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Impact Sensation Presentation Based on Pseudo-Haptic Approach in VR

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I. INTRODUCTION

With the rapid development of virtual reality (VR), numerous methods have been proposed that integrate multiple sensory modalities-vision, audition, and touch-to deliver immersive, realistic experiences in which users feel as though they are truly interacting with and exerting forces on virtual objects. Grounded in the framework of pseudo-haptics, the present study proposes a system that deliberately introduces temporal mismatches between visual and haptic cues to elicit the perception of high-intensity impact (e.g., sensation of punching).

A representative prior work on impact reproduction is Impacto by Lopes et al. [1], which emphasized perceived mass and realism by combining visual information with tactile stimuli. In that system, striking sensations were recreated by blending electrical muscle stimulation (EMS) with solenoid tapping.

Within pseudo-haptics research, many techniques intentionally disrupted the temporal or spatial consistency among visual, motor, and haptic signals to evoke impressions such as texture or resistance. For example, Watanabe et al. [2] showed that altering the velocity of a moving object when a user-controlled cursor visually contacts it produces a pseudo-collision sensation, resembling the sense of friction or sense of resistance. The phenomenon is induced not by manipulating the cursor itself but by adjusting background or target motion, underscoring the importance of dynamic visual change in cross-modal perceptual integration.

Building on these insights, we focus on a punching action in VR and propose a method that induces a vivid sense of impact by manipulating the timing of (i) the avatar's visual reaction and (ii) force feedback delivered to the user's forearm.

II. APPROACH

The goal is to generate a sense of impact through a pseudo-haptic approach. Following Watanabe et al. [2], that achieved impressions of resistance and mass by modifying the mapping between movement input (force application) and visual output (object motion), we adopt a slow–fast visual manipulation. While the user applies force, the object (here, the avatar) is first shown moving extremely slowly; this visual slowdown is then followed by a rapid motion, creating a perceptual impression of reactive force (i.e., impact).

This approach is also inspired by a cinematic technique long used in film and animation: briefly switching to slow motion at the moment of impact and then returning to real time to highlight the force of the blow.

III. SYSTEM

The system developed in this study is designed to integrally control visual feedback linked to the avatar's motion, and haptic feedback delivered to the user's upper forearm.

The system is constructed by linking Unity, Cycling '74 Max, and TouchDesigner, and each module is connected by UDP and serial communication. When the user performs a straight punch inside the VR space, contact with the avatar is detected, and a signal is sent to control the motors of the haptic device. The presentation timing of the visual feedback (avatar being blown away) and the haptic feedback (device activation) is designed so that the timing of both visual and haptic feedback presentations can be precisely synchronized and managed within Unity.

As hardware, we adopted a head-mounted display (HMD) Meta Quest 3 and the force-presentation device FEEL TECH Wear [3]. Using the hand-tracking function of Meta Quest 3, the user's punch was visualized. FEEL TECH Wear is composed of a four-channel rotary skin-stretch tactor, and by attaching it to the user's forearm (over the bulk of the forearm's flexor and extensor muscle groups) and twisting the skin at a fixed angle of 90 degrees (shear stimulation), it can present a preset intensity of force sensation (the feeling that force is applied, tightening, and muscles are compressed). This was used as substitute stimulation for the force that would act on the forearm during a straight punch. The appearance of the force-presentation device is shown in Fig. 1.

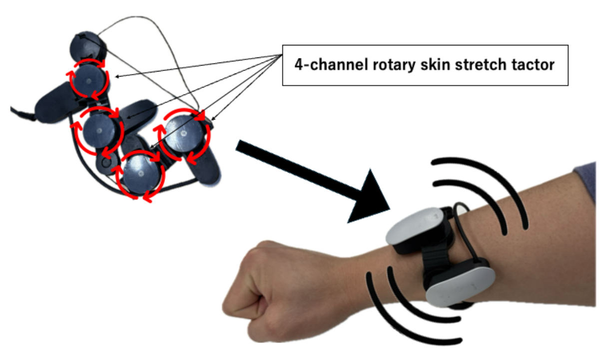

Fig. 1. The device that twists the skin to apply shear stimulation

IV. USER EXPERIENCE PROTOTYPE

As a proof of concept, we implemented the following user experience prototype. The parameters were determined

