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A Concept For A Virtual Reality Driving Simulation In Combination With A Real Car

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Abstract
Autonomous driving has been developed since the 1980s and grown faster in recent years. However, the human-machine interaction for autonomous driving (in all forms of semi, highly or fully autonomous) is still under development. Driving simulation is still the most practical way of conducting research and evaluates the research outcome with less effort and danger. In order to increase the driver's feeling when using driving simulation, virtual reality helps to create the virtual world with a 360-degree view and 6 degrees of freedom movement. This paper presents our concept and the initial work we have done in the area of increasing the level of immersion of virtual reality driving simulation with a real car.

Author Keywords
Virtual Reality; Driving Simulation; Immersion.

CCS Concepts
• **Human-centered computing~Virtual reality**

Introduction

Autonomous driving has been developed since 1980s [16] and grown faster in recent years to evolve from a dream to the reality. Many companies invested in developing autonomous driving systems [4][11][3]; different approaches and different algorithms have been developed towards fully autonomous driving [6][13][8]. The technical aspects of autonomous driving can be achieved by technology development. However, the cooperative aspect between the human and the car is still an open question and needs more investigation. Human factor plays an important role in designing the user interface for an autonomous driving system. It also affects the driving behavior of autonomous driving algorithms [14]. Legal aspect also affects the designing of response from the car and it changes from country to country. Therefore, there is the demand for a complete human-machine interaction (HMI) design concept for an autonomous driving system that takes all aspects into consideration.

The KoFFI (Kooperative Fahrer-Fahrzeug-Interaktion) project aims to develop an HMI concept that takes into account the different relevant factors like, e.g. humans, legal aspects etc. for an autonomous driving system; so that it can improve the trust of the driver in the automation system through interaction [12]. To prove the design concepts, an iterative and final testing is mandatory. Because of the human factor, testing the interaction with autonomous driving system needs humans using the system instead of computer-based simulation testing. Driving simulation is the most practical way to test the interaction of such system [5].

Driving simulation in cooperation with traffic simulation is not a new topic; it has been developed since the 1960s [1]. With the development of virtual reality (VR), users have the ability to see the 360-degree and 6 degrees of freedom movement within the virtual world. This helps to increase the immersion level especially in the application of driving simulation. In order to have the overall and realistic evaluation results, the partners of KoFFI project develop different types of driving simulators with different levels of immersion. We planned to create a concept that has the highest level of immersion by augmented virtuality approach [15] which combining VR with a real car.

Concept

The aim of the driving simulator is to give the user a maximal driving feeling. In other setup, the physical feeling is often ignored which reduces the immersion. To improve this limitation, we use an Audi S8 car that is cut in half and removed the backside. All uneccessary mechanical parts and also the engine have been removed to save weight. All other parts of the car that are important for driving simulation, for example, the steering wheel, the chair, and pedals, are kept original, including the fully working infotainment system. In order to simulate the movement, a motion platform from D-Box[1] with four 6-inches-actuators is mounted into the car's frame to generate motion. With the setup of four actuators at four corners of the car, the motion platform can generate 3 degrees of freedom movement: roll, pitch, and heave. The simulated motion is achieved by using the relative G-force in the tilted coordinate. Due to the fact that all mechanical parts of the car have been removed, the steering wheel has no feedback from the wheels anymore. Another steering wheel force feedback system

[1] http://www.d-box.com

Figure 1 The actuator is attached to the car's frame

Figure 2 Final concept of VR driving simulation in combination with a real car

from SensoDrive[2] is attached to the steering wheel to generate the haptic feedback and get the steering wheel angle. Force sensors are mounted to acceleration and brake pedals to detect the force adapted by the user.

To generate the immersive view of the virtual driving, the driver is equipped with a head-mounted display (HMD). In our concept, the driver does not move in space, but only the head and hands move. Consequently, both HTC Vive[3] and Oculus Rift[4] HMDs meet the requirements. All activities and interactions are taken place in VR; therefore, the real car will not receive any signals or feedbacks from the environment. Instead, the virtual car inside VR will receive information and react respectively. In order to connect the virtual car and the real car, we use Vector CANoe[5] software to simulate all devices and sensors states through CANbus and getting the reaction of the real car also through those CAN signals.

Two computers are used for the simulation. The first computer runs the residual bus simulator and the second powerful computer with 64GB of RAM, 12 cores CPU, and dual Nvidia GTX 1080 graphic card is used for the VR simulation. The interaction between the driver and the car is done through two main inputs: voice and touch/press/gesture. However, to reduce the complexity of the driving simulator and shift the focus on the immersion, we only use touch/press/gesture as the input for interaction. Motion tracking especially hand tracking in VR achieves good results recently. There are generally three technologies of hand tracking: using an infrared camera, using markers and the combination of both techniques. We plan to use Leap Motion[6] or PST Base[7] for hand tracking. To increase the immersion when driving, the real terrain with roads and rivers of the state Baden-Württemberg in Germany is also modeled. The scene is enriched with weather effects and high-quality texture. The final concept model is shown in Figure 3.

