

Designing Natural Flight Locomotion in VR via Self-Initiated Movements

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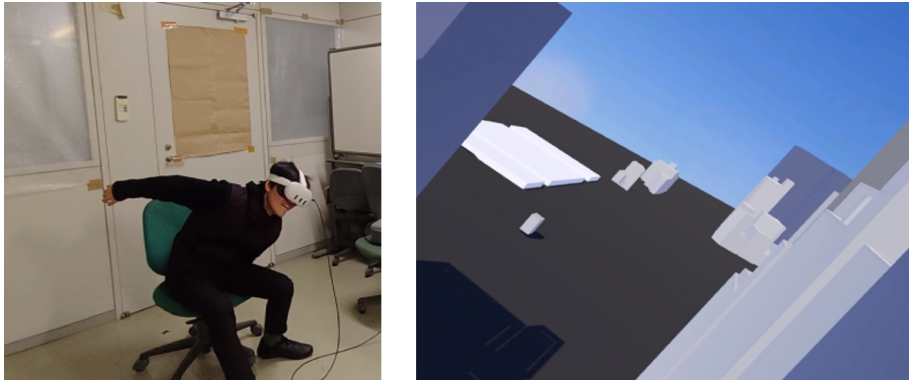


Fig. 1. Overview of the proposed VR flight locomotion system driven by self-initiated movements: a participant performing body movements (left) and the resulting first-person VR view (right), rendered using a real-world urban environment model (Akihabara, Tokyo).

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**; *Interaction techniques*; *Gestural input*.

Additional Key Words and Phrases: Virtual Reality, Human-Computer Interaction, VR Locomotion, Embodied Interaction, Self-Initiated Movements

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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

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Fig. 2. Examples of body-based flight in fictional works: (left) wing-assisted flight [5] and (right) magic-based flight [6].

such as anime, games, and films often depict characters flying using only their bodies (Fig. 2) [5, 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 or large-scale equipment, limiting their practicality in everyday environments. In addition, flight behaviors in such systems are typically predefined, which may not reflect users' self-initiated movements. In this work, we design a VR flight locomotion system based on self-initiated movements using a minimal setup consisting of an HMD and a monocular camera, with a focus on seated use for accessibility in home environments. 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 (Fig. 3, Fig. 4), 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. 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



Fig. 3. Setup for collecting self-initiated flight movements using a transparent Wizard of Oz (WoZ) method.



Fig. 4. Example of a predefined flight route, where sequential rings indicate the path and direction of movement.

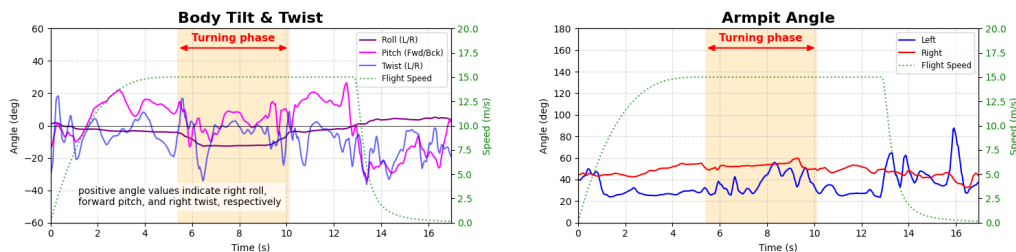


Fig. 5. Example of recorded body movements from a participant during a left turning route.

data were collected using MediaPipe [4]. 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 (Table 1). The torso pitch angle during forward movement averaged 7.57° (SD: 13.17°), with a mean of 6.99° at movement onset, while the torso roll angle during turning averaged 9.55° (SD: 7.67°). In contrast, arm movements showed larger variability. The SD of arm angles during forward movement (anteroposterior direction) was 29.30° (mean: -3.70°), and during stopping (lateral direction) was 20.30° (mean: 21.65°). The torso twist (yaw) also showed noticeable variability (SD: 13.60°, mean: 3.61°), which is relatively large considering the limited range of motion in the seated condition. The relative pitch angle of the head (HMD) with respect to the torso averaged -7.52° (SD: 13.40°) during straight forward movement and -22.78° (SD: 14.0°) during climb, indicating relatively consistent behavior. In contrast, descent showed substantially larger variability (mean: 9.4°, SD: 24.18°). These observations suggest that torso-based movements provide more stable cues for control, while arm and twist movements exhibit higher variability. These findings informed the design of the flight control logic described in the next section.

Table 1. 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)	Lean or twist the torso toward the direction of movement.	

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

Table 2. Input conditions for each movement.

Movement	Condition and Behavior
Forward	Initiated when the pitch angle exceeds 5°. Accelerates at 0.5G up to 15 m/s.
Stopping	Initiated when the pitch angle falls below 5°. Decelerates at -1.0G to a stop.
Turning	Initiated when the roll angle exceeds 10°. Turning radius is fixed at 45 m.

4 Prototype Implementation

To examine whether the extracted movement patterns support intuitive flight control, we implemented a VR flight locomotion prototype. The system uses camera-based pose estimation to enable level flight, stopping, and turning. The system takes RGB input from a monocular camera and estimates upper-body pose using MediaPipe to derive control parameters in real time. The input conditions for each movement are summarized in Table 2, and 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 (Fig. 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), and to introduce climbing and descending flight motions by incorporating gaze direction to distinguish them from forward acceleration.

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