2024 IEEE Conference on Virtual Reality and 3D User Interfaces Abstracts and Workshops (VRW) | 979-8-3503-7449-0/24/$31.00 ©2024 IEEE | DOI: 10.1109/VRW62533.2024.00153

Enhancing Body Ownership of Avian Avatars in Virtual Reality through Multimodal Haptic Feedback

Ziqi Wang*
Tsinghua University

Ze Gao†
Hong Kong University of Science and Technology and Hong Kong Polytechnic University

Abstract

This paper uses multimodal haptic feedback to enhance users' body ownership in virtual reality through wearable devices. In this case, the human is transformed into a bird, which belongs to the beyond-real transformations category in virtual reality interactions. For body transformation, wearable retractable straps can help people mimic the movement mechanism of avian bodies; for space transformation, the inflatable cushions and blowers can simulate the air resistance and lift, oxygen deprivation, and temperature decrease during the take-off process of avian avatars. The system aims to establish a realistic fidelity of the haptic feedback to enhance the user's body ownership.

Index Terms: Wearable Haptic Devices—Virtual Reality—Haptic Feedback—Body Ownership

1 Introduction

For humans, the experience of flying like birds is new and exciting. Spatially, when birds take off, their bodies feel the lack of oxygen, the drop in temperature, and the atmospheric friction from the change in altitude. From the body's movement mechanism, they fully mobilize their back and chest muscles to beat their wings to enhance lift and counter-resistance. The user's familiar haptic experience is very different from that of birds, and enhancing the user's body ownership presents challenges that this experiment hopes to address. To immerse the user in an unprecedented experience, the haptic feedback system must be delicately coordinated both spatially and bodily. To enhance the user's body ownership in a virtual reality environment, we plan to use a wearable retractable belt device controlled by a motorized reel to simulate the bird's movement mechanism, complemented by a wearable inflatable cushion and blower to provide spatial haptic feedback. To better assess the quality of haptic feedback, we will set up two additional sets of wearable devices as control experiments and combine them with a blower and a cushion. We will score and compare the user experience of this experiment based on the haptic feedback quality assessment framework proposed by [5], and finally select the devices and combination with the highest overall score. Furthermore, a survey [1] of research in the field of beyond-real interaction has shown that most research on beyond-real transformations has been conducted in isolation, and there is a lack of understanding of how different transformations, like body and space, interact with each other. Therefore, our experiments can also establish a framework for interacting these two transformations for later researchers and designers.
The contributions of this study are as follows: 1. This study develops a design methodology to enhance body ownership by simulating the movement mechanisms of non-human avatars through haptic feedback 2. After evaluating to find the combination of spatial and bodily haptic feedback devices with the highest score, 3. Enhancing the field's understanding of how space transformation interacts with body transformation in the beyond-real virtual reality. Establish a framework based on the effects of these interactions on body ownership.

*e-mail: ziqiwang0017@gmail.com
†Corresponding author, e-mail: zegao@polyu.edu.hk

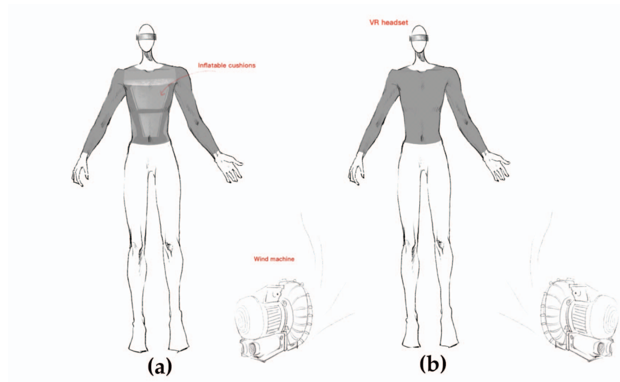

Figure 1: space transformation group; (a) shows the inflatable cushions; (b) shows the blower.