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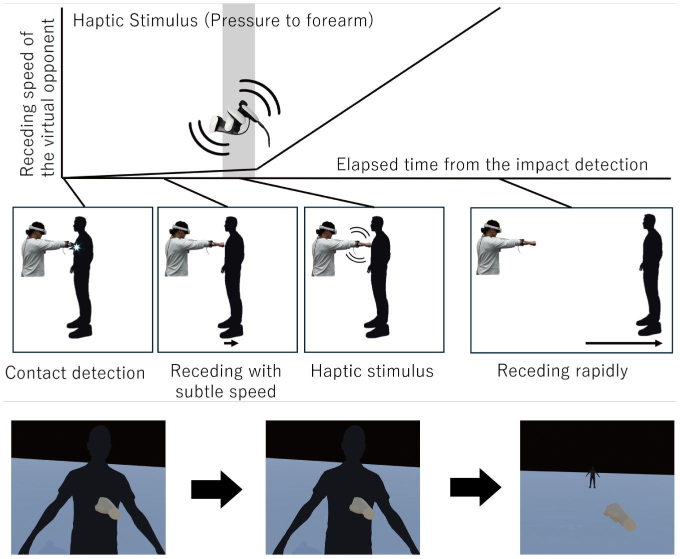

Fig. 2. Overview of the experience. (Top) Timeline of the visual change (receding speed of the oponent) and the haptic stimulus are illustrated. The timing of haptic stimulus varies within the "slow-motion" duration (SL). In this illustration, haptics stimuli is presented at the end of the slow-motion period. (Bottom) The sequence of subjective view

through trial and error during the system's preliminary development phase.

1) The participant stands and wears the HMD and the haptic device.
2) The participant throws a straight punch at a full-body black humanoid avatar positioned directly in front.
3) The system delivers a simulated sensation of impact.

To explore the illusion of resistance produced by the proposed method, we employed an avatar animation that, when presented without any delay or haptic feedback, evokes little-if any-sense of resistance or mass. Throughout the animation, the avatar's posture remained unchanged, creating the impression that the avatar with no mass was gliding across an ice surface with minimal friction between its soles and the ground.Upon contact, the avatar first moved back 0.1 m during slow-motion duration (SL), then 10 m backward at 10 m/s. Shear stimulation (Rotational skin-stretch) duration to the forearm was presented 0.2 s, which was fixed in whole pilot study. We varied SL and the timing of stimulus onset within SL to investigate individual differences in optimal timing. During the development, we identified that SL more than 0.6 msec significantly decrease the causality between the punch and the avatar movement, so in the exploration we set the limit to 0.6 msec. The delayed conditions were also compared to a condition where stimulation was presented immediately upon impact. The shear angle was fixed at 90°, and stimulus intensity remained constant across all conditions (Fig. 2). We varied SL and the stimulus-onset timing within SL to investigate individual differences in optimal timing. During development, we found that an SL longer than 0.6 s markedly reduced the perceived causality between the punch and the avatar's reaction; therefore, in subsequent exploration we limited SL to a maximum of 0.6 s. The delayed-onset conditions were also compared with a condition in which stimulation was delivered immediately upon impact. The shear angle was fixed at 90°, and stimulus intensity remained constant across all conditions (Fig. 2).

V. Conclusion and Future Work

In this study, we aimed to elicit a sense of impact by manipulating the timing of an avatar's visual reaction and shear-type haptic feedback applied to the user's forearm in response to a punching motion.

Preliminary trials, based on the experience described in the previous section, revealed that participants generally perceived an illusion of resistance. However, the preferred slow-motion duration (SL) and the timing of the haptic stimulus that maximized the sense of resistance varied across individuals. Some participants also reported that haptic stimulation presented without delay at the moment of contact felt more natural. These individual differences are likely attributable to perceptual characteristics and contextual factors such as expectations about impact strength and appropriate avatar reaction speed. For example, participants familiar with fighting video games regarded the visual delay as natural because similar effects are widely used in games.

Future work will focus on refining the avatar's visual expression, diversifying haptic intensities and presentation patterns, and expanding the stimulation areas, with the goal of developing a more versatile and broadly applicable method for delivering impact sensations. In the present study, we deliberately chose an avatar animation that, on its own, rarely evokes a feeling of resistance in order to isolate the effect of the proposed method. Naturally, we expect cross-modal enhancement-more realistic avatar animation should further strengthen the illusion of resistance. Likewise, no haptic stimulus was applied to the participant's knuckle so that we could isolate the contribution of the forearm shear cue, even though knuckle feedback is normally essential for conveying impact. To enrich the presentation of impact sensations, we plan to integrate additional haptic modalities such as electrical muscle stimulation (EMS), solenoid tapping, and vibration, as proposed in prior research.

Through this work, we aim to establish a method that supports force-sensation presentation, thereby contributing to the foundational technologies for haptic interaction in VR.

References

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