Drone Rider: Virtual Flight Meets Exergaming

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***Abstract*—We developed Drone Rider, an extended reality (XR) system designed to simulate a flying experience. The system enhances immersion through multisensory feedback, including lower-body vibration stimuli, passive tilting of the foot platform, wind feedback proportional to flying speed, and real-time projection of the user' s arms into the virtual environment. This study explores the potential of Drone Rider as an exergame—a form of interactive entertainment that integrates gameplay with physical activity. In a user study, 10 participants tracked virtual flight targets for 90 s. The average heart rate increased by 10.4 bpm, indicating moderate physical engagement. Reports of cybersickness were minimal (mean = 2.3 on a 0–9 scale), and participants positively evaluated its potential as an e-sports platform (mean = 5.0). These findings support the potential of Drone Rider as a fitness-oriented XR system involving moderate physical engagement.**

***Index Terms*—flight simulator, drone, exergaming, fitness game.**

I. Introduction

We developed an extended reality (XR) system called *Drone Rider* to provide an immersive flight experience [1], [2], motivated by similar goals as those in earlier studies [3]–[5]. In this system, users ride a simulated drone, flying through urban landscapes and over mountainous terrain. By incorporating multiple sensory feedback modalities, the system enhances the realism and presence of the flight experience.

One promising application of this system is exergaming, which integrates gameplay with physical activities such as muscle training, balance exercises, and stretching [6]–[8]. In Drone Rider, users control the drone by dynamically shifting their body weight on a passively tilting platform, thereby engaging their sense of balance and postural control.

This study focuses on these body-weight shifting movements and investigates the feasibility of Drone Rider as a novel exergame. We quantitatively assess participants' physiological responses—specifically, changes in heart rate—to evaluate physical engagement. An increase in heart rate is expected following a certain duration of the flight experience. Additionally, we assess cybersickness and user satisfaction through questionnaires to determine whether the system satisfies key criteria for effective exergaming.

II. Drone Rider

As shown in Fig. 1, Drone Rider [1] system mainly consists of a head-mounted display (Meta Quest3, Meta Platforms, Inc, USA), electric fans [9], and a bungee-coded footplate with vibratory feedback function. The software system was developed with Unity (2021.3.2f1) and Arduino IDE (2024.1.8.19).

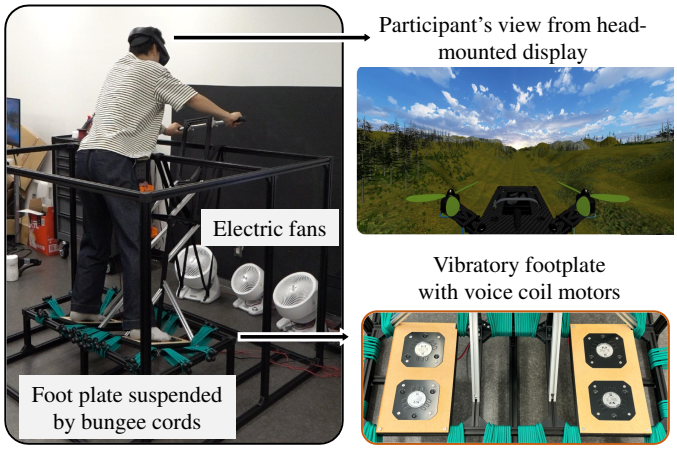

Fig. 1: Overview of Drone Rider. Adapted from [10].

The operator controlled the simulated drone by gripping the handlebars with both hands and standing on the footplate, tilting it forward and sideways. By aligning the body's tilt with the visual tilt presented in the VR environment, a harmonized sensory experience was achieved between vision and vestibular perception.

The footplate provided auditory and vibratory feedback from the drone's propellers, delivering these sensations from the soles of the feet to the lower body. Additionally, an electric fan was positioned in front of the operator, with its wind speed dynamically adjusting to match the simulated drone's flight speed.

The operator's forearms and hands were projected into the VR scene, forming a mixed-reality condition [10], [11]. For this purpose, Meta Platform's see-through functionality and gesture control technology were used.

III. Experiment

A. Participants

Ten university students (four females, aged 20–29) participated in the experiment after providing signed consent.

