Virtual Reality Automated Driving Simulator for Rapid HCI Prototyping

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Abstract
Nowadays, HCI Research on automated driving is commonly carried out using either low-quality setups with 2D monitors or expensive driving simulators with motion platforms. Furthermore, software for automated driving scenarios is often expensive and hard to modify for different scenarios. We plan to fill this gap by proposing a low-cost, high-fidelity immersive prototyping solution by utilizing the recent advances in development of virtual reality (VR): AutoWSD - Automated driving simulator for research on windshield displays. We showcase a hybrid software and hardware solution as well as demonstrate how to create scenarios for user studies, and thereby encourage discussion about potential improvements and extensions for AutoWSD, as well as the topic of trust, acceptance, user experience and simulator sickness in automation.

Author Keywords
Virtual Reality, Augmented Reality, Windshield Display, Head-up Display, User Studies, Prototyping, Driving Simulator.

Introduction
Evaluating human-centered concepts and theories on automated driving is often conducted with the help of user studies. For example, in 2018's AutoUI proceedings, 30 of 35 published full papers utilized them, whereas 27 (90%) of

Figure 1: Take over request trigger, displayed in yellow, for triggering a manual take over.

Figure 2: City scene.

Figure 3: View from the user's perspective with an example text shown on the windshield display.

those implemented functional prototypes (i.e. no low-fidelity paper prototyping or similar). However, having realized user studies on HCI concepts for automated driving in the past, planning and executing them is often a time-consuming and repetitive task. In many cases, we had to start from scratch when designing a new scenario, especially when involving multiple devices and types of interaction and communication. Therefore, we designed and implemented a software framework in combination with external hardware for more immersive user studies. This setup allows study organizers to have full control over the use case scenarios which is often limited when using proprietary software. The presented system is already in use, and with our demo, we want to foster discussion of possible use cases, improvements, changes and extensions for this implementation.

System Description

AutoWSD is a software system with interfaces for hardware devices (e.g., steering wheel, pedals, microphone, webcam; see Figure 5) which aims to facilitate the design, implementation and evaluation of HCI user studies in the context of automated driving. Therefore, we introduce a low-cost high-fidelity driving simulator in virtual reality, created in the popular and widely-used Unity development platform [14]. Although we recommend the use of this simulator in virtual reality using a VR headset (see Figure 4), however, the use of one or multiple monitors is also possible. The VR approach has the benefit of allowing users to experience the vehicle with 6DOF, and according to a comparative study by Walch et al. [15], VR was preferred to flat screens in racing games.

Figure 4 shows a typical setting we use when conducting user studies. The study participant is wearing the HTC Vive Pro Virtual Reality headset, which includes speakers for audio output. The Logitech steering wheel and pedals are utilized for manual driving as well as handling take over re-

Figure 4: Demo setup with a virtual reality head-mounted display, steering wheel and 4K screen.

quests. The microphone next to the steering wheel is used for speech input. The monitor is used by the study organizer to see the progress of the participant.

WSD System

Our research focuses on windshield displays (WSDs) [10, 9]. Therefore, the view management of the AutoWSD VR driving simulator renders content on these large 3D displays with continuous depth (see *WSD System* in Figure 5). This has the benefit of reducing or even eliminating physical and visual clutter in the center console [11], a single interface for all in-vehicle infotainment systems [4], and the visualization of potential dangers directly in the driver's field of view [7]. Figure 3 displays an example of such a WSD application, that presents text content (as placeholder for e.g. emails or news articles). For this demo, we showcase different content placement and visualization strategies for WSDs.

