Adding Difference Flow between Virtual and Actual Motion to Reduce Sensory Mismatch and VR Sickness while Moving

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Abstract

Enjoying Virtual Reality in vehicles presents a problem because of the sensory mismatch and sickness. While moving, the vestibular sense perceives actual motion in one direction, and the visual sense, visual motion in another. We propose to zero out such physiological mismatch by mixing in motion information as computed by the difference between those of the actual and virtual, namely, "Difference" flow. We present the system for computing and visualizing the difference flow and validate our approach through a small pilot field experiment. Although tested only with a low number of subjects, the initial results are promising.

Index Terms: Human-centered computing—Visualization—Visualization techniques—Treemaps; Human-centered computing—Visualization—Visualization design and evaluation methods

1 Introduction

Humans spend a significant portion of their time in moving vehicles. Virtual reality (VR) is a promising media that can be used effectively in vehicles for various purposes e.g. for work, meetings, and entertainment. However, one major expected obstacle is the sickness emanating not only from the use of the VR but also from the vehicle motion. Such sickness is attributed to the sensory mismatch between visual feedback and vestibular sense [5].

We propose to cancel out this physiological mismatch by adding and mixing in motion trail information as computed by the difference between those of the actual and virtual, namely, "Difference" flow. That is, by artificially adding the difference flow, the total visual motion equates that of the actual motion and the sensory mismatch and sickness can be reduced (See Figure 1). We present the system for computing and visualizing the difference flow and validate our approach through a small initial pilot field experiment.

2 Related Work

Motion sickness refers to sickness due to riding in vehicles, including cars, buses, boats, and airplanes. Major symptoms include disorientation, headache, nausea, and ocular strains [5]. Typically, humans, while in motion, will receive sensor stimulation in a manner consistent with that of the visual and vestibular senses. The main cause of motion sickness is the "sensory mismatch" between visual and vestibular stimulation [5]. Cyber or simulator sickness is similar to motion sickness but arises when using a motion simulator (instead of an actual moving vehicle). The sickness, in this case, is caused by the same sensory mismatch but in a reverse manner, where the user's body is typically stationary but the visual feedback possesses dynamic components, as exemplified in VR roller coasters.

Extensive efforts have been expended to enable the use of VR in moving vehicles with minimal sickness. Most early approaches were based on replicating actual pathways in a virtual space [2] [4]. In a previous work, the authors have proposed to mix in actual vehicle motion information into "static" VR contents (no virtual navigation), thus making visual motion equal or similar to the actual, to alleviate the degree of VR/motion sickness [1]. The work here extends this approach for the situation where there exist virtual movement whose navigation direction is different from the actual. In another vein, the authors also previously proposed mixing in and visualizing the motion trail in the reverse direction to the virtual motion (extracted from the optical flow) as experienced by a stationary VR user, to similarly cancel out the physiologically perceived visual motion and "match" it to the stationary state as detected by the vestibular sense [7].

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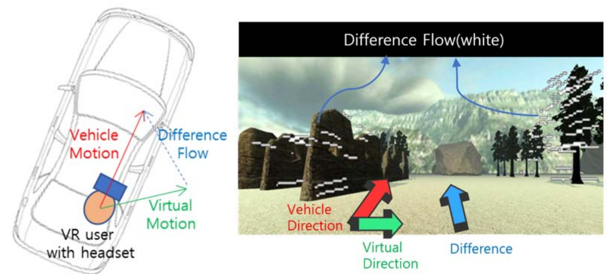

Figure 1: The concept of "Difference" flow for canceling out physiologically (visual and vestibular) sensed motion (left) and the difference flow overlaid as short animated white line segments on the original navigation VR content used while riding in a vehicle (right).

3 System Configuration

The overall proposed system configuration is shown in Figure 2. The motion of a vehicle is sensed by an on-board diagnostic module (OBD) and an IMU sensor in the user worn headset (for now, we enforce the user not to make any view rotation so that the IMU sensor senses the rotation of the vehicle only).

As the user navigates in the virtual space (while riding), visual features from the previous image frame are extracted and its optical flow estimated with respect to the current image frame using the Lucas-Kanade's fast optical flow algorithm [6]. At the same time, with the sensed vehicle motion information, a secondary virtual camera produces an alternative or pseudo current image as if the virtual content moved in the direction of the vehicle. The same feature-wise optical flow is extracted and for each corresponding feature, the difference from the original forward flow is computed. Each difference identifies a new point to where the difference flow should be directed from the feature point. This process is continued and refreshed over a short time window generating a series of difference flow points who are connected as poly-lines and visualized over the content. Figure 1 (right) shows images of the proposed visualization.

4 Pilot Experiment and Results

The pilot experiment was designed as a one-factor within-subject single measure, the factor being whether the difference flow was mixed in or not into the virtual navigation content. A total of 5 paid (KRW 20,000) subjects (4 males and 1 female, mean = 26.6/SD = 3.51) participated in the experiment.

