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床の触覚要素がVR空間における浮遊感に与える影響に関する予備的研究

A Preliminary Study on How Floor Tactile Texture Affects the Floating Experience in Virtual Reality

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概要: 本研究では、仮想空間における浮遊体験に対して、床の触覚テクスチャが体験者の浮遊感に与える影響について予備的検証を行った。視覚と触覚のクロスモーダルな効果を検証するため、3D プリンタで作成した床のテクスチャを用い、床モジュールに振動フィードバックを組み込み、さらに、ユーザーテストを通じてその効果を評価した。

キーワード： Mixed Reality, Virtual Reality, Floating Sensation, Multimodal, Floor Texture

1. Introduction

From antiquity to the jet age, and now to orbital tourism, people have dreamt of slipping Earth's gravity grasp. Balloons, gliders, rockets, and space stations all attest to our determination to inhabit the sky. Today, consumer VR headset provide another route: a digital lift off that lets users float weightlessly, pilot personal craft, or even watch an entire room ascend like a balloon. Our work begins with that vision. We ask how a headset, paired with some specific physical cues, can deliver a deeply convincing sense of floating.

Enhancing the feeling of floating in VR demands more than arresting imagery. So long as a user's feet remain on a rigid floor, the body's proprioceptive and vestibular cues contradict what the eyes see, which may erode immersion. A promising remedy is multimodal interaction. By altering floor textures and injecting vibration through the soles, we can narrow the sensory gap and reinforce the illusion of floating. Because this project is in an early exploratory stage, we prioritize an experimental platform that is affordable, easily reproduced, and easy to reconfigure. Our design delivers tactile patterns plus controllable vibration to both feet, transforming an ordinary surface into an unstable, haptically active 'floating' floor.

To materialize this concept, we have built an initial platform that clips interchangeable 3D printed textured tiles onto a haptic floor unit. The raised patterns create uneven pressure fields that cue instability under each foot, while the actuator streams motion, derived in real time from the virtual scene. We have run a preliminary controlled, within-subject study that toggles texture and vibration to quantify their individual and combined effects on perceived float quality inside a mixed-reality scenario. These preliminary results will chart the course for deeper investigations into multimodal flight interfaces.

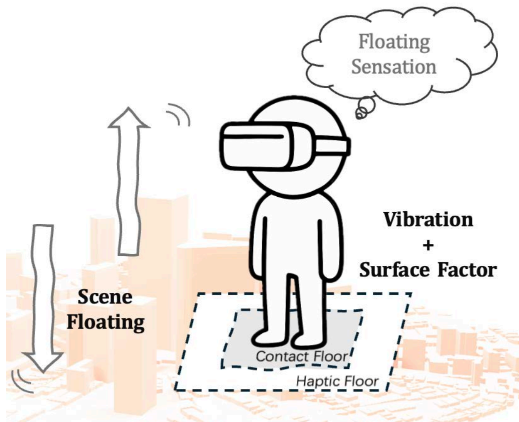

図 1: Concept Design

2. Related Works

Previous research in this area can be broadly divided into two categories, input alternatives and multimodal. The first focuses on enhancing the sense of floating or flying by altering the input method. Instead of using conventional headset controllers, these studies employ either external physical devices or the user' s own body posture as input, which allow users to engage with the flying experience in a more intuitive and embodied way[1, 2, 3, 4, 5]. For instance, Birdly[3] enables users to lie prone on a motion platform and use bodily movements to simulate the experience of flight, thereby enhancing the illusion of motion. Although this approach achieves a high level of sensorimotor involvement, it is limited by high cost and narrow applicability. Magic Carpet[1] explores alternative seated postures as input, while Lost Spirit[2] uses full-body poses to control flight trajectories. However, such systems may lead to user fatigue and often lack complementary multimodal feedback.

The second category of approaches focuses on introducing multimodal interaction to create immersive floating or flying experiences. Among these, applying stimulation to the feet[6, 7] has been explored as a means to enhance the sense of flotation. Drone Rider[6] has demonstrated that delivering compound vibration to the soles of the feet can reduce sensory adaptation, significantly improve the sensation of flight, and avoid exacerbating motion sickness. But this line of work has not investigated whether changes in floor texture, when combined with vibration, could further enhance immersion.

