm reach.

The arm is fully stretched when using a pointing gesture (Figure 2a). To reach positions inside the maximum arm reach sphere, we retract the virtual wrist along the direction between the casting point and shoulder by computing the retraction fraction r. This r is the distance between the fingertip and the MCP joint (d) divided by the length of the index finger, and ranges from 0.15 to 1. The distance decreases as the user bends the finger inwards, and the virtual wrist retracts closer to the shoulder (Figure 2bc). Therefore, the position of the virtual wrist (P_w) is computed as retraction

[1] Oculus Quest

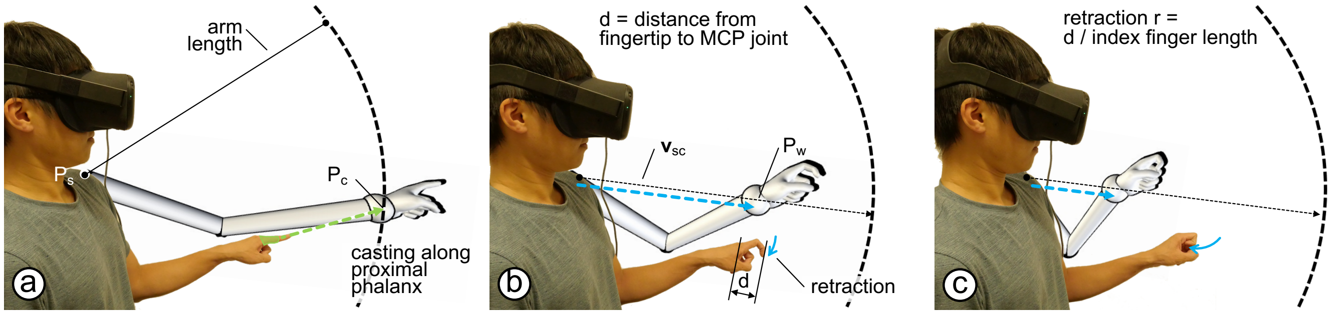

Figure 2: (a) *Attach* casts a ray along the proximal phalanx to a sphere with the user's arm length attached on the shoulder. (b)(c) When user bends their index finger, we compute retraction fraction with d to retract the virtual wrist towards the shoulder.

amount multiplies by the arm length and the unit vector from the shoulder position to the casting point, as shown in equation 1. The rotation of the virtual upper and lower arms are calculated by solving inverse kinematics using P_w as the target. We apply the 1€ Filter [2] to the smoothen the virtual arm movement.

$$P_w = P_s + r \cdot l_{arm} \cdot \hat{\mathbf{v}}_{cs}, \text{where } r \text{ is } 0.15 < r < 1 \text{ and } \mathbf{v}_{sc} = P_c - P_s \quad (1)$$

Hand Motion. In an early prototype we experimented with a rigid hand model as the virtual hand that either points or grabs. However, this static representation felt more awkward since simple finger motions that the user performed were not transferred to the virtual arm. To increase some form of VBO and agency we attached and map the tracking information of the physical fingers to the virtual fingers of the arm. This allows users to not only position the virtual arm in space but also to have more precise finger interactions at this new location and also perform simple manipulations.

Selection. FingerMapper partially impedes the ability to grab or pickup objects since bending index finger additionally bends the virtual arm. To overcome this limitation, we added a selection functionality based on a certain hand gesture. For example, moving thumb to touch the knuckle of middle finger, similar to a button click. The selection is triggered as the thumb fingertip contacts the middle finger knuckle and supports holding an object in VR.

Spatial Extension. With Attach mapping, the user can use their fingers to control the virtual arm movements in six directions within the maximum arm's reach. However, when moving the physical hand forward or backward, there is no corresponded spatial movement on the virtual wrist. We develop a spatial offset function that changes virtual arm length when the user moves the physical hand forward or backward. This extension outside of the comfortable interaction position of the user seems initially counter intuitive to our goal of reducing motions. Still, we found that not including this spatial movement leads to a heavy break of agency and control over the virtual arm in early experiments.

