Designing Natural Flight Locomotion in VR via Self-Initiated Movements

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Abstract

This paper presents a VR flight locomotion system based on self-initiated movements. To inform the design, we employed a transparent Wizard of Oz (WoZ) approach to capture users' spontaneous motion patterns. The observed movements were analyzed to extract common posture transitions during flight. Based on these insights, we implemented a camera-based prototype that determines flight behavior from pitch and roll inputs. A preliminary evaluation suggests that users can control flight in accordance with their intentions.

CCS Concepts

• **Human-centered computing** → **Interaction design**; *Virtual reality*.

Keywords

Virtual Reality, Human-Computer Interaction, VR Locomotion, Embodied Interaction, Self-Initiated Movements

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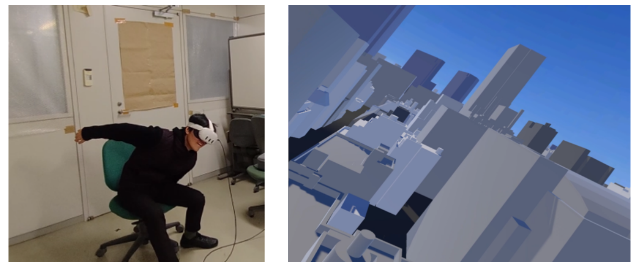

Figure 1: Overview of the proposed VR flight locomotion system driven by self-initiated movements: a participant performing body movements (left) and the resulting first-person VR view (right), enabling intuitive flight control in a real-world urban environment model (Akihabara, Tokyo).

1 Introduction

Since ancient times, humans have aspired to fly freely through the sky [1]. Although modern aircraft enable flight, they require operating machines and differ from moving through the air using one's own body. In contrast, fictional media such as anime, games, and films often depict characters flying using only their bodies [4, 6]. These depictions commonly involve phase-dependent posture transitions, such as a jump-like motion at takeoff and a forward-leaning posture during flight, suggesting a shared mental model of embodied flight. Recent studies have explored VR-based flight systems [3, 7, 8]. However, many rely on specialized equipment or flight metaphors such as broom flying, and the mapping between user movements and flight behavior is typically predefined rather than derived from users' self-initiated movements. In this work, we design a VR flight locomotion system based on self-initiated movements without relying on flight metaphors [8]. The system uses a minimal setup consisting of an HMD and a web camera for use in home environments and is designed for seated interaction to improve safety and comfort [3]. To inform the design, we capture and examine users' motion patterns and extract common characteristics of flight-related movements. Based on these insights, we implement a prototype system for natural flight control.

2 Data Collection of Self-Initiated Flight Movements

Ten participants experienced four flight routes (climb, descent, right turn, and left turn), each including level flight and stopping phases (Figure 2), resulting in 40 trials and 120 movement samples. For simplicity, forward movement was presented at a constant speed of 15 m/s based on preliminary evaluations. Transitions from and to the stationary state were modeled using accelerations of approximately 0.5G and −1.0G, respectively, ensuring gradual changes. The turning radius was approximately 45 m, with gradual transitions from and to straight-line motion. The climb/descent angle was set

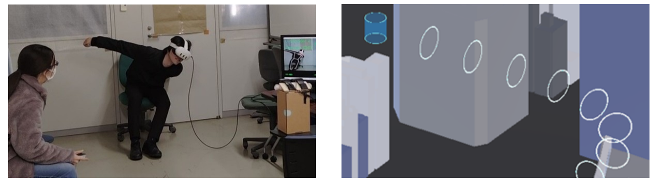

Figure 2: Setup for collecting self-initiated flight movements using a transparent Wizard of Oz (WoZ) method (left), and an example of a predefined flight route, where sequential rings indicate the path and direction of movement (right).