In this preliminary study, we pair interchangeable 3D printed textured tiles with a programmable vibration base to deliver rich and low cost plantar stimulation. The design aims to offer a more vivid and coherent sense of floating without sacrificing hardware effectiveness.

3. Method

3.1 Concept

This research seeks to clarify how foot based tactile cues influence the subjective sense of floating in virtual reality. We focus on two modalities that have rarely been examined together: a static textural signal created by three dimensional printed floor panels and a dynamic signal delivered by a low frequency vibration platform. By comparing a smooth control surface with a texture only floor, a vibration only floor, and a hybrid floor that merges both cues, we want to determine whether their combination produces additive or even synergistic gains in perceived floating intensity, presence, and comfort. Participants stand throughout the experience and provide questionnaire responses after each condition.

3.2 System

The system is divided into two parts: software and hardware. The software is responsible for providing Unity scenes, while the hardware is responsible for providing multimodal haptic interaction. The hardware component is responsible for providing static floor textures and dynamic floor vibration feedback.

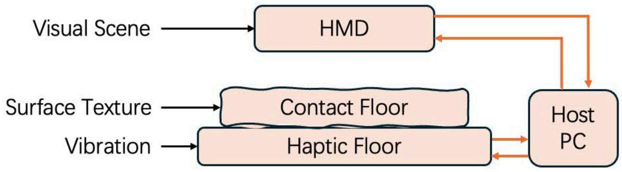

図 **2**: System Architecture

3.3 Software

The application is built in Unity 2022.3.61 with the Meta XR SDK v63 for standalone Quest 3 passthrough, supplemented by the Cesium for Unity package to stream geospatial tiles. All interaction logic is written in C# and Python.

3.4 Hardware

The haptic hardware comprises two Vibro-Transducer VP604 loudspeakers (5 W, 4 Ω) mounted beneath the standing platform and driven by an amplifier. Software converts the vertical velocity of the virtual room into amplitude and pulse width parameters so that gentle rumble accompanies slow ascent, while sharper bursts signal rapid downward motion, mapping scene movement and airflow simulation onto the soles of the feet in real time.

Contact floor is supplied by a set of interchangeable floors printed on a Bambu X1 printer. The tiles measure about 25 centimeters on one side and feature bumps.

The Unity application runs natively on the Quest3 headset, yet remains tethered to a Macbook through a single data cable that carries real time motion vectors and orientation data. A lightweight relay script parses these values and streams them to the amplifier. This architecture keeps all rendering on the headset, maximized system stability.

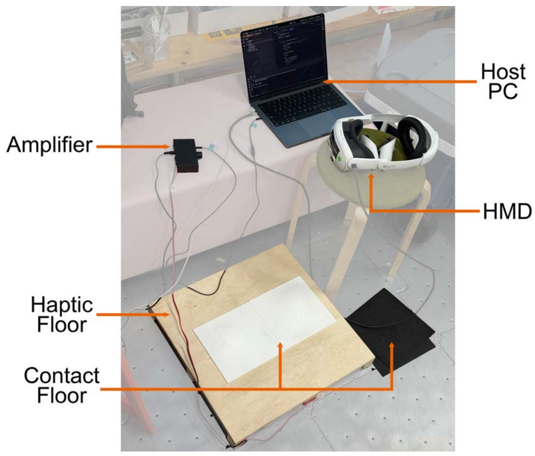

図 **3**: Hardware Showcase

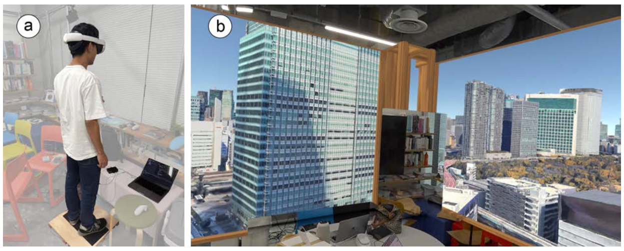

図 4: Overview of the System: (a)User Test. (b)MR Scene Showcase in the Implemented Prototype

