Diminished Effects of Overlay Projection of One's Own Body Parts on Embodiment in a Virtual Environment

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***Abstract*—In virtual reality (VR) systems, particularly in practical applications such as simulators, enhancing embodiment in the virtual space is crucial. This study examines a VR application in which users experience flying on a drone. In this setup, the operator's hands and arms were overlaid onto the virtual environment using the built-in function of a commercial head-mounted display. We investigated how the visibility of one's own hands in VR affects the sense of self-location and agency. Additionally, we examined the impact of the clarity of the projected hands. We expected that the appearance of the operator's actual hands would enhance the embodiment felt in the VR simulator; however, our experiment involving ten participants did not exhibit substantial effects of the seen body parts on the embodiment rated by them. These results suggest that the assumption that seeing one's own body parts in VR always contributes positively to embodiment may not hold universally.**

***Index Terms*—embodiment, flight simulator, drone.**

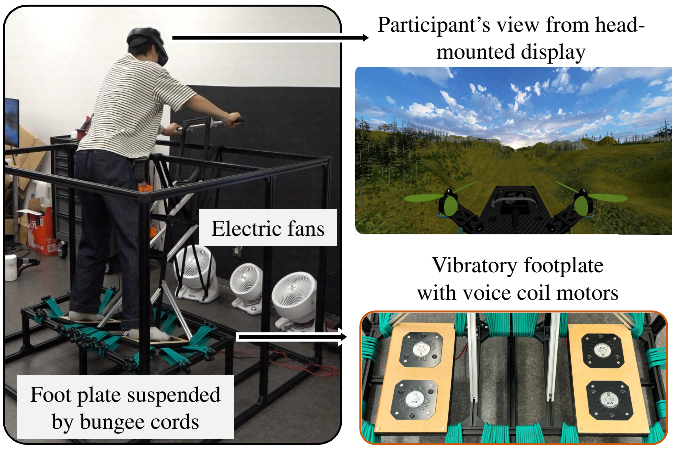

Fig. 1: Overview of Drone Rider.

I. Introduction

A common goal of virtual reality (VR) systems is to provide the experience of flying through the sky [1]–[3]. Our research team has developed a VR system called 'Drone Rider' to simulate the experience of flying on a small vehicle [4]–[6]. In this system, the operator rides a virtual drone, navigating and racing through environments with buildings and mountains. This platform serves both as a testbed for technological development and as a means to evaluate methods for enhancing embodiment in VR experience.

Previous studies have shown that the transparency of virtual avatars affects the sense of body ownership [7]–[9]. For example, Goto et al. reported that using a semi-transparent avatar substantially increased the sense of body ownership [7]. In contrast, Martini et al. reported that the sense of body ownership was lower when using a semi-transparent avatar than when using a vivid one [8]. They agree that the level of opacity of avatar influence the embodiment; however, their conclusions disagree. Based on these studies, our study hypothesized that the visibility of user's real hands in the VR environment affects the sense of embodiment during the VR experience, and the transparency of hands modulates this effect.

The primary objective of this study is to investigate how the visual presence of one's actual hands in VR affects the sense of embodiment. Embodiment, including the sense of body ownership, is more likely to occur when realistic hands are presented [10], [11]. Therefore, displaying images of one's actual hands may be more effective than using computer-generated hands. The sense of embodiment is a multidimensional concept comprising body ownership, agency, and self-location [10]. In the context of Drone Rider, the sense of agency refers to the control over the simulated drone, while the sense of self-location pertains to the feeling of being on the drone. The projection of the operator's hands is expected to influence these two sensations, which are the primary focus of this study.

II. Drone Rider

As shown in Fig. 1, Drone Rider [4] system mainly consists of a rubber-suspended platform, head-mounted display (Meta Quest3, Meta Platforms, Inc, USA), electric fans, and a vibration footplate.

The Drone rider system was developed with Unity (2021.3.2f1) and Arduino IDE (2024.1.8.19). Leveraging Meta Platform's see-through functionality and hand tracking technology, the operator's forearm movements were projected into the VR environment. As illustrated in Fig. 2, the operator's forearm overlapped with the VR imagery in real-time, with both elements updating synchronously. The opacity of the overlaid video can be adjusted. Drone Rider was controlled by tilting the operator's body forward, backward, left, or right

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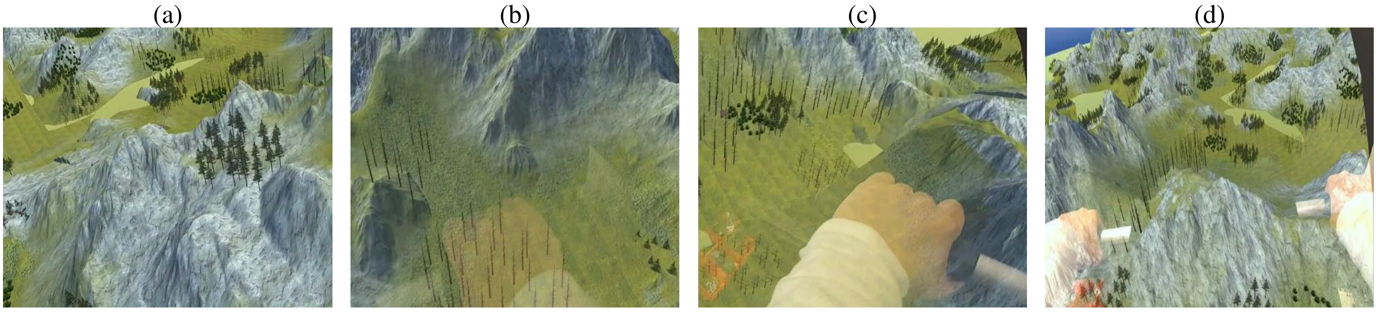