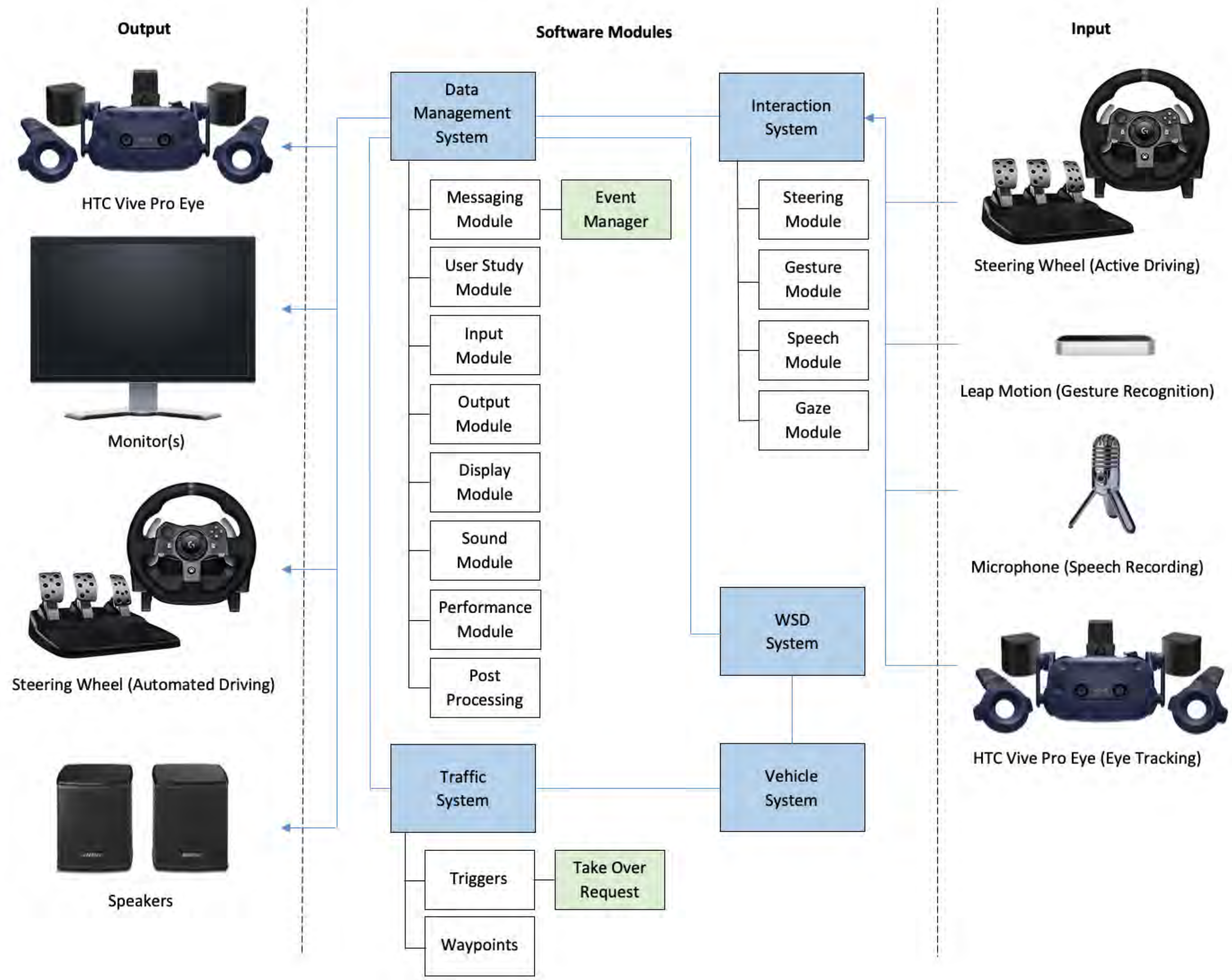

Figure 5: Graphic representation of the various architectural components constituting the AutoWSD driving simulator.

Envisioned Interaction

The users of this demo will have the possibility to experience all the interaction interfaces (speech, gestures, gaze and steering wheel/pedals) and get a feeling for the level of immersivity conveyed by such a novel realistic setting. The experience is also interesting for people in the audience not wearing the VR headset: they will have the opportunity of controlling some events including take-over requests (see Figure 1) and switching between manual and automated driving. It is possible to interact with the vehicle using speech, gestures, gaze and the steering wheel/pedals.

Interaction System

We pursue a multimodal approach for interaction types. For this purpose, we implemented interfaces for the interaction modalities *speech*, *gesture* and *gaze* that can be used either independently or combined. As shown in Figure 5, we have separate modules for each interaction modality. Other components of the system can register for interaction events using the *EventManager*, and perform actions upon occurring events.

Gestural Interaction

Gesture interactions can be used for many applications in vehicles, such as controlling infotainment systems [1] and performing maneuver-based interventions in automated vehicles [16]. Since the driver can observe the outside environment (e.g., road, pedestrians) instead of focusing attention to in-vehicle controls, gestures enable the advantages of increased road safety [5] and natural interaction [11]. In AutoWSD, we utilize the hand and finger tracking capabilities of Leap Motion and implemented multiple gestures, such as *Swiping* left/right, up/down, forward/backward, *Palm* facing up/down, *Finger postures* (thumb up/down, index finger forward) and *Fist*. In the context of a combined view and interaction management concept, a potential use of the fist gesture would be to show the main menu, while a swipe down gesture could trigger a minimize-all-windows operation. Swiping left and right could render previous and next applications, analogous to the app switcher on tablets.

Gaze Interaction

The human attention focus is closely related to the viewing direction [3], and gaze as input modality has been researched [8, 2]. Additionally, gaze has the potential to further augment interactions, such as pointing gestures [12]. Therefore, we also consider gaze an integral part of interaction design for windshield displays in automated driving.

In the future, we plan to elaborate the use of eye gaze as support for other interaction modalities, such as gestural or speech input.

Speech Interaction

With voice user interfaces (e.g., Amazon Echo, Google Home or Apple Homepod) gaining more and more popularity recently, speech as interaction modality, with little or no visual feedback, is gaining more traction for automated vehicles. Auditory user interfaces in the context of automated driving offer many advantages, for the purpose of warning the driver or infotainment commands (e.g., [6, 13]). We use the Microsoft Speech API (SAPI) to recognize spoken (key)words by the user and transform them into text, which is further processed. For example, spoken keywords or phrases such as *Open Music Player* or *Show News* can be used instead of, or in combination with, eye gaze or gestural inputs.

Experience

We will host a live and interactive demonstration of the AutoWSD system. The users of this demo will have the possibility to experience all aforementioned interfaces and different scenarios (e.g., our city scene; see Figure 2) in an immersive virtual reality environment. Additionally, we make all source code and project files visible at the booth. If requested, we will explain how to design scenarios in the Unity Editor, such as creating streets, waypoints for the vehicles to follow, windshield display user interfaces, take-over request triggers etc.

In the future, we intend to open-source release the presented software framework and we are confident that AutoWSD will help the scientific and industrial UX community in rapidly prototyping and testing automotive applications and scenarios.

On-Site Requirements

Space: a booth to introduce people to the system, and showcase an example implementation;

Power: 5 power sockets to power the laptop running the VR simulation and the hardware (VR lighthouses, steering wheel and pedals);

Connectivity: wired/wireless internet connection for accessing the speech recognition service of the driving simulator;

Optional: monitor or beamer to present the driving simulator's view to all participants, at all times.

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