An Approach of Reducing Motion Sickness in Passive Virtual Driving through Multi-sensory Simulation of Wind Sensation

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Abstract

This paper introduces a method to reduce the occurrence of motion sickness (MS) during passive motion in virtual reality (VR), such as virtual driving. The approach improves the user's sense of embodiment (SoE) by adjusting the vestibular, visual, auditory, and tactile perceptions through simulated wind sensation and visual-auditory cues. We developed an interactive wind-sensing simulation helmet to provide airflow around the head and created a virtual motorcycle driving environment with matching visual and auditory cues. Preliminary experiments helped identify the helmet parameters, and subsequent formal experiments tested the effects of various sensory inputs on motion sickness. The results indicate that the wind sensation simulation can effectively: 1) improve proprioception and SoE; 2) reduce the risk of motion sickness during passive driving.

Index Terms: Motion Sickness, Sense of Embodiment, Wind Sensation, Proprioception, Passive Virtual Driving.

1 Introduction

Experiencing virtual reality (VR) from a first-person perspective can help achieve a high level of immersion. Compared to active motion in VR (e.g., the driver in virtual driving), users face a significantly higher risk of experiencing visual-induced motion sickness when engaging in passive motion (e.g., the passenger in virtual driving) [3]. Visually induced motion sickness (VIMS) is a condition in which symptoms of motion sickness are triggered by visual perception of motion, even without any actual physical movement, which can seriously disrupt user immersion and engagement. In this case, exploring effective methods to reduce the risk of motion sickness (MS) is a crucial research question.

Several theories, including Postural Instability Theory, Vestibular Afferent Enhancement Theory, and Sensory Conflict Theory, explain the mechanisms behind motion sickness, particularly why passive movement increases its risk. The widely accepted Sensory Conflict Theory suggests that mismatched vestibular and visual information causes VR motion sickness [5]. In virtual driving, the risk of motion sickness increases because passive driving, unlike active driving, reduces control, increases perceptual conflict, and exacerbates sensory mismatch, particularly between vestibular feedback and expected motion states [4]. As a result, passive driving leads to a more pronounced sensory conflict, increasing the risk of motion sickness.

Research suggests that integrating multiple sensory modalities, such as visual, auditory, and vibrotactile input, can enhance the sense of embodiment (SoE) and reduce perceptual conflicts. SoE refers to perceiving the virtual body as one's own, which encompasses self-location, agency, and body ownership [6]. Body ownership arises from both bottom-up sensory inputs (multiple sensory signals make the virtual body feel real) and top-down cognitive processes (such as expectations and goals). Synchronizing visual, auditory, tactile, and vestibular inputs can therefore enhance SoE and potentially mitigate motion sickness by reducing sensory conflicts.

Among these sensory modalities, proprioceptive perception plays a key role in enhancing the Sense of Embodiment. Although studies have shown that integrating sensory modalities such as vision, touch, and hearing can improve SoE, consistent proprioceptive feedback also helps to reduce perceptual conflicts and lower the risk of motion sickness [2]. However, the potential of improving proprioception to improve SoE and mitigate motion sickness has not been fully explored.

Therefore, this paper aims to explore a method to reduce motion sickness in passive VR moving by simulating wind sensations around the head to enhance the sense of embodiment. A helmet with four built-in fans was designed to provide directional wind cues in a cost-effective manner. Integrated into a passive VR driving scenario, these wind sensations were synchronized with visual and auditory cues to improve SoE. A user experiment was conducted to assess the helmet's impact on motion sickness, analyzing how different movement directions and states influence motion sickness and embodied sensation.

2 Design

2.1 Theoretical Foundation

Perceptual Conflict Theory and VR Motion Sickness. In VR, mismatches between visual and sensory feedback cause perceptual conflicts, weakening embodiment, and increasing risk of motion sickness. Deviations in sensory information amplify vestibular signals, disrupting motion control [4]. Adjusting sensory feedback can reduce prediction errors and mitigate motion sickness.

Sensory Consistency and Embodiment. Virtual embodiment relies on synchronized visual, tactile, and proprioception cues. Consistent feedback improves ownership and control [1]. Sensory consistency is crucial for motion control. Enhancing proprioception through sensory consistency improves embodiment and reduces motion sickness.

Based on these, we constructed a relational model of multi-sensory coherence on SoE and VR motion sickness (see figure 1).

2.2 Overall Design and Complement

We propose a method of reducing motion sickness through Multi-sensory Simulation of Wind Sensation. It consists of two main components: a prototype VR passive driving scenario and an interactive wind-sensing simulation helmet for use in VR driving situations.