The extension refers to the Go-Go technique [13] to compute the spatial offset for Attach mapping. Figure 3a shows the default posture that the user takes a sitting position and fixes their elbows to both lateral sides of the waist. We use the default posture to simulate using VR in a confined and restricted interaction space. The sitting

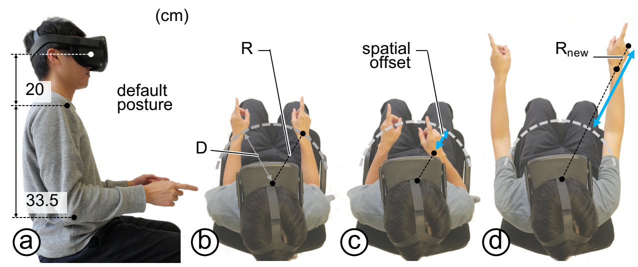

Figure 3: (a) The default posture of FingerMapper. (b) R is the projected hand-to-chest distance, and D is the default distance for calculating spatial offset. (c) When user moves their hands in the range of D, we reduce the virtual arm length by the spatial offset (the blue line). (d) Otherwise, we extend R to R_{new} through our extension function and increase the virtual arm length.

shoulder height is 20 cm below the eye and the sitting elbow height is 33.5 cm below shoulder, approximated using the average body dimensions [12]. The chest position is 36.75 cm below the HMD. We define the chest height at the middle between sitting shoulder and elbow height. For a next step, we calculate the projected distance from the physical wrist to the chest (R), as shown in Figure 3b. This distance is projected onto the plane that always has its normal vector pointing upwards from the user's head since we need the forward and backward spatial offset. The projected distance of default posture (D) is the criterion for computing spatial offset, which set as 18 cm through our first experimentation.

$$R_{new} = \begin{cases} R & \text{if R < D} \\ R + k(R-D)^2 & \text{otherwise} \end{cases}, \; k = 0.6 \quad (2)$$

As shown in Figure 3c, when user's hand is within the range of D, The spatial offset is $D - R$. As user extends their hand out of the range of D (Figure 3d), we compute R_{new} using Go-Go function shown in equation 2. The spatial offset then becomes $R_{new} - D$. The offset is added to the radius of the shoulder sphere of Attach.

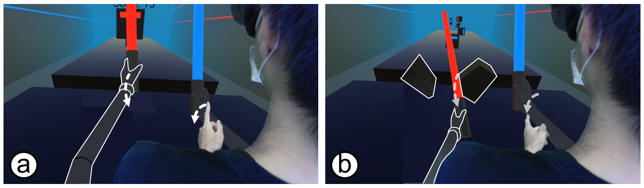

Figure 4: (a) We use Attach mapping to control the virtual arm holding a saber to do swing motions. (b) User has to slice cubes in the correct direction and corresponding color.

Therefore, the user can perceive the arm extended or shorten when they move their hand forward and backward.

Hardware Requirement. FingerMapper requires six-degree-of-freedom tracking on the wrist, joints, and fingertips of the hand. Our current prototype uses Oculus Quest hand tracking to acquire the necessary position and rotation data from both hands. However, the concept is also compatible with other VR systems providing similar hand tracking data.

4 DEMO APPLICATION: FINGERSABER

FingerSaber is inspired by the VR rhythm game, Beat Saber[2] but using fingers to do the swing interaction (Figure 4a). The main concept of Beat Saber is that differently colored cubes are flying towards the user following a certain beat. The goal of the user is to slice every block in a certain direction (indicated on the blocks). The original concept of Beat Saber revolves around having a full body experience, in which players are using wide arm motions and sometimes even move their whole bodies to the beat. To enable FingerSaber to work with the concept we implemented Attach mapping and positioned two virtual lightsabers inside user's hand. Since no trigger is needed we kept the lightsabers constantly attached to the user's hand without using a grabbing motion.

When interacting with the game, we observed that certain actions (e.g., slicing a cube on the right with the right finger) were more difficult then expected. While in Beat Saber a user would position the body accordingly by raising the elbow and rotate the hand, in FingerSaber the same motion is more uncomfortable due to the degrees of freedom of the hand and wrist. Nevertheless, FingerMapper enables the Beat Saber experience to work using small finger motions instead of large arm motions, without having to alter the game mechanics.

5 CONCLUSION

We presented FingerMapper, a mapping technique that allows users to control arm and hand interactions inside VR using small finger motions. We show one scenario FingerSaber that allows for large slicing motions. FingerMapper can also enable other application scenarios (e.g., locomotion, selection). We implement Attach mapping grounded in a combination of ray casting and hand tracking, allowing users to have hand-based interaction with less physical motion in a confined space. FingerMapper is an situational alternative to hand tracking (if the user interacts inside a confined space) and ray-casting (if the user needs more functionality and expression).

[2]Beat Saber

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