3.5 MR Experience of Floating

In this preliminary study, the goal is to convince users that their real world room has begun to float. The application runs in passthrough MR mode on Quest 3, so the headset's cameras show the actual room in real time. MR is part of VR. Every wall in the virtual scene is rendered with a depth only shader, it writes to the depth buffer but outputs no color, which can make the physical walls visually transparent. Through these 'invisible' boundaries, users see a live, geolocated cityscape streamed via Google Maps 3D Buildings, making the room's wall 'disappear'.

Vertical motion is controlled by the user via the Quest controller, allowing them to move the entire scene upward or downward along a nonlinear animation curve. To simulate the imperfect glide of an airborne craft, the motion includes deliberate pauses, subtle jolts, and minor oscillations. This interplay of transparent walls, geo anchored cityscape, and gently irregular movement creates the illusion that the user's own room has lifted off the ground and is now drifting through the surrounding skyline. Meanwhile, the 3D printed and haptic floors provide users with multimodal interaction. The 3D printed floor delivers a sense of instability through foot based tactile feedback, while the haptic floor generates customized vibrations based on the scene's vertical velocity.

4. Preliminary User Test

4.1 Experimental Purpose

The pilot study investigated whether tactile cues from the floor (surface texture and vibration) enhance VR floating sensation. Specifically, we would like to explore the following questions through a questionnaire:

- Does adding plantar vibration (Haptic) and/or a 3D printed bumpy surface (Bumpy) increase perceived floating strength?
- Do the same cues improve overall immersion compared with a visually identical baseline?

The outcome variables were (i) immersion rank, participants ordered the four conditions from most to least immersive; and (ii) floating feeling score, a 7-point rating (1 = very weak, 7 = very strong), as listed in Table 1.

In addition, we added an exploratory question to record which of the three stages (Ascending, Apex Floating, and Descending) the subjects found most immersive, in order to provide clues for subsequent stage-based design:

- Which stage makes you feel the most immersed?

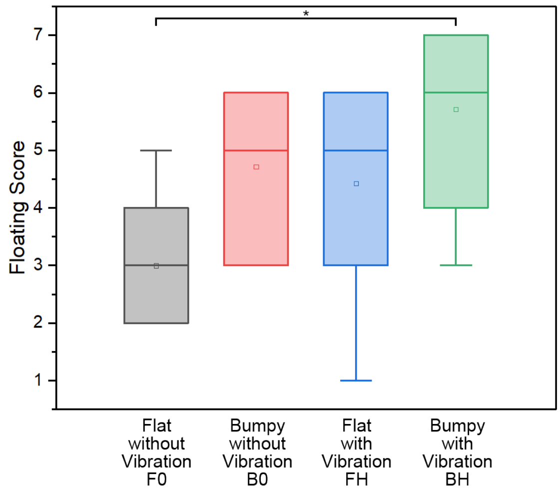

図 5: Box Chart of Floating Score

4.2 Experimental Procedure

7 volunteers (3 males, 4 females; normal or corrected-to-normal vision; no vestibular disorders) completed the test in a design within subjects. Each experienced the following four MR flight/floating sequences, presented in order of Table 2.

4.3 Preliminary Experimental Result

The Friedman test revealed a significant main effect of floor condition on both immersion rank, $\chi^2(3) = 7.80$, $p < .05$, and floating score, $\chi^2(3) = 8.46$, $p < .05$. For floating scores, Post hoc comparisons using the Conover test with Bonferroni correction revealed that Condition F0 differed significantly from Condition BH ($p_{\text{bonf}} < .05$), whereas no significant difference was observed between other pairs, such as F0 and B0 or BH and FH($p_{\text{bonf}} > .05$).These results indicate that the combined BH produces a stronger floating sensation than the F0 baseline, whereas bumpy-only or vibration-only floors did not reach significance, possibly due to the limited sample size ($n = 7$).

Five out of seven participants (71%) reported that the takeoff and climb phase felt the most immersive, while two (29%) selected the descent phase. This suggests that altitude gain and acceleration may enhance immersion more than steady states.