2 Experiment Methodology

Participants in the experiment use a VR headset designed based on a sensorimotor loop [1]. To initiate take-off commands, participants spread their arms, mimicking the flapping motion of birds. The device triggers the take-off program when the amplitude of this motion exceeds a threshold, like 0.6 meters, resulting in the avatar's body ascending and the surrounding space rapidly descending. The experiment will start with the space transformation, delivered through devices targeting the body's surface and core: one Blower creates a counterwind effect and cooler temperature on the skin, as shown in Figure 1(b). The other simulates high-altitude breathlessness using inflatable cushions, shown in Figure 1(a). The data collected in the experiment are evaluated with professional framework [5] for body ownership and haptic fidelity scores.

The second section is the body transformation, which is divided into realistic simulation, movements simulation, and abstract simulation. The realistic simulation involves wearing wings with adjustable weights and a harness that provides a downward pulling force, allowing participants to feel the weight and resistance shown in Figure 2 (a). For movement simulation, retractable elastic straps will be placed across the upper body by shortening the strap connecting the chest and waist to encourage a forward bend and shift the core force points to the back, chest, and scapular regions. This setup increases the pulling force and skin stretch for flapping motions, simulating the force generating mechanism of the bird wings, shown in Figure 2(b). In the abstract simulation section, participants use lightweight devices that provide vibration, offering an abstract [5] form of haptic feedback. Comparative haptic feedback quality and body ownership evaluation are performed in these categories. Participants also engage in experiments combining spatial and bodily wearable devices, using three types of bodily devices and two types of spatial devices in six trials, recording data for evaluation.

979-8-3503-7449-0/24/$31.00 ©2024 IEEE
DOI 10.1109/VRW62533.2024.00153

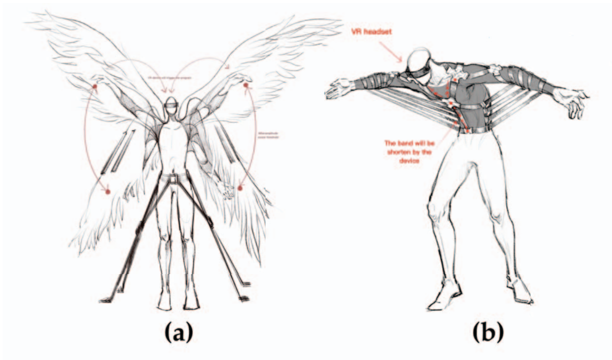

Figure 2: body transformation group; (a) shows the realistic simulation; (b) shows movement simulation.

3 Design approach

The design strategy of this study is to simulate the real world from both spatial and physical perspectives and to pursue a more realistic haptic feedback effect rather than design for visual effects. Since the VR headset will provide a visual experience, the design will focus on the bird's movement mechanism to provide users with a more realistic haptic experience of flight movement.

From the perspective of space, blower, and a wearable inflatable cushion were chosen. The cushion can be inflated to squeeze the lungs and simulate the feeling of utter drowsiness. In reality, atmospheric pressure decreases with increasing altitude, causing declining oxygen levels. On the other hand, the blower creates a headwind that creates lift strength and brings cooler temperatures when avatar lifts off. From the perspective of body : this study aims to help the human body mimic the movement mechanisms of birds. The primary flight muscles in birds include the pectoral and scapular muscles designed for work and power output [6]. Birds have also been shown [4] to utilize the drag and lifting forces in the airand use their back muscles and flapping wings with force to create upward lift and support about half of their body weight. Based on the above information, a retractable elastic strap was chosen for simulating the changeable pressure and body force [5]when taking off from the ground. The retractable straps are remotely controlled in length by a motorized reel, which changes the tension of the pulland drag. In addition, the straps connecting the arms to the waist were designed to, for one, simulate atmospheric resistance, corporating with the lift provided by the blower, while exploring how spatial and body haptic feedbacks interact. For two, it mobilizes the target muscles fully. Because the brachioradialis (BR) and anterior deltoid (AD) have been measured to be highly active during pulling movements [3]. The AD is connected to the pectoralis and the BR is in the upper arm. These two muscles, BR and AD, adjust their force as the tension of the retractable straps changes and drives the pectoralis muscle. This mechanism mimics the constant adjustment of the force a bird applies during take-off. For three, the retractable chest strap helps the human bend forward moderately, and during forward bending, the back muscles are the main force-generating area to maintain balance and support the spine [2], which is close to the way the back force is generated in birds.