Fig. 2: Level of opacity: (a) None. (b) Light (level 0.2). (c) Medium (level 0.6). (d) Vivid (level 1.0). The values in the parentheses are the opacity values of objects' property in Unity.

TABLE I: Questionnaire items.

	Items	Category
Q1	Did you feel like you were able to pilot the drone on your own?	Agency
Q2	Did you feel like you were riding on the drone?	Self-location
Q3	Did you feel immersed in the VR space?	Immersion
Q4	Did you experience a sense of flying in the sky?	Flight

on a free-reclining platform. The same apparatus was also used in [12].

III. Experiment

A. Participants

Ten university students (aged 20–29) participated in the experiment after providing written informed consent. Nobody used head-mounted displays in their daily lives.

B. Ethical Statement

This study was approved by the institutional review board of Hino Campus, Tokyo Metropolitan University (R6-009).

C. Stimuli: Hand Projection with Different Opacity Levels

To manipulate the clarity of the projected hands, we adjusted their opacity using Unity's object transparency settings. Four levels of visual clarity were tested: 0, 0.2, 0.6, and 1. As shown in Fig. 2, an opacity level of 0 rendered the operator's hands completely invisible, whereas an opacity level of 1 provided the clearest visibility of the hands.

D. Procedures

Prior to formal trials, participants completed drone operation training until demonstrating stable tracking capability of a flying target (typically 3–5 min). Training sessions used maximum opacity settings (level 1.0).

In the main experiment, operators continuously tracked the target (flying crane) for 90 s under four randomly ordered conditions, each experienced once with 2-min inter-trial breaks. Post-trial questionnaires (Table I) employed a 10-point Likert scale (0: not at all, 9: strongly experienced).

E. Data Analysis

We compared the effects of different opacities on each of four types of questionnaire scores using a single-factor repeated-measures analysis of variance (ANOVA).

IV. Results

The visibility factor did not significantly affect any of the four types of questionnaire items: Q1: $F(3,36) = 0.20$, $p = 0.90$, $\eta^2 = 0.016$; Q2: $F(3,36) = 0.23$, $p = 0.88$, $\eta^2 = 0.019$; Q3: $F(3,36) = 0.17$, $p = 0.91$, $\eta^2 = 0.014$; Q4: $F(3,36) = 0.25$, $p = 0.86$, $\eta^2 = 0.020$. These results indicate that the changes in opacity had negligible effects on the sense of agency, self-location, immersion, and flight.

V. Discussion

Based on previous studies [7], [8], we reasonably hypothesized the effects of visibility of participants' hands on the sense of embodiment. However, the questionnaire results suggested that variations in transparency have a limited impact on embodiment. Nevertheless, it is premature to draw definitive conclusions about this hypothesis without addressing potential confounding factors.

One possible explanation is that participants overly focused on chasing the crane target, which may have diverted their attention from their visible hands. If the task was substantially demanding, this cognitive load could have diminished any potential embodiment effects. Adjusting task difficulty in future experiments may yield different insights into the influence of hand visibility. Additionally, incorporating explicit prompts to direct attention to the hands could help clarify their role in embodiment.

Another factor to consider is the limited duration for which participants could see their hands within their field of view. The handgrip was positioned approximately in front of the abdomen, requiring participants to look downward to see their hands. Some participants may have viewed their hands for only about 10 s, which could have diminished any embodiment effects. This duration is considerably shorter than those reported in previous studies [13], [14]. For example, Kalckert and Ehrsson found that a sense of ownership over a rubber hand typically emerges after an average of 23 s of continuous viewing [13]. Future studies should implement methods to control for visual exposure duration to better assess its impact.

VI. Conclusion

This study investigated the effects of hand visibility and hand opacity on the sense of embodiment, specifically the sense of agency and the sense of self-location, in a drone operating task within a virtual reality environment. While no statistically significant effects were observed across conditions, the vivid-hand condition consistently yielded the highest embodiment scores, indicating a positive trend.

These results suggest that vivid visual representations of the hands may enhance users' embodied experiences, even if the effects are subtle. Although hand projection alone may not drastically influence agency or self-location, it shows potential as a supportive factor in VR interface design.

Future research will examine the role of visibility of user's own body parts, aiming to clarify the conditions under which such cues strengthen embodiment and task performance in immersive systems.

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