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Drone Rider: Wind Stimulation to Enhance Speed Perception of Virtual Flight

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Abstract

Wind stimulation is recognized as an effective method for inducing the sense of self-locomotion in virtual reality (VR) environments; however, its influence on perceived locomotive speed remains unclear. This study revealed the impact of wind stimulation on enhancing speed perception within a VR flight simulator through a user study.

CCS Concepts
• ***Computing methodologies*** → ***Virtual reality;*** • ***Human-centered computing*** → ***Virtual reality;***

1. Introduction

The perception of self-locomotion is essential for immersive VR experiences. However, accurately judging locomotive speed in VR environments is challenging due to the absence of perceptual cues present in real-world settings [HAAD20, OOA23]. Despite previous studies on the effects of wind stimulation (e.g., [MK04, PSKK24]), it remains unclear whether wind stimuli enhance the perceived speed of self-locomotion in VR environments. This study investigates how wind stimulation impacts speed perception in a VR drone flight simulator, where wind is introduced as an additional sensory cue.

2. Methods

2.1. Participants and ethical statement

Six participants (four males, two females) were recruited and all of them provided written informed consent before the experiment. The study was approved by the Institutional Review Board, Hino Campus, Tokyo Metropolitan University. Anonymous University (R6-009).

2.2. Apparatus

The experimental setup, referred to as Drone Rider [SGO24, SSGO24] (Figure 1), was designed to simulate the experience of boarding on a flying drone. Key components include a VR headset (Quest Pro, Meta, Inc., USA), an electric fan for wind stimulation, bungee cords for platform suspension, and a footplate to simulate vibrations from drone propellers. The VR headset was connected to Unity, with pitch and roll movements controlling the drone's forward/backward and yaw motions, respectively.

An electric fan (633DC-JP, Vornado Air Circulation Systems, Inc., USA) positioned in front of the participant simulated wind, of which speed was controlled by a microcomputer (Arduino Mega 2560) by using pulse-width modulation. The maximum wind speed was 3.4 m/s measured at the position of the participant's head.

2.3. Experimental design

The experiment aimed to examine how simulated drone speed and wind speed affect perceived speed. A two-way analysis of variance (ANOVA) design was adopted, with each participant experiencing six conditions (two speed levels $\times$ three wind levels). The drone's simulated speed was set at either 24.25 m/s or 48.49 m/s, and the wind speeds was either 0 m/s, 2.5 m/s, or 3.4 m/s. The optical flow from the VR goggles reflected the simulated velocities, and perceived speed was measured using the magnitude estimation method.

2.4. Procedure

Participants completed a 2-minute training session before starting the experiment for familiarizing themselves with the control of a VR drone. They experienced six conditions in random order with different drone and wind speeds. After testing each condition, they took a 1.5-minute break. Each participant completed 12 trials, with each 20-second trial involving constant-speed flight while receiving wind stimulation. After each trial, participants rated the perceived speed relative to a reference condition (drone speed: 48.49 m/s, wind speeds: 2.5 m/s) using the psychophysical method of magnitude estimation.

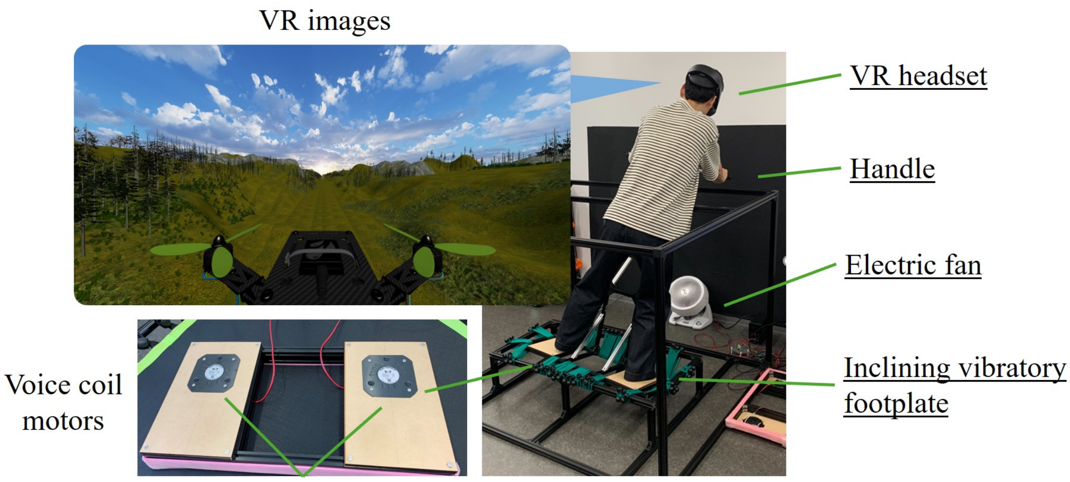

Figure 1: *Drone Rider system, including VR headset, wind-stimulating fans, bungee-hung platform, and vibratory footplate.*

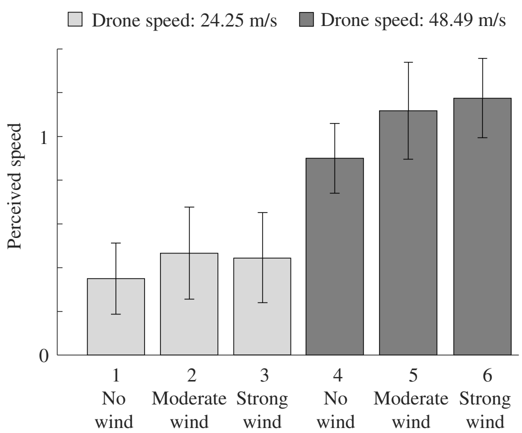

Figure 2: *Mean ratings of perceived speeds with standard errors for different drone speeds and wind conditions.*

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3. Results

The geometric mean of the individual ratings was calculated for each condition. These ratings were then analyzed using a two-way ANOVA, with simulated drone speed and wind velocity as the two factors.

Figure 2 shows the means and standard errors of perceived speed for each condition across the participants. The high drone speeds significantly increased perceived speed ($F(1,66) = 202.74$, $p = 8.45 \times 10^{-22}$). Wind intensity also had a significant effect ($F(2,66) = 6.81$, $p = 0.0020$), with stronger winds enhancing speed perception. There was no interaction between the two factors ($F(2,66) = 1.32$, $p = 0.27$). Post-hoc tests revealed no substantial differences between the moderate and strong wind conditions, suggesting that the effect of wind was primarily noticeable when comparing conditions with and without wind.

4. Discussion

The results show that both drone speed and wind stimulation significantly affected perceived speed in VR simulations without an interaction between them. The lack of difference between moderate and strong wind conditions may be due to participants adapting to the continuous wind stimulation. Introducing fluctuations in wind intensity could address this issue. This study highlights the importance of wind stimuli in enhancing speed perception, and future research should focus on refining wind stimulation techniques for VR applications.

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