Diminished Reality for Sense of Movement with XR Mobility Platform

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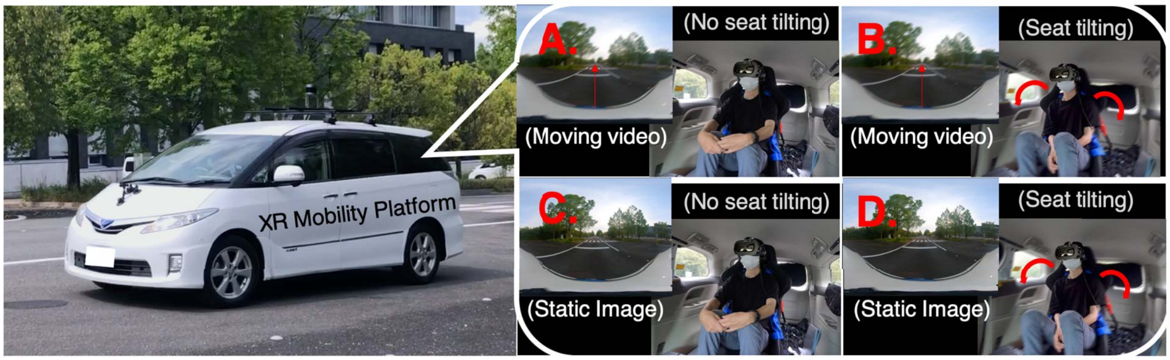

Figure 1: Diminished reality for sense of movement by controlling visual and force acceleration by using XR mobility platform.

Abstract

This paper proposes a method to reduce a sense of movement by controlling a passenger's sense of movement using a multimodal XR system mounted on an autonomous vehicle. The passenger should not be given the sense of movement from the accelerating stimulus, in order to make the space comfortable during self-driving. In the field of VR, technologies have been developed to simulate a sense of movement that does not occur, such as in a driving simulator. However, the purpose of this paper is to solve the inverse problem to reduce the sense of movement generated by real autonomous driving. By using a multimodal XR mobility platform that consists of an immersive display and a motion platform with a tilting seat, we develop a state-of-the-art method to reduce the passenger's perceived sense of movement. This method enables one to perceive the vehicle as if they are not moving, even though they are in automated driving. In the experiments, we evaluated 20 participants under the condition of the combination of visual and force acceleration stimuli. From experimental results, it was confirmed that the sense of movement was reduced significantly when both visual and force acceleration stimuli were not presented in the condition.

Keywords: autonomous vehicle, sense of movement, visual stimuli, haptic stimuli, XR mobility platform

Index Terms: Human-centered computing-Human computer interaction (HCI)-HCI design and evaluation methods, Human-centered computing-Human computer interaction (HCI)-Interaction paradigms

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1 Introduction

In autonomous vehicle research, safety issues and efficiency issues are always targeted to realize the safe autonomous vehicles in the world since more than 90 % of traffic accidents are contributed by human factors [2, 12]. However, considering passengers' comfort inside an autonomous vehicle is also an essential issue as well as safety issues and efficiency issues in terms of widespread in human society and social acceptance [3, 7]. The interior comfortable environment for passengers inside the vehicle will change dramatically when autonomous vehicles are realized. For example, since the driver is freed from driving, he or she becomes a passenger without steering authority, and the windshield and windows are turned into multiple information screens [11]. To build a comfortable space inside an autonomous vehicle, it is important to control the passengers' perceived acceleration stimulus generated by driving and to make the sense of movement disappear [5].

This research focuses to diminish the generated acceleration stimuli problem by using a multimodal XR mobility platform consisting of an immersive display and a motion platform with tilting seats and automatic driving functions.

2 Related work

2.1 Visual effect to control a sense of movement

There is research about controlling the passengers' sense of movement by using visual effects. Benz et al. investigate how a virtual driving simulation system could be visually presented within a real vehicle using HMDs [1]. They show the effect of HMDs or fixed displays can induce a strong presence and movement. Our past research uses the vection effect through the video-see through HMD to induce passenger's body movement for motion sickness reduction inside moving vehicles [14]. However, the vection effect from visual stimuli is not accurate and not strong enough to control passenger's body movement.

2.2 Haptic effect to control a sense of movement

Yoren et al. studies using haptic and tactile information feedback to people inside the vehicle [4]. This study was conducted in a driving simulator to investigate the effects of haptic feedback on drivers' responses. Udara et al. investigate haptic feedback for controlling

2022 IEEE International Symposium on Mixed and Augmented Reality Adjunct (ISMAR-Adjunct) | 978-1-6654-5365-3/22/$31.00 ©2022 IEEE | DOI: 10.1109/ISMAR-ADJUNCT57072.2022.00076

2771-1110/22/$31.00 ©2022 IEEE
DOI 10.1109/ISMAR-Adjunct57072.2022.00076

lateral and longitudinal motions of autonomous vehicles [9]. They created two types of driver-vehicle interfaces for vehicle control; a haptic interface with kinesthetic and tactile feedback, and a hand-gesture interface with augmented reality feedback. These studies mainly use haptic and tactile feedback to provide driving assistance and advance notification of hazards and do not focus on passenger comfort in an autonomous vehicle.