Virtual Scenario Design: A passive motion scenario is created where the user is a motorbike passenger behind a virtual driver.

Interactive Wind-Sensing Simulation Helmet: The helmet simulates air flow based on virtual scene movements.

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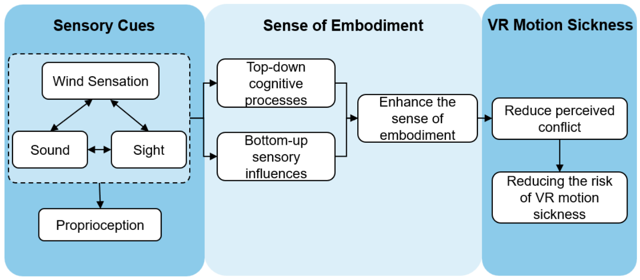

Figure 1: A relational model of multisensory coherence on sense of embodiment and VR motion sickness.

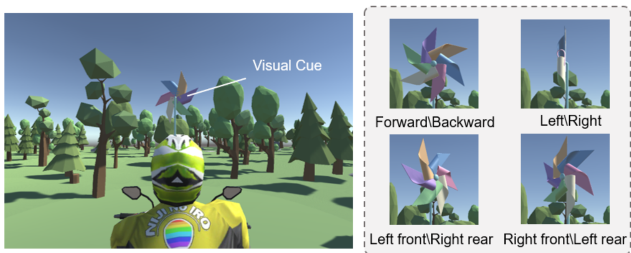

Figure 2: Visual cues in virtual passive driving scenarios.

2.2.1 VR Test Scene Construction

The system simulates a motorbike passenger in passive motion from a first-person view, controlled by a simulator, a VR joystick, or a keyboard. Users feel the direction of the wind through a rotating windmill, providing visual cues that match the movement (see Fig. 2). It supports single- and multidirectional movement with adjustable speed and acceleration to mimic real motorbike dynamics.

2.2.2 The interactive wind-sensing simulation helmet

The interactive wind-sensing simulation helmet uses an STC89C52RC microcontroller, ULN2003 driver, and four fans to simulate wind from all directions. Controlled via Unity 3D serial commands, the wind speed is adjusted by varying the PWM duty cycle to match the user's movement.

3 User Study

An experiment was conducted to evaluate the effect of our method on VR motion sickness, analyzing how moving directions and moving states affect the sense of embodiment and motion sickness.

Figure 3: Schematic diagram of the test environment.

In the pre-experiment, sixteen participants wore an interactive wind-simulation helmet to experience various motion states and directions. The helmet's performance was tested to ensure the settings of related parameters (e.g. intensity and speed of wind) were appropriate, in preparation for the formal experiment.

The formal experiment used a 2 (helmet on/off)×2 (constant/accelerated motion speed)×2 (single/compound directions) within-subjects design to assess the effects of our method on VR motion sickness, sense of embodiment, and presence. Sixteen college students ($M = 21.88, SD = 2.74$) participated in the experiment in a virtual environment like in figure (see Fig. 3). They experienced a variety of motion conditions, including constant/accelerated motion speed in single/compound directions (front, back, left, right, and four combinations). Motion sickness was measured after each condition using the Simulator Sickness Questionnaire (SSQ) and testing was stopped if participants reported significant discomfort. In addition, their sense of embodiment and presence were assessed using 5-point Likert scales. The total experiment lasted approximately 30 minutes, with participants receiving course credits as compensation. The study was conducted according to the guidelines of the Declaration of Helsinki and approved by the IRB of Weihai Maternal and Child Health Hospital.

The results indicated that 1) the SoE score with the helmet on was significantly higher than without the helmet ($t = 4.790, p < 0.001$); 2) the sense of presence with the helmet on was significantly higher than without the helmet ($t = 5.918, p < 0.001$); 3) the level of motion sickness in the compound direction was higher than in the single direction; 4) an increased SoE score significantly correlated with a reduction of VR motion sickness.

4 Conclusion

In this work, we explore a method to reduce VR motion sickness by enhancing the embodied sensation through low-resolution wind simulation during driving. An interactive wind-sensing simulation helmet and a virtual driving scenario were set up to create a passive driving experience with consistent visual, auditory, and tactile feedback. Experimental results show that the this method method significantly improves user perception of embodiment and immersion, while reducing the severity of motion sickness.

Acknowledgments

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