Preliminary results

Audi engineers helped us to cut the Audi S8 in half and attached to the motion platform a steel frame as shown in Figure 1. Based on the simulated motion when tilting coordinate, the motion platform can simulate the basic motion of acceleration, braking and turn left/right. The vibration of the engine can also be simulated. The acceleration pedal from the Audi uses a throttle/pedal position sensor DTC P2122/104. When applying 5V to both input voltage terminals (VCPA and VCP2), the sensor terminals (VPA and VPA2) give the output from 0V to 5V in proportion to the degree of depressing the accelerator pedal. We use an analog-to-digital board attached to a Raspberry Pi 2 to read the voltage signal and convert to a digital signal by a Python script. The braking system is a fully mechanical system; in consequence, no position or pressure detection mechanism exists in the brake pedal. We apply a force sensor on the brake pedal to detect the pressure. The force from driver applies to the brake pedal can be up to 500N [7], therefore the normal force sensor which has the characteristic only up to 20N can not be

[2] https://www.sensodrive.de/DE/Produkte/Force-Feedback-Wheels/Senso-Wheel-SD-LC.php

[3] https://www.vive.com

[4] https://www.oculus.com/rift/

[5] https://vector.com/vi_canoe_en.html

[6] http://leapmotion.com

[7] http://www.ps-tech.com/optical-trackers/optical-tracker-pst-base/specifications

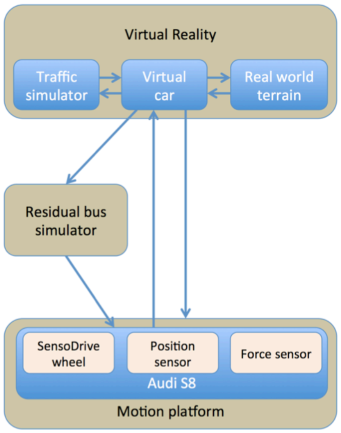

Figure 3 Concept model

applied. We employed the load sensor from a personal weight scale as an alternative solution. Both signals from acceleration and brake pedals are transmitted to the motion platform controller application and the virtual car controller application. An area of 8 km x 8 km surrounding a medium sized city in Baden-Württemberg is modeled with full roads structure.

Current Problems and challenges

"*It is physically impossible to correctly simulate large scale ego-motion in the limited space of a laboratory*" [9]. In the setup of the real car, the four actuators are installed at the corner of a rectangle of 1.7m x 1.2m. The maximal extent of the actuator is 6" (approximately 0.15m). Therefore, the maximal pitching angle is around 5 degree that is not enough to generate a good acceleration and braking motion. To overcome the limitation, some tricks in motion simulation can be applied [9] and the "shifting perception" [2][10] trick in VR can also be applied. The force sensor on brake pedal does not react linear to the brake mechanical system. For that reason, the signal is not reliable enough. The solution can be replaced with other types of force sensors or using the force-feedback pedal from SensoDrive.

The integration between different technologies also generates a delay in signal processing from the sensor to the motion platform or the virtual car. A solution here would be to create a private reliable IP network between the components by using the UDP transmission protocol to reduce the transmission time. The real car can only be in working state when all sensors and devices in are in working status. However, the removed mechanical parts cannot generate any signals. In consequence, a complete signal simulator has to be developed which simulates all the missing parts of the car. This residual bus simulator also plays the role as a gateway to transmit the signal between the virtual car and the real car.

Using infrared cameras gives the driver the freedom of movement and the physical feeling of hands. However, this technique is only accurate for static objects [18], in an application which requires gestural interaction, the virtual dashboard UI, and the real car dashboard need to match precisely. The inaccurate hand tracking will create ambiguous feeling to the driver [17]. The proper solution is to use infrared camera in combination with markers. The graphic processors' power is still an obstacle in generating detail and high-quality graphics in VR. The high-quality Audi dashboard 3D model with 15 million polygons when running in the Unity3D engine can only render 15FPS with the powerful computer.

Conclusion and Outlook

Increasing the immersive level requires fine works in every detail. There are rooms need to refine the integration quality from the smoother motion, the precise hand and object tracking to the detail graphic quality. Many programming tasks need to be done to simulate all ECUs of the car. Also, the data transmission between the virtual environment and the real car are not yet clearly defined. We also have to experiment and compare between solutions to find the best combination for hand tracking. A traffic generator algorithm for traffic simulation is also not clear to use the waypoint or an AI system to react to the set of traffic rules. We are confident that the project success will create the next generation of driving simulation where the driver is fully immersed in the virtual world.

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