2.3 Visual and haptic effect to control a sense of movement

McGill et al. aims to improve passenger journeys across transportation by utilizing a Mixed Reality head-mounted display [10]. Kodama et al. proposed a novel virtual reality entertainment system using the car as a motion platform that combines with virtual reality content [8]. They both use visual perception or force perception to affect passenger's movement, however, their research mainly focuses on the entertainment inside future autonomous vehicles.

To summarize, no research clarifies the diminished reality for the sense of movement inside the autonomous vehicle by controlling passengers' visual perception and force perception yet.

3 XR MOBILITY PLATFORM

Authors developed XR mobility platform that consists of an immersive VR and see-through AR information display screen or HMD system with a motion platform seat inside a fully autonomous vehicle [13]. Outside view of the autonomous vehicle is a Minivan type with a Lidar scanner mounted on the top of the roof. The projection-based detachable cylindrical screen with a wide field of view or Head-Mounted Display (HMD) can be used as an immersive display to realize a high-presence VR environment inside the autonomous vehicle. Moreover, the system has a function to make a video see-through AR environment by using a projection-based display or HMD that displays images recorded by a dashboard camera. Furthermore, a motion platform with the passenger seat is mounted at the backspace of the Mini-Van that can control the angle of the tilt seat. The seat is only for a passenger, and multiple actuators are connected to the back of the seat to control the tilt by a computer.

4 SENSE OF MOVEMENT REDUCTION METHOD

4.1 Implementation

For the visual cue of acceleration, an omnidirectional camera (Insta360 one X2) was used to capture a full-dome image before starting experiments. In the experiment, participants watch those captured full-dome images through VR HMD. The subject views the image through an HMD (Varjo XR-1) as an immersive display so that the subject cannot perceive the actual horizontal. XR-1 makes it possible to build truly photorealistic mixed reality experiences where virtual objects seamlessly merge with reality for the first time in a full field of view. In conditions in which translational acceleration is given, images are synchronously played back from the previously captured full-dome images, which are cut out according to the direction of gaze. In the condition in which translational acceleration is not given, the image of the starting point is always displayed.

4.2 Motion based control

Actuators are controlled to cancel these acceleration stimuli using the partial force of gravity. At each time point, the position of actuators at which the acceleration stimuli are properly canceled out needs to be estimated. Therefore, the magnitude of the partial force of gravity generated by all combinations of two actuators in their range of motion (0-150 mm) was measured. Actuators 0 and 1 represent the left and right actuator, respectively, looking at the seat from behind, and the numbers on the axes mean their lengths. For example, if only actuator 0 is long, the seat tilts to the right, and acceleration stimulation in the right direction is possible using a portion of gravity. If both actuators are long, the seat will tilt forward and a forward acceleration stimulus can be generated. The speed of actuators were set to 10 mm/s, a sufficiently slow speed that the subject could not perceive the rotation of the chair itself. The motion of actuators in this experiment is shown in Fig 5.

5 EXPERIMENT

5.1 Overview of subjective experiment

In this experiment, we evaluate whether the XR motion platform with the XR system installed in the vehicle can reduce the sense of movement perceived by passengers in an automated vehicle. In general, humans mainly perceive the sense of movement through visuals, force, and hearing. In this experiment, we focus on the sense of visual and the sense of force. In particular, for the sense of force, we investigate the sense of translation in the horizontal plane, such as the back and forth direction generated when the vehicle starts and stops, and the centrifugal force generated when the vehicle curves. There are four combinations of acceleration stimuli as shown in Fig. 1. In this experiment, the automated vehicle automatically drives along a preset route at the auto-driving test area. The route is around 300 m oval course as shown in Fig. 4. Fig. 3 shows the results of measuring the acceleration stimuli received by the subject when seat control is applied (conditions C and D). We recruited a total of 20 participants: 15 males and 5 females, mean age of 25.3 (SD=3.2).

5.2 Experimental procedure

This experiment is conducted after the approval of the Ethical Review Committee of our organization. Each subject was explained the experiment and informed consent before the experiment. Additionally, the questionnaire was about the characteristics of the participant such as driving experiences, car sickness experiences, and VR sickness experiences. First of all, participants were to ride in condition A as a training run and were instructed to answer the sense of movement questionnaire, they felt from this run was the standard for the amount of movement. Condition A is similar condition as the normal driving scenario in that there are visual stimuli and force stimuli. After that, four conditions A-D were ridden by each subject in random order. After each ride, the subjects were asked to answer questions about their sense of movement on a 7-point Likert scale. The questions were as follows.