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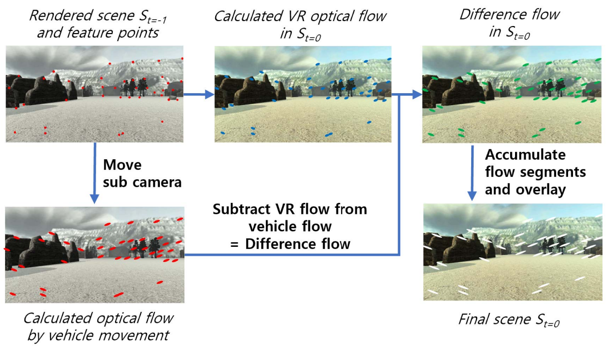

Figure 2: The system configuration of the "Difference" flow visualizer. The directions of the optical flow from the virtual navigation (with the use of the virtual camera), and actual vehicle motion obtained by the sensors (with the use of a secondary camera) are computed for feature points in the content. Then, their differences are computed and overlaid upon the corresponding features as short white line segments, and repeatedly refreshed over a short time window.

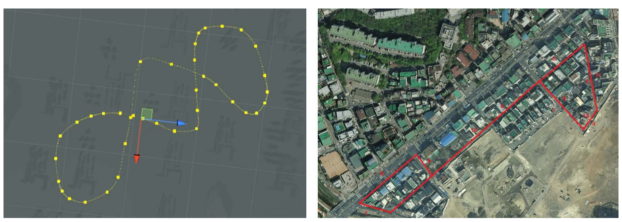

Figure 3: The test navigation courses in the virtual space (left) and the vehicle ride in the real (right).

The subject sat on the passenger side, wore the Oculus Quest2 headset, and experienced the test conditions in a balanced order. The virtual content was a continuous fixed loop navigation over an outdoor field (see Figure 1 (right)) without any roads (so that the user would not have any previous notion of where the navigation was headed). The velocities over the navigation course (about 1.25 km long) was varied with the average speed of 56.25 km/h. The car was driven by a helper moving around a designated course (two times) on local streets near the university campus (approximately 1.5 km, 11 turns in each course round), at an maximum speed of 33.15 km/h (average: 17.39 km/h), which required approximately 5 min. Figure 3 shows the test navigation courses in the virtual and actual.

We primarily measured the motion/simulator sickness levels using the SSQ (Simulation Sickness Questionnaire) developed by Kennedy et al., which involved 16 symptom-specific questions. All questions were answered on a four-point Likert scale (0 = no sickness, 3 = severe sickness), where a higher score corresponded to a higher sickness level. The subcategory scores were scaled by the weight factors, as indicated in [3], for comparison (N = 9.54; O = 7.58; D = 13.92). Between the trials, the user was given at least 10 minutes of rest, during until which the sickness was measured to be negligible (e.g., a total SSQ score of less than 30, as recommended by [3]). After each ride, the subjects filled out a survey to record the experimental effects. In addition to sickness, we also surveyed for the level of immersion/presence and motion perception. After experiencing all treatments, a few additional questions were posed regarding their preferences, and post-briefings were conducted.

The experimental results are shown in Figure 4. Substantial reduction in sickness was observed in all sickness categories. However, no statistically significant differences were found with only five subjects. No particular differences were observed for the user felt

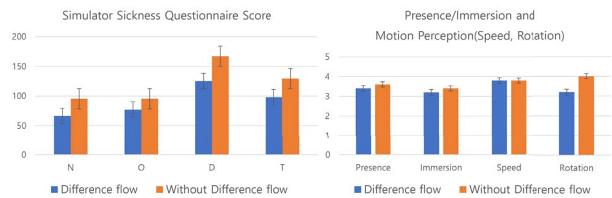

Figure 4: Results of the pilot experiment: although statistically significant differences were not found with five subjects, reduction in sickness was observed. No particular differences were observed for the user felt presence/immersion nor motion perception with the difference flow visualized.

presence/immersion nor motion perception with the difference flow visualized. The post-briefings were mostly consistent with the above results. Subjects reported that without the difference flow, the sickness was more serious, and it did not affect the perception of motion (even though physiologically the motion was supposedly zeroed out). Three subjects answered the difference flow visualized as short line segments were intrusive.

5 Conclusion

In this work, we presented a new method, which visualizes the "Difference" flow between the forward virtual motion and vehicle motion. We believe the difference flow will reduce the sensory mismatch which is the root cause of the motion/simulator sickness. While the initial pilot test showed promising results, further formal validation with a much larger subject pool still remains. The content intrusiveness of the added difference flow is also another issue. We plan to investigate ways to minimize such effects e.g. by applying the proposed method e.g. only sparingly on a need basis (e.g. when there is a relatively high acceleration) or making the visualization less distinct.

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