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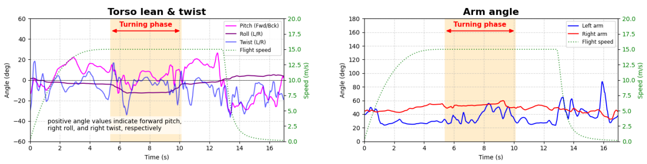

Figure 3: Example of recorded body movements from a participant during a left turning route.

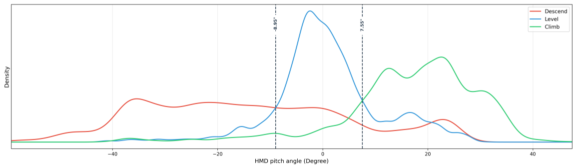

Figure 4: Representative distributions of measured angles. The vertical lines indicate the selected thresholds.

to apporoximately ±20°. Participants were asked to imagine flying with their own bodies and to move in a way that felt natural for initiating, controlling, and stopping flight. A transparent Wizard of Oz (WoZ) method [2] was employed, in which an operator observed participants' movements and manually triggered motion along predefined paths in the virtual environment. All trials were conducted with participants in a seated position. During the study, video recordings and head and body tracking data were collected using MediaPipe [5] (Figure 3). Post-experience interviews were also conducted after each route to capture participants' subjective descriptions of their movements.

3 Analysis of Self-Initiated Movements

The collected data showed variations in both motion and self-reported descriptions. To extract design-relevant patterns, the movements were abstracted into a unified representation and categorized. For example, descriptions such as "tilting forward" or "shifting the upper body forward" were consistently interpreted as leaning the torso forward. From this process, we identified common body movements associated with key flight transitions, including movement initiation, directional control, and stopping (see the Common Movements column in Table 1). Next, we analyzed the distributions of the measured angles to determine thresholds for distinguishing different flight transitions (Figure 4). For each transition, we selected the angle that provided the clearest separation from the others with minimal overlap (see the Condition column in Table 1). These findings directly informed the design of the flight control logic described in the next section.

4 Prototype Implementation

To validate the proposed design, we implemented a VR flight locomotion prototype. The system uses camera-based pose estimation

Table 1: Flight control logic derived from the analysis of self-initiated movements, including common body movements, control conditions, and corresponding flight behaviors.

Transition Type	Common Movements	Condition	Flight Behavior
Accelerating	Lean the torso forward. Extend the arms backward.	0° 22° Decelerate Cruise Accelerate Torso pitch relative to flight path	Accelerates at 0.5G up to 15 m/s.
Decelerating	Raise the torso or lean backward. Lower the arms to the sides or spread them.		Decelerates at -1.0G to a stop.
Turning (left/right)	Lean or twist the torso toward the direction of movement.	-5° 5° Left Turn Straight Right Turn Torso roll	Turning radius is fixed at 45 m.
Climb/Descent	Direct the head and gaze toward the direction of movement.	-9° 8° Descent Lebel Climb HMD pitch	Climb/descent angle is fixed at ±20°.

to support level flight, climb, descent, turning, and stopping. RGB images from a web camera are processed using MediaPipe to estimate the upper-body pose and derive control parameters in real time. The resulting flight control logic, including the input conditions and corresponding flight behaviors, is summarized in Table 1. These control rules were designed to reflect the posture patterns identified in the analysis. The estimated pose is mapped to control parameters to update the user's viewpoint in the virtual environment. We conducted an initial user test with several participants (Figure 1). Users were generally able to control flight in accordance with their intended movements. However, unintended behaviors were also observed, likely due to inaccuracies in camera-based pose estimation.

5 Conclusion

This paper presented a VR flight locomotion system based on self-initiated movements. The implemented prototype enabled users to generally control flight in accordance with their intentions, demonstrating the feasibility of the proposed approach. However, unintended behaviors were occasionally observed, likely due to limitations in camera-based pose estimation. Future work includes improving robustness, exploring alternative input methods, and refining the control mapping by analyzing how pitch and roll angles relate to flight parameters such as speed and turning radius. We also plan to incorporate additional body cues, such as arm angles and torso twist (yaw), into the control mapping.

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