- How was the sense of movement? (No movement/A lot of movement)
- How was the sense of translation? (No translation/A lot of translation)
- How was the sense of rotation? (No rotation/A lot of rotation)
- How was the consistency between visual movement and body movement? (Very mismatching/Very matching)
- How was the vehicle's trajectory? (No understand/ Perfectly understand)
- How comfortable is the run? (Very discomfort/Very comfort)

The most important question in this experiment is the first question about the sense of movement. The sense of movement consists of translation and rotation. Thus, the second and third questions about translation and rotation are for supplementary evaluation.

In addition, although it is not the main topic of this study, the Simulator Sickness Questionnaire (SSQ) questionnaire was conducted at the beginning and end of the experiment because riding in a moving vehicle with a VR system is a special environment where VR sickness and car sickness occur simultaneously [6].

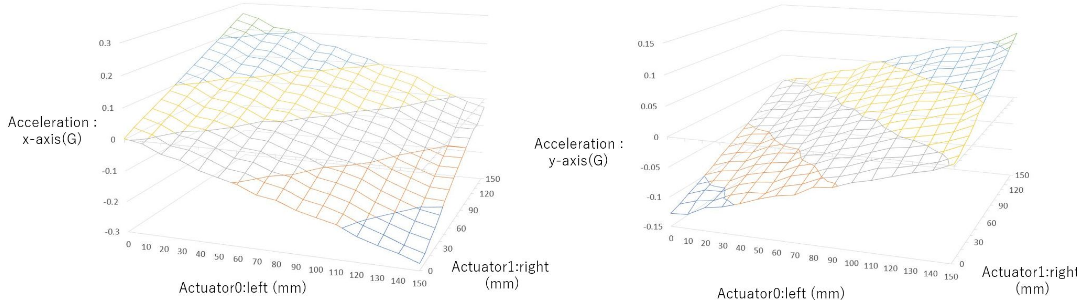

Figure 2: Relationship between the position of the actuator and the acceleration generated from gravity. Actuators 0 and 1 represent the left and right actuators, respectively, looking at the seat from behind, and the numbers on the axes mean their lengths. For example, if only actuator 0 is long, the seat tilts to the right, and acceleration stimulation in the right direction is possible using a portion of gravity. If both actuators are long, the seat will tilt forward and a forward acceleration stimulus can be generated.

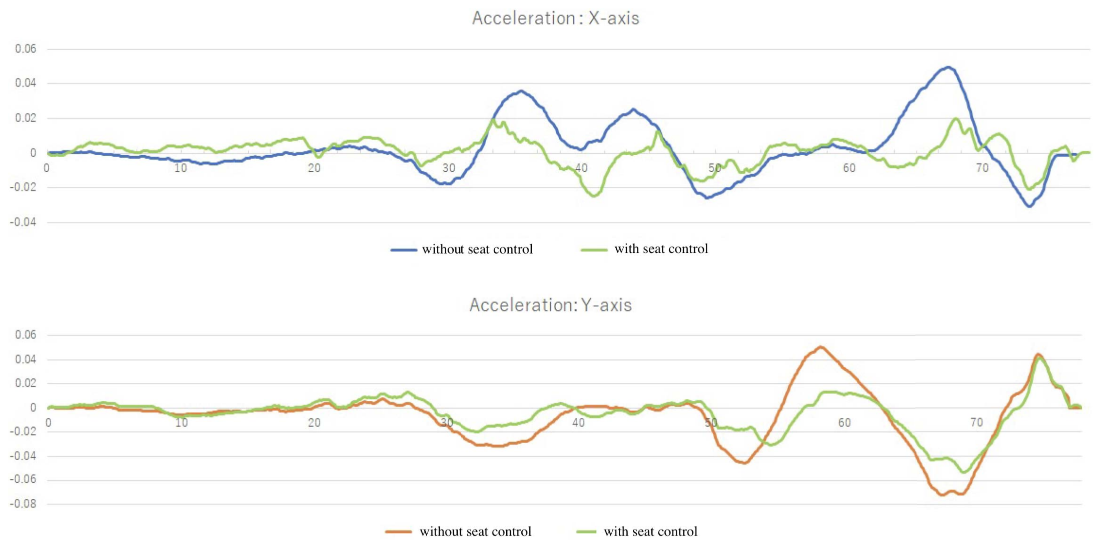

Figure 3: Translational acceleration of movement measured by the sensor when the seat is controlled. Blue and orange lines are the translation acceleration in the X-axis and Y-axis, respectively, without sheet control. The green line is the acceleration with sheet control.