4 Technical implementation

Motorized reels achieve the stretchability of our elastic straps. The motorized reel design uses three equal-sized reels placed in front of the waist, connected to the chest by a strap, and on either side of the body connecting to the arms. A single electric motor links them through a belt drive system. The movement of the motor will be precisely controlled by an Arduino microcontroller with an integrated Bluetooth module to support remote operation. All reels are mounted in parallel on a sturdy frame to ensure synchronized rotation during assembly. The connections between the motors and the Arduino are meticulously laid out to manage power and signal transmission. At the same time, sensors are used to monitor and regulate the tension of the reels. This compact system is designed to provide consistent and controlled tension regulation of the clamping.

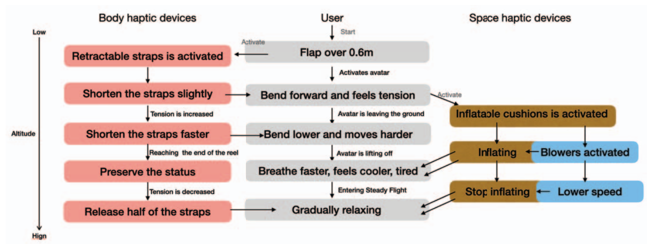

Figure 3: Flowchart of the interaction between haptic feedback devices and the user during the taking-off process.

In addition, in the collation session of the experimental results, participants, after completing the experiment, will score the questionnaire on the quality of haptic feedback from 14 factors based on the framework proposed in the study by [5]. The haptic fidelity score will be derived from the specialized formula in that study. In this study, the data from the two body and space transformation groups will be compared within each group. In contrast, the data records of the two collaborative experiments will be compared with the scores based on different combinations to find the most realistic combination of haptic fidelity. Based on the analysis of versatility in the study, we will also evaluate the wide range of scenarios in which these devices can be applied as a reference for future applications.

5 Conclusion

This experiment establishes a methodology for a haptic feedback system based on human movement mechanisms that mimic non-human avatars. Besides, we explore the impact of Beyond-real space and body transformations on user body ownership. It also establishes a framework for multi-type transformation interactions. Due to size limitations, the experiment does not include haptic feedback for lower-limb assistance in take-off, marking this as a future research direction.

References

[1] P. Abtahi, S. Q. Hough, J. A. Landay, and S. Follmer. Beyond Being Real: A Sensorimotor Control Perspective on Interactions in Virtual Reality. In *CHI Conference on Human Factors in Computing Systems*, pp. 1–17. ACM, New Orleans LA USA, Apr. 2022. doi: 10.1145/3491102.3517706

[2] A. Albayrak, R. H. Goossens, C. J. Snijders, H. De Ridder, and G. Kazemier. Impact of a chest support on lower back muscles activity during forward bending. *Applied Bionics and Biomechanics*, 7(2):131–142, May 2010. doi: 10.1080/11762320903541453

[3] A. Bennett, A. Todd, and S. Desai. Pushing and pulling, technique and load effects: An electromyographical study. *Work*, 38(3):291–299, 2011. doi: 10.3233/WOR-2011-1132

[4] D. D. Chin and D. Lentink. Birds repurpose the role of drag and lift to take off and land. *Nature Communications*, 10(1):5354, Nov. 2019. doi: 10.1038/s41467-019-13347-3

[5] T. Muender, M. Bonfert, A. V. Reinschluessel, R. Malaka, and T. Döring. Haptic Fidelity Framework: Defining the Factors of Realistic Haptic Feedback for Virtual Reality. In *CHI Conference on Human Factors in Computing Systems*, pp. 1–17. ACM, New Orleans LA USA, Apr. 2022. doi: 10.1145/3491102.3501953

[6] B. W. Tobalske. Biomechanics of bird flight. *Journal of Experimental Biology*, 210(18):3135–3146, Sept. 2007. doi: 10.1242/jeb.000273