In-Car 6-DoF Mixed Reality for Rear-Seat and Co-Driver Entertainment

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Abstract

Conventional VR tracking methods inside a driving vehicle fail out-of-the-box. We present two novel tracking solutions for experiencing a virtual scene on a head-mounted display in a moving vehicle. We leverage advanced vehicle positioning via sensor fusion of existing car sensors to extract an accurate vehicle pose, which we use to mirror car movements virtually. For 6-DoF head-tracking, we exploit IMU-only tracking for two separate approaches - with and without additional hardware. The virtual car, in which the demo user is situated, moves in a virtual urban scene with diverse and appealing VR scenery generated from real world map data.

Index Terms: Human-centered computing—Mixed / augmented reality; Human-centered computing—Virtual reality

1 Introduction

Virtual Reality (VR) and Augmented Reality (AR) open up a variety of interesting applications for use in vehicles, which may be suitable to satisfy the increased entertainment needs during autonomous transit. Of particular interest are Head-Mounted Displays (HMD) that allow full immersion into a virtual reality. Potential use-cases include gaming and entertainment scenarios for passengers, such as a VR roller coaster or a ride through a fictitious landscape while driving. On the other hand, AR HMDs can be used as a full-view headup-display. Contextual information can be merged with the real world, such as historic sites or driving related information.

There are several challenges when using VR and AR HMDs inside a moving car. Conventional tracking methods for HMDs will not work out of the box in a vehicle. This is because the physical forces measured by the HMD's Inertial Measurement Unit (IMU) will reflect the car and head motion combined, while other tracking sensor data may still only provide evidence for the head motion. This creates observation conflicts during the sensor fusion for the final HMD pose. Moreover, the drift of todays IMUs is much too high for high-quality tracking while driving. This creates conflicts between the vehicle movement and the visual representation in the HMDs, leading to motion-sickness and a bad virtual experience.

We solve this problem by an advanced positioning algorithm inside the vehicle and a sensor fusion with the HMD's IMU. In a second step, we add positional tracking with an infrared tracking system. Together with a highly-precise vehicle positioning, we achieve a high-quality immersion and virtual experience which proved to minimize motion-sickness in various test-drives. We evaluate our system in a virtual city model (see Fig. 1) that is built along real map data. We will present this as a drive demo along the roads around the conference venue.

2 Related Work

Hock et al. [2] used a car diagnostic tool and an extra IMU in the vehicle to get a velocity estimate of the car and measure forces on the car. Mapping the vehicle's movement to the virtual helicopter led to

Figure 1: View of the virtual Unity3D scene inside the car from the co-driver seat.

a more immersive VR experience. McGill and Brewster [5] similarly used an extra smartphone as an IMU, a vehicle diagnostic tool and a Samsung Gear VR for rotational-only tracking. They examined multiple scenarios for VR inside the car including 360° video and concluded to include positional tracking since their solution showed high angular drift. Kodama et al. [3] utilize a car as a motion platform to navigate in virtual reality on a track forward and backward. The real world forces of the system are subtracted from the acceleration of the virtual camera to provide visual consistency. Castrol Edge [1] let race drivers wear a virtual reality helmet while racing each other live on the same virtual track.

Compared to mentioned works, our system aims at replicating the real world in VR using sensor fusion of all available sensor data of the car to reduce motion sickness. Our approaches use series sensors and only one additional external sensor for positional tracking. As a result our approach delivers a high quality VR experience with minimized positioning error and motion sickness compared to the state of the art.

3 Rotation & Position Tracking inside moving car

What all commercial state of the art HMD tracking systems like the HTC Vive, Microsoft HoloLens or Oculus Rift have in common is that their tracking results are based on the fusion of some low latency relative IMU measurement and a higher latency absolute measurement. During our experiments we found no practicable solution for such a system to be used directly in a moving environment like a car due to the aforementioned sensor fusion conflicts.

Moreover, preliminary tests quickly revealed that a key challenge of our system is to overcome VR-induced motion sickness while driving. Our approach for addressing this is trying to mimic real head motions as accurate as possible in VR, albeit an 1:1 version of reality is not being possible to achieve with today's hardware. Instead we are targeting the following points:

- An accurate and robust 6-DoF pose estimation of the vehicle.
- An accurate and robust 6-DoF pose estimation for the headset relative to the car coordinate system.
- Preferably low latency between all tracking nodes.
- A virtual street system that resembles the real one.