6 RESULTS

6.1 Sense of movement

The result of the sense of movement is shown in Fig. 6. The horizontal axis is the four conditions of the experiment in order of A, B, C, and D. The vertical axis shows the average values of the 7 points Likert Scale, for 1 is no movement, and 7 is a lot of movement that passenger felt. The value of A is 5.1 with a standard deviation of 1.55, and with a standard error of 0.3. The value of B is 5.0 a standard deviation of 1.19, and a standard error of 0.3. The value of C is 3.8 with a standard deviation of 1.77, and with a standard error of 0.4. The value of D is 3.5 with a standard deviation of 1.93, and with a standard error of 0.4. For a test of significance, first, we use the Friedman test for a non-parametric statistical test, that shows the existence of significance with a *: $p < .05$, and **: $p < .01$. Therefore, we use the Multiple-comparison with Bonferroni correction as a method to counteract the problem of multiple comparisons. As the result, there is significance in 4 states, B-D with a p-value of 0.011, A-D with a p-value of 0.005, B-C with a p-value of 0.030, and A-C with a p-value of 0.015.

6.2 Discussion

From the result of the average value of a sense of movement, condition D without visual (static image) and without force (seat titling to control angle) is the most less sense of movement than other conditions. Especially, the proposed method of condition D compared with the passenger inside manual driving condition A in the vehicle with visual from HMD (video-see through) and with force stimuli (no seat tilting), it is obvious the effect of seat tilting to reduce acceleration stimuli to passenger's sense of movement.

There are some limitations to this experiment. First, the control algorithm is simple, few participants still felt a sense of movement even with the control condition of D. Second, the realtime-feedback control is necessary to adjust to the outside environment of the autonomous vehicle and prevent motion sickness. Third, the balance of participants needs to be considered. We recruited a total of 20 participants: 15 males and 5 females. However, gender balance influences the result.

7 CONCLUSION

This paper has proposed a method to reduce the sense of movement by using a multi-modal XR system mounted on the autonomous

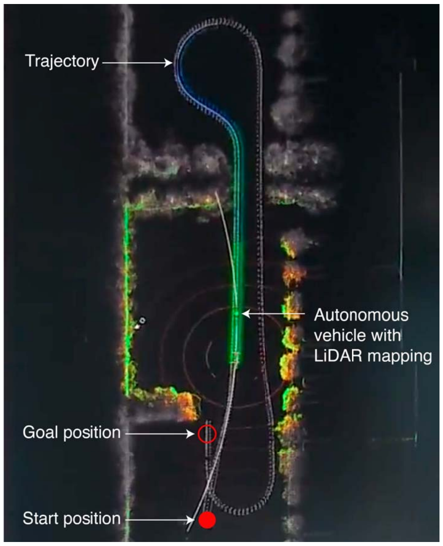

Figure 4: Route of the autonomous vehicle in the experiment.

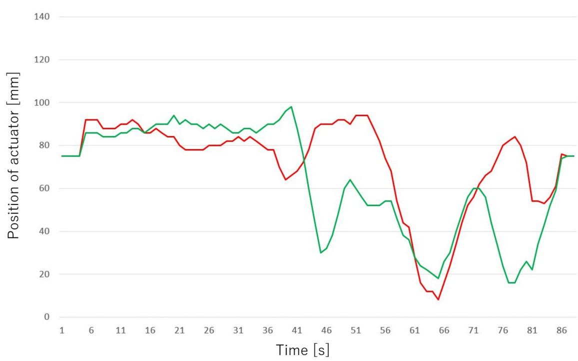

Figure 5: Positions of two actuators in route of experimental. The red line and green line indicate the positions of actuator 0 (left) and 1 (right), respectively.

vehicle for passenger comfort during auto-driving. By using a multimodal XR mobility platform consisting of an immersive display and a motion platform with a tilting seat, and by improving the technology used in conventional drive simulators, we develop a method to reduce the passenger's perceived sense of movement. From the experimental results of 20 subjects, it was confirmed that the sense of movement was reduced significantly when both visual and force acceleration stimuli were not presented. This method enables passengers to perceive the vehicle as if they are not moving, even though they are in an automated driving environment.

Acknowledgments

This work was supported in part by a grant from JSPS KAKENHI Grant Number JP21H03484.

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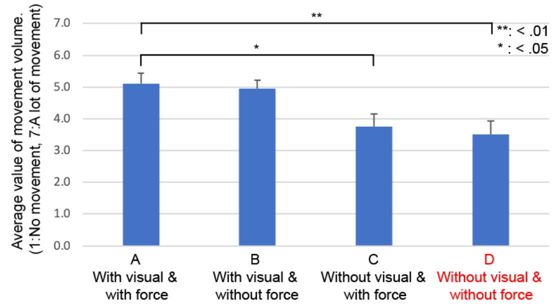

Figure 6: Average value of the sense of movement.

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