STUDY: IN-CAR VR HMD USE IN-MOTION

We examined the use of VR HMDs in-motion through an in-car study of passengers wearing VR HMDs watching 360° VR video content as they were driven around a city. We could recreate an ecologically valid driving experience, of particular relevance to autonomous cars and public transport, and examine the effects of real-world motion cues, specifically rotations and accelerations/decelerations, over a set route. Our aims were to examine:

- VR HMDs where all rotations affect VR viewing orientation, regardless of whether they occurred through user head movements or vehicle motion;
- Future positionally-tracked VR HMDs that can compensate, correct for or ignore external vehicle rotation;
- The utility of peripheral visual motion cues to give some sense of external vehicle motion.

Figure 1. Left: Gear VR HMD used in study. Right: Peripheral blending of Condition 6, combining motion landscape and 360° video.

Six conditions were defined. They evaluated the effect of providing a stable VR view relative to car motion (contrasting current VR HMDs in-motion and future VR HMDs that could ignore vehicle motion), and of re-incorporating some perception of vehicle motion through mid-peripheral vision. There were two baselines: ((1) VR video and (2) motion only), an additional Condition (3) to test the accuracy of our motion cues, and three Conditions (4–6) to examine these effects (V=Video, M=Motion)[1]:

1: VR Video Baseline simulator sickness. Users were stationary, wearing a VR HMD, watching 360° video. This was to get a baseline for standard simulator sickness;

2: Motion Only Baseline motion sickness. Users were in motion but not watching VR. This gave a baseline for motion sickness from just being driven in a car;

3: VR Motion Environment In-motion, wearing a VR HMD. The motion of the car was synchronously portrayed in VR, with the HMD user perceiving themselves moving through a basic landscape. This was to evaluate whether our sensing of motion matched what was physically perceived;

4: VR V+M In-motion, wearing a VR HMD, with all rotations (head movements and vehicle rotations) interpreted as head movements. **This conveyed turning of the car**;

5: VR V+M with compensation In-motion, wearing a VR HMD, with compensatory rotations of the video counteracting vehicle rotations. This provided a stable view in VR, **conveying no vehicle motion**;

6: VR V+M with peripheral feedback As Condition 5, with compensatory rotations of the video counteracting vehicle rotations, but with the motion environment of Condition 3 blended into the peripheral $\pm 10°$ of the VR view. This was to evaluate the effectiveness of presenting motion cues mid-peripherally alongside existing VR content. **This conveyed turning and acceleration peripherally**.

Implementation

For the VR HMD, we used a Samsung Gear VR mobile HMD (SM-R322, 310 grams, 96° FOV, see Figure 1) paired with a Samsung S7 smartphone (VR framework version 11, service version 2.4.29, 60Hz). To have the capability to both convey the motions of the car in VR, and counteract the rotations of the car, a Nexus 5 smartphone was used. It was mounted to the car, with its gyroscope (sampled at 30Hz at a latency of ~40ms) providing bearing changes. It was also paired with an OBD2 device (OBDLink LX [72], ~14Hz at a latency of 100ms) for capturing car velocity in real-time. For communicating the car motion to the HMD, we used a SocketIO server over which both the Nexus 5 and S7-powered HMD communicated. The study was conducted in a 2015 model Vauxhall Insignia, chosen both to minimize oscillations (through a modern suspension system) and provide a fast OBD2 link.

There were three software elements. Firstly, we created a motion environment synchronized to the car motion. An initial gyroscope bearing was taken with users looking straight ahead whilst wearing the headset. Subsequent changes in this bearing determined the direction of the forward vector in the motion environment, with velocity also portrayed. Secondly, we stabilized the VR view with respect to car motion. Given the black box sensor fusion of the VR HMD tracking, we chose to exploit the fact that 360° VR video is typically rendered on a sphere, using gyroscope readings to perform counter-rotations of the sphere. Pilot testing showed that readings taken every second frame, combined with linear interpolation to smooth transitions, provided the most comfortable and accurate counter-rotation, accounting for variance in the gyroscope readings. Thirdly, we blended the stabilized video content and the motion environment for the peripheral motion cues. For this we used a shader effect combined with raycasting to determine the current video fixation point, with alpha blending to combine the motion environment and the video.

It is important to note that this approach, whilst suited to a prototype system, had some drawbacks regarding gyroscope drift. A gyroscope is subject to drift over time and motion. In the case of the Gear VR, a combination of gyroscope, accelerometer and magnetometer are used to retain a relatively accurate bearing. However, magnetometer readings are unreliable in-motion, due to variances in the magnetic field and the environment. Thus, it was inevitable that drift would occur. We designed a mechanism to allow users to re-orient the system, taking a new bearing for the forward vector and resetting the Gear VR tracking. To do this, users interacted with the Gear VR touchpad, located on the right side of the headset. If any desynchronization was perceived, they were to look straight ahead and swipe downwards. The VR view then faded out and back in over the course of 2 seconds.

[1] To see how conditions operated in-motion, view the attached video.