4 System Overview

This section describes our system architecture to address the aforementioned objectives. It is laid out as distributed network using the

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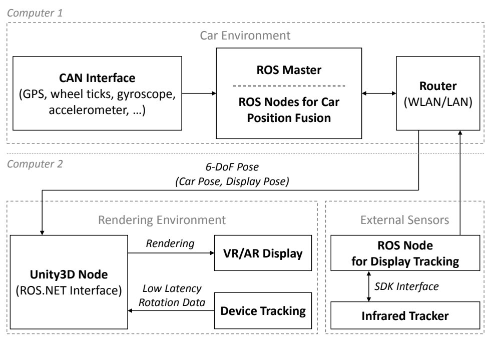

Figure 2: Architecture of our complete system.

Robot Operating System (ROS) to serve as broker between different machines and devices. This flexible approach allows us to use various other head-worn or handheld AR/VR devices besides the Oculus Rift.

4.1 Architecture

Our system can roughly be divided into three parts as depicted by Fig. 2, which will be described subsequently.
The car environment is the basis for our development. It provides relevant information of the current state of the car which among others includes a 6-DoF pose of the car relative to earth, image data of the built-in cameras and information like steering angle.
Additional **external sensors** can be added to the pipeline easily. In the demo we use the infrared tracker PST-Base of PS-Tech to provide 6-DoF pose data of the VR headset.
As **rendering environment** we chose the Unity3D engine because of its wide range of compatibility with available VR/AR devices. As car-embedded systems are to date not capable of rendering high-fidelity 3D scenes, the engine runs on a separate computer. We chose the Oculus Rift CV1 as HMD because of the low latency rotational tracking and the support for integration with a custom positional tracking. Using ROS.NET, we establish connections to Unity over LAN and WLAN with different devices like the VR HMDs plus additional Android, iOS, OSX and Windows devices.

4.2 Sensor Fusion and Tracking

The car environment estimates a 6-DoF pose of the car relative to earth. As GPS alone delivers a too high pose error, we use sensor fusion of gyroscope, accelerometer, GPS and wheel ticks, among others, to compute a much more accurate pose. Furthermore, we experimented with map matching algorithms to counteract the GPS error. Our straightforward implementation, however, produced unnatural lateral car movement which results in even higher motion sickness during user tests and was therefore discarded in the current implementation. Having an accurate 6-DoF car pose, we further reduce the difference between the real and the virtual world through a 1:1 virtual model of the real car in our scene and by calibrating our infrared tracking system to the car coordinate system. Hence, the user virtually experiences the car motion at exact the same spot as it occurs in the real car. Based on the 6-DoF *car pose*, our system currently supports a 3-DoF-rotational and 6-DoF-positional *HMD pose* tracking.

3-DoF-Rotational Tracking

In our scenario the user is restrained to the car seat which is why we tested a tracking method that works without an external sensor. To ensure that the user can estimate depth from head motion without a positional tracking we use a neck model similar to LaValle et al. [4], which estimates a rough head position from rotation only. The Oculus Rift and our car position fusion both estimate an absolute rotation measurement. Since the head rotation has no relation to the car coordinate system, we have to calibrate the forward direction of the headset once after the application starts. This is currently done by a single click on the Oculus remote.

6-DoF-Positional Tracking

An extension to our rotational only method is our positional tracking approach. With the help of a PST Base infrared tracking system we get a position and rotation update of the headset. To keep the low latency rotational tracking update of the headset we use the rotational update of the slower PST only for forward calibration. The positional part of the pose estimation is applied to the head center separately.

4.3 Limitations

Due to third-party software limitations we are currently not able to read the raw linear acceleration of the headset which is why the position update of the headset only relies on the position update of the PST. This latency amounts to up to 70 ms until a head position change takes effect in the virtual world. We are currently working on solutions for reducing this latency.

5 Demo

In our demo, the user sits on the passenger seat of a Mercedes Benz S-Class wearing an Oculus Rift. The demo drive starts and ends outside the Stadthalle Reutlingen and will take about ten minutes. Inside the virtual environment, users will find themselves in an exact virtual mirror of the car while being chauffeured through Reutlingen. The street layout corresponds to real map data. However, the landscape is very different from the real world. While in reality smog or bad weather conditions may prevail, in VR the user drives towards the sunset through a small town, massive cave systems and idyllic forests.

6 Conclusion and Future Work

During the development of the system and demo application, we subsequently reduced VR motion sickness. Whereas in the beginning inexperienced VR users were not able to complete the track without pausing in-between, our current state mimics the experienced physical motion well enough that most users are able to complete the track only feeling a little motion sick afterwards. This achievement is the result of the deep level of integration with various vehicle sensors, combined with the inclusion of optical tracking inside the car, which makes our demo the most accurate in-car VR experience to date.
Accuracy is especially important as a technical basis on which to develop additional entertainment applications. These applications will not necessarily require realism in the visualization, but still an accurate mapping to real forces. Furthermore, a vehicle has already various actuators to, for instance, simulate wind, temperature, and haptic forces, which we will explore to further intensify the immersion in the future.

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