Vehicle-Ride Sensation Sharing for Immersive Remote Collaboration with Vestibular Haptic Chair to reduce VR Sickness

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Abstract
We proposed a telepresence system presenting vehicle-ride sensation in real time for remote collaborative tasks. We used a Segway, a personal vehicle for a local driver, and a rotary chair with vestibular haptic feedback for an expert who remotely attends the task. The telepresence system will enable an expert to collaborate remotely with a local driver regarding a highly professional local surveillance task. We conducted a preliminary test on the feedback system design using a rotary seat built for the evaluation. The result showed that the participants adjusted the angular acceleration of the rotary seat at about a half of the angular acceleration of the camera in motion. The seat rotation needed to be in-phase with the rotation of the camera to reduce VR sickness.

CCS Concepts
• Human-centered computing → Human computer interaction (HCI) → Interaction paradigms → Virtual reality;

1. Introduction
Various telepresence technologies which make the user feel as if being in a remote location in real-time, have been widely studied [FFK*12][KR15]. These technologies will allow an expert to perform a task remotely by using the avatar robot sent to various places. However, the latency of network communication has decreased the quality of the current telepresence system so that the user may not control the robot effectively to achieve the task. At the same time, VR sickness usually occurs when the camera attached to the robot head is rotated quickly, which is a common issue for telepresence. These problems need to be solved in order for anyone to be able to experience or operate the remote environment with high perceptual quality.

2. Vehicle-ride sensation sharing system
As a solution to the issue of telepresence, we proposed a TwinCam Go, a vehicle-ride sensation sharing system, for a remote collaboration task that required a vehicle deployed to the long distance workplace such as building or construction surveillance. In our previous study, we proposed TwinCam system that used two 360-degree cameras (THETA V) for reducing motion blur and VR sickness during head rotation by fixing the direction of each camera lens constant in the world coordinate [TFI*17]. This can transmit stereoscopic 3D images in low apparent latency and low motion blur even during quick head rotation.

In the present study, we attached this camera system (TwinCam) to a Segway vehicle via a motion stabilizer. Figure 1 shows our system (TwinCam Go) that can provide both visual and vestibular haptic feedback to an expert observer who sits on a chair and receives the sensation of remote site as the Segway driver. Not only being provided with an omnidirectional view, but the observer receives the sensation of vehicle rotation the driver made, that corresponds to his/her remote body orientation change. We modified an office chair by attaching a DC motor to evoke the sensation of body rotation. We considered that a body motion feedback reduces VR sickness during the visual field rotation. This paper preliminarily reports the relation between rotation of the 360-degree camera and a rotary seat built for the experiment, and shows the effectiveness of rotational motion sensation in reducing VR sickness.

3. Preliminary test for feedback design
3.1. Optimal rotation acceleration for vestibular feedback
The purpose of the test was to investigate the relation between angular acceleration of the camera and optimal angu-
lar acceleration of the rotary seat shown in Fig. 2. Seven 
male students participated in the test. Participants were 
presented the live view from a single 360-degree camera 
(RICOH, THETA V) through the head mounted display 
(HMD, Oculus Rift CV). The camera was rotated by a stepping 
motor in a sine-wave trajectory with the amplitude of 
60 degrees (Fig. 2, right). Participants sat on the rotary seat 
and adjusted the amplitude of rotation of the seat by using a 
controller. The optimal amplitude of the seat was selected in 
terms of three levels of angular acceleration of camera rota-
tion. White noise was presented over the headphones during 
the test. The rotation of the seat and the camera could be 
stopped and restarted at any time.

Figure 2: Rotary seat (left), 360-degree camera (center), 
and waveforms of camera and seat rotation (right).

Figure 3 shows the optimal angular acceleration of the 
seat to the camera. The result suggested that the appropriate 
value of the angular acceleration of the rotary seat was about 
a half of the camera. Since the vision and vestibular sensa-
tion are closely related and processed in an acceptable sen-
sory integration, the equation is expected not to conform to 
a simple linear mapping. Further research is needed for this 
value and the feedback design. Based on this result, power 
to rotate the seat may be less than required for equivalent 
motion of the vehicle.

3.2. Suppression effect of VR sickness

The trajectory profile required for vestibular haptic feedback 
to reduce VR sickness was examined. Ten male students par-
ticipated in the test. The amplitude of camera rotation was 
60 degrees and the angular accelerations of the rotary seat 
were determined based on the result of previous section. The 
vestibular haptic feedback was three levels: no rotation, in-
phase rotation to the camera, and antiphase rotation to the 
camera. The in-phase rotation has the same direction of ro-
tation as the camera, and the antiphase the opposite 
direction of rotation. After each trial, the participant was 
asked to fill in the questionnaire of SSQ evaluation 
[KLB*93].

Figure 4 shows the result. The one-way ANOVA revealed 
that the seat stimulus was highly significant $[F(2, 18) = 6.2, 
p < .001]$. Bonferroni post-hoc test indicated the significant 
difference between in-phase rotation condition and other 
conditions (ps < .05). The in-phase rotation of the rotary seat 
indicated significant reduction of the SSQ total score, which 
means the vestibular stimulus was effective to reduce VR 
Sickness induced by image rotation if the direction of the seat 
was the same as the camera. The antiphase had no effect, and 
did not increase the SSQ score, the reason of which is un-
known.

4. Conclusion

We proposed a telepresence system with providing a vehicle 
riding sensation for remote collaboration. Our preliminary 
test revealed that about a half of angular acceleration of the 
camera rotation was necessary in providing the vestibular 
haptic feedback to reduce VR sickness. Our future work in-
cludes clarification of the effect of vestibular stimulus on 
VR sickness reduction, and to increase the degree of free-
dom of motion of the seat. In addition, the effectiveness of 
our ride sensation system in remote collaboration task needs 
validation.

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