B. Ethical Statement

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

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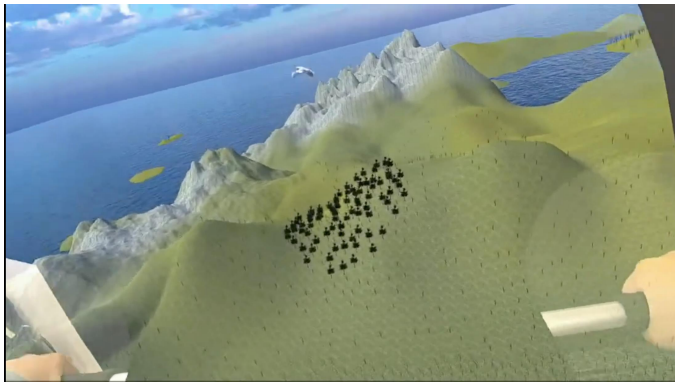

Fig. 2: Example of the visual scene presented to a participant during the task. The simulated crane, represented as a white bird, appears in the upper central region of the display.

TABLE I: Questionnaire items rated on a 10-point scale (0–9).

Item	Description	Label
Q1	Level of cybersickness	Sickness
Q2	Satisfaction as an exergame	Satisfaction
Q3	Perceived potential as an exergame	Potential

C. Procedures

Prior to the formal experiment, participants underwent drone operation training until demonstrating stable tracking capability of a flying target (typically 3–5 min). A mandatory recovery period of at least 5 minutes was provided to allow cardiovascular parameters to return to baseline. Subsequently, heart rate monitoring was conducted using an Apple Watch (Series 7, watchOS 11.3.1).

In the main experiment, the operator chased a simulated crane that flew ahead for 90 s. The crane flew in the sky while drawing a figure of eight; hence, the drone's operation involved turning motions into left and right directions.

The heart rate immediately after the experiment was recorded. The participants then answered questionnaire items listed in Table I on a 10-point scale with 0 and 9 indicating not-applicable and strongly applicable, respectively. Q1 asked about the level of cybersickness, for which three typical symptoms were refferred to: nausea, vestibular irregularity, and oculomotor irregularity [12].

D. Data analysis

The heart rate (beats per minute) was compared between the pre- and post-experiment conditions using a paired two-tailed t-test. Additionally, a two-tailed t-test was conducted to determine whether the mean questionnaire scores were significantly greater than zero, with p-values adjusted using the Bonferroni correction (factor of three).

IV. Results

Fig. 3 shows the means and standard errors of questionnaire scores. The average of each item was significantly greater than 0 (Q1: $t(9) = 3.08$, $p = 0.040$, Cohen's $d = 0.97$; Q2: $t(9) = 5.72$, $p < 0.001$, Cohen's $d = 1.81$; Q3: $t(9) = 5.59$, $p < 0.001$, Cohen's $d = 1.77$).

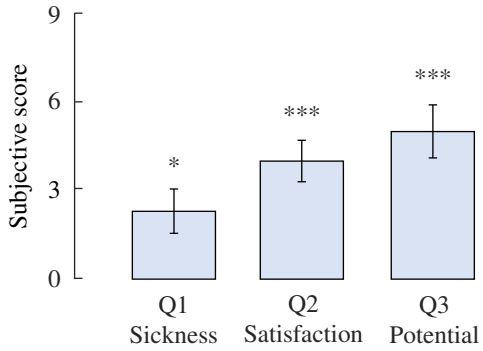

Fig. 3: Questionnaire score. Means and standard errors. Questionnaire labels correspond to those in Table I. Asterisks (* and ***) indicate significant difference from 0 at $p < 0.01$ and $p < 0.001$, respectively.

After the experiment, the heart rate significantly increased ($t(9) = 3.34$, $p = 0.009$, Cohen's $d = 1.03$). The mean and standard error of the heart rate before the experiment was 77.3 ± 1.7 min^{-1}. Those after the experiment were 88.7 ± 14.0 min^{-1}. The mean and standard error of the increase were 11.4 ± 10.2 min^{-1}.

V. Discussion

This study confirmed a significant increase in heart rate while obtaining positive evaluations in subjective assessments (Q2 and Q3). These findings suggest that the Drone Rider system has the potential to provide an enjoyable flying experience while simultaneously delivering exercise benefits, thereby indicating its applicability as a novel form of exergame. However, further research is necessary to determine whether this exergame meets the intensity criteria required by international physical activity guidelines [13].

In this experiment, participants' heart rates were measured only before and after the trial, and due to the short duration of each session, we did not aim to evaluate whether elevated heart rates were sustained during the activity. Additionally, the average satisfaction score regarding its potential as an exergame was 4.0 out of 9 points, with several participants commenting on the insufficient physical intensity of the exercise. Future development should aim to extend trial durations and design intensive exercise programs, with careful consideration given to the mitigation of cybersickness reported by participants.

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