表 1: Questionnaire Design

Questions	Context	Anchors
Q.1–Q.4	Which one do you think is the 1st / 2nd / 3rd / 4th most immersive?	4 floor conditions
Q.5–Q.8	How strong do you feel the floating feeling? (each condition)	Not at all – Very strong
Q.9	Which stage makes you feel most immersed?	Ascending / Apex floating / Descending
Q.10	Comments and suggestions	If any

表 2: Experimental Sequences

Label	Floor Texture	Vibrations
F0	Flat 3D printed plate (black)	Off
B0	Bumpy 3D printed plate (white)	Off
FH	Flat 3D printed plate (black)	On
BH	Bumpy 3D printed plate (white)	On

4.4 Discussion

Quantitative results indicate that the BH condition significantly enhances the floating sensation. Participant feedback supports this trend, highlighting that the combination of vibration and textured floor surfaces contributes not only to kinesthetic realism but also to increased bodily awareness, particularly in relation to balance and shifting center of gravity. These multimodal cues appear to be effective in reinforcing the illusion of floating within the scene.

Several suggestions indicate potential directions for future improvement. Some participants reported that the feeling of instability decreased as time passed. This suggests a need to measure responses at different moments or introduce stimuli in separate phases to maintain immersion. Other comments highlighted the role of visual design, showing that changes to some visual components may enhance the experience. In addition, some feedback suggested using objective data, such as foot pressure or body movements, to complement subjective responses and improve the reliability of immersion assessment.

Taking all factors into consideration, future studies will include a larger number of participants and analyze floor texture and vibration as independent factors, to better understand their individual and combined contributions.

5. Conclusion

This preliminary study suggests that floor-based tactile cues can meaningfully enhance the floating experience in MR. The combined use of texture and vibration proved most effective, supporting the importance of multimodal integration. Future work will expand the sample and incorporate other elements to refine the system.

参考文献

[1] Daniel Medeiros, Maurıcio Sousa, Alberto Raposo, and Joaquim Jorge. Magic carpet: Interaction fidelity for flying in vr. *IEEE Transactions on Visualization and Computer Graphics*, Vol. 26, No. 9, pp. 2793–2804, 2020.

[2] Xin Tong, Alexandra Kitson, Mahsoo Salimi, Dave Fracchia, Diane Gromala, and Bernhard E. Riecke. Exploring embodied experience of flying in a virtual reality game with kinect. In *2016 IEEE International Workshop on Mixed Reality Art (MRA)*, pp. 5–6, 2016.

[3] Max Rheiner. Birdly an attempt to fly. In *ACM SIGGRAPH 2014 Emerging Technologies*, SIGGRAPH '14, New York, NY, USA, 2014. Association for Computing Machinery.

[4] Pinyao Liu, Ekaterina R. Stepanova, Alexandra Kitson, Thecla Schiphorst, and Bernhard E. Riecke. Virtual transcendent dream: Empowering people through embodied flying in virtual reality. In *Proceedings of the 2022 CHI Conference on Human Factors in Computing Systems*, CHI '22, New York, NY, USA, 2022. Association for Computing Machinery.

[5] Ashu Adhikari, Abraham M Hashemian, Thinh Nguyen-Vo, Ernst Kruijff, Markus von der Heyde, and Bernhard E Riecke. Lean to fly: leaning-based embodied flying can improve performance and user experience in 3d navigation. *Frontiers in Virtual Reality*, Vol. 2, p. 730334, 2021.

[6] Kazuya Shimato, Yuta Goto, and Shogo Okamoto. Drone rider: Foot vibration stimuli to enhance immersion and flight sensation in vr. *Applied Sciences*, Vol. 14, No. 24, p. 12019, 2024.

[7] Rolf Nordahl, Niels C Nilsson, Luca Turchet, and Stefania Serafin. Vertical illusory self-motion through haptic stimulation of the feet. In *2012 IEEE VR Workshop on Perceptual Illusions in Virtual Environments*, pp. 21–26. IEEE, 2012.