Analysis of Self-Initiated Movements for Natural Flight Locomotion in VR

Mai Nomura
Nagoya Institute of Technology, Japan
m.nomura.641@stn.nitech.ac.jp

Kenji Funahashi
Nagoya Institute of Technology, Japan
kenji@nitech.ac.jp

***Abstract*—This study analyzes self-initiated body movements for natural flight locomotion in VR. Data were collected using a transparent Wizard of Oz (WoZ) method to observe spontaneous user movements. By cross-referencing video recordings, tracking data, and post-experience interviews, the movements were classified and analyzed. The results revealed common posture transition patterns across participants during different flight phases. Based on these findings, a simple flight system was implemented using a minimal setup with an HMD and a webcam, and preliminary evaluation confirmed that flight generally followed users' intended movements.**

***Index Terms*—Virtual Reality, Human-Computer Interaction, VR Locomotion, Embodied Interaction, Self-Initiated Movements**

I. Introduction

Since ancient times, humanity has held a strong desire to fly freely in the sky [1]. While modern aircraft make flight possible, the experience involves operating machinery and differs from moving through the air using one's own body. On the other hand, fictional works such as anime, games, movies, and novels often depict characters flying using only their bodies (Fig. 1) [2], [3]. These depictions commonly include posture transitions depending on the phase of flight, such as a jump-like motion when initiating flight and a forward-leaning posture during flight. This consistency suggests that people share a mental image of body movements associated with flying using their own bodies.

In recent years, various VR-based flight systems have been proposed [4]–[6]. However, many require large-scale equipment, limiting their accessibility in home environments. Moreover, the flight mechanics in these systems are typically predefined by developers and may not align with users' self-initiated movements.

Therefore, this study investigates self-initiated body movements for flight in order to inform the design of a VR flight locomotion method with a minimal setup, such as an HMD and a web camera. We collect and analyze body movements to identify common patterns across participants. Based on these findings, we implement a simple VR flight locomotion system and conduct a preliminary evaluation.

II. Data Collection of Self-Initiated Flight Movements

Ten participants took part in the study and experienced four types of flight routes: climb, descent, right-turning, and left-turning, all of which included forward movement and stopping phases (Fig. 2, Fig. 3). Each participant performed one trial per route, and three instances of movement data were recorded per trial, resulting in a total of 40 trials and 120 movement samples. Participants were instructed to imagine how they would move their bodies to start, move, and stop if they could fly, and to move freely. A transparent Wizard of Oz (WoZ) method [7] was used to control the movement. Specifically, the operator observed the participant's movements to initiate flight and manually triggered motion along predefined routes in the VR space. Participants were instructed to perform body movements that felt natural in response to changes in the visual scene. For safety, all trials were conducted with participants seated on an office chair.

During the study, video recordings and head and body tracking data were collected. MediaPipe [8] was used for pose tracking. Fig. 4 shows an example of recorded body movements during flight. In addition, post-experience interviews were conducted after each route to collect self-reported data on body movements.

Fig. 1. Examples of body-based flight in fictional works: (left) wing-assisted flight [2] and (right) magic-based flight [3].

Fig. 2. Setup for collecting self-initiated flight movements using a transparent Wizard of Oz method.

Fig. 3. Example of a predefined flight route, where sequential rings indicate the path and direction of movement.

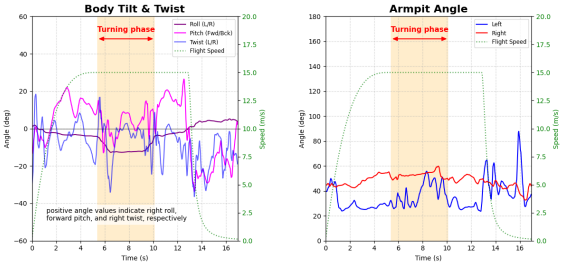

Fig. 4. Example of recorded body movements from a participant during a left turning route.

III. Analysis of Self-Initiated Movements

The collected movement data varied across participants in both motion details and self-reported descriptions. To identify common patterns, the movements were abstracted into a comparable representation and then classified. Specifically, self-reports such as "tilting the body slightly forward" or "shifting the upper body's center of gravity forward" were verified using video recordings and tracking data, and were consistently categorized as "leaning the torso forward." Analysis of the classified data revealed common body movements shared among participants at key flight state transitions. The results are summarized in Table I.

Furthermore, analysis of the relationship between movement direction and the HMD forward vector showed that the angle between them was within 30 degrees in approximately 92.5% of all frames. This suggests that users tend to align their movement direction with the center of their field of view.

TABLE I
Common self-initiated body movements associated with each flight state transition.

Transition Type	Common Movements	Illustration*
Forward flight	Lean the torso forward. Extend the arms backward.	
Stopping	Raise the torso or lean backward. Lower the arms to the sides or spread them.	
Turning (left/right)	Tilt or twist the torso in the direction of movement.	

*Illustrations represent typical movement patterns and do not correspond to the exact postures of all participants.

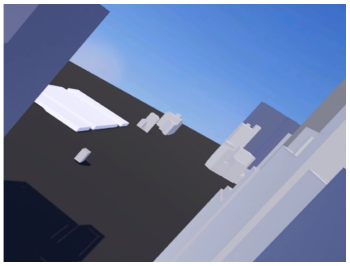

Fig. 5. Overview of the simple flight system: a participant performing flight movements (left) and the corresponding VR view (right).

To examine whether the extracted movement patterns could support intended flight, a simple flight system was implemented based on the analysis results (Fig. 5). The system uses camera-based pose estimation and supports forward movement, stopping, and left/right turning. When several participants used the system, they generally reported being able to fly according to their intentions. However, unintended behaviors were also observed, likely due to errors in camera-based pose estimation.

IV. Conclusion

This study collected and analyzed self-initiated body movements that users perform when intending to fly in VR. A simple flight system based on the extracted movements enabled participants to generally fly according to their intentions. However, unintended behaviors were occasionally observed. Future work includes improving the accuracy of camera-based pose estimation and exploring alternative methods using the positions of the controller and HMD.

Acknowledgment This work was supported in part by JSPS KAKENHI Grant Number JP23K11182.

References

[1] J. D. Anderson Jr., The Airplane: A History of Its Technology. AIAA, 2003.
[2] R. Kawahara, Sword Art Online 3: Fairy Dance (in Japanese). [Novel]. ASCII Media Works, 2009.
[3] miHoYo, Genshin Impact. [Video game]. HoYoverse, 2020.
[4] H. Eidenberger and A. Mossel, "Indoor skydiving in immersive virtual reality with embedded storytelling," in Proc. 21st ACM Symp. Virtual Reality Softw. Technol. (VRST '15), 2015, pp. 9–12.
[5] M. Kobayashi, "A flying sensation display by using a jet pool and underwater VR," Master's thesis, Nara Institute of Science and Technology, 2021 (in Japanese).
[6] Y. Ban, K. Yoshida, and Y. Ujidoko, "Improving presence of virtual flight experience in seated position by presenting non-ground contact feeling with sole," in Proc. 27th Annual Conf. Virtual Reality Soc. Japan, 2022, 1B4-4 (in Japanese).
[7] M. Lee and M. Billinghurst, "A Wizard of Oz study for an AR multimodal interface," in Proc. 10th Int. Conf. Multimodal Interfaces (ICMI), 2008, pp. 249–256.
[8] Google, "MediaPipe." [Online]. Available: https://developers.google.com/mediapipe. [Accessed: Feb. 5, 2026].