TeleOperationStation: XR-Exploration of User Interfaces for Remote Automated Vehicle Operation

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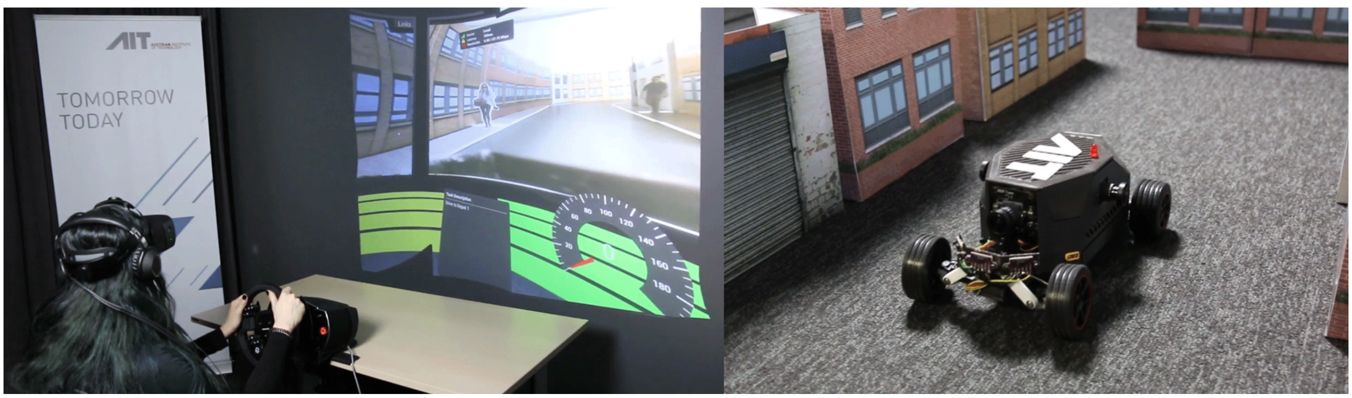

Figure 1: The VR operation station (left) and the vehicle equipped with four 120° cameras and proximity sensors in the physical model environment (right).

ABSTRACT

With increased automation levels of vehicle technology, human involvement is expected to be transformed from a driver towards an operator role. This transition will entail remote monitoring and possibilities for intervention of driverless vehicle fleets. Thus far, there are insufficient tools available for user interface development and experimentation, which renders it difficult to quickly devise, prototype, and test solutions to support operators in their specific work contexts. We present the TeleOperationStation, an extended-reality experience prototyping environment, which coherently simulates automated fleet operation workflows, covering non-driving tasks, monitoring, takeover requests, and full remote vehicle operation. During this interactive demonstration, on-site and online conference participants will be enabled to experience and co-create user interfaces for remote automated vehicle operation, using AR from a first-person viewpoint, and controlling a physical miniature vehicle.

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CCS CONCEPTS

• **Human-centered computing** → *HCI design and evaluation methods*; **Systems and tools for interaction design**.

KEYWORDS

Human-Computer Interaction (HCI), remote operation, teleoperation, automated vehicles

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1 INTRODUCTION AND MOTIVATION

The introduction of automated vehicles is expected to transform the management of vehicle fleets in individual and public transportation [8], as well as freight transport and intralogistics [2, 3]. With increased automation levels of vehicle technology, the role of the driver will shift towards an operator and passenger. Moreover, monitoring and control interventions will increasingly be performed from remote locations, whereby operators may have to manage an increasing number of vehicles at the same time. As a consequence, human factors research has started to define requirements for the support of human remote operation of driverless automated vehicles, [1, 5–7]. The need for interactive prototypes for testing novel UI features for remote operation has been recognized, but experimental environments are restricted to highly specialized scenarios and functionalities, such as predictive displays for specific cars [4] or for public transportation scenarios [8].

Consequently, it has so far been difficult to iteratively test new ideas scenarios that are representative for the work context of a remote operator. Figure 2 illustrates a typical workflow which often involves non-driving related tasks, in which the vehicles are driving autonomously. In case of an event in which the automated vehicle needs an operator to refocus her/his attention, a takeover request has to be issued by the system that suits the respective work situation. The system then has to provide the operator with an overall briefing of the situation (i.e. about the overall position of the system, the problem that occurred, and potentially recommended further actions).

When the operator has then achieved situational awareness and decides to intervene by a teleoperation, he/she needs to be prepared for teleoperation. Once situation awareness has been received to the required operational level (e.g. having oriented from a first-person perspective, knowing where to drive, recognize the surrounding traffic, other road users and obstacles), the operator performs the remote driving activity, navigates and, if necessary, communicates with other process participants. After the teleoperation phase, the human operator then should be prepared for the non-driving related task and the handover should be realized.

To help evaluate different interaction methods and HMI aspects throughout this cycle we present "TeleoperationStation" - a pervasive experience prototyping environment for developing and testing automated vehicle fleet operations in extended reality. Its core is a miniature vehicle which is controlled remotely by a human operator. Operation via VR with visuals only coming from vehicle-mounted cameras provides a low-cost setup with a high degree of realism and immersion. Deployment of the vehicle in a miniature environment instead of a fully simulated one provides a degree of physicality and further enhances its ecological validity.

2 DESIGN GOALS

In order to achieve its intended contribution, TeleOperationStation follows the following design goals:

- Coherent experience simulation of automated fleet operation workflows: Through VR simulation, the flow from a non-driving task, as depicted in Figure 2, can be experienced. This makes it possible to design for control transitions and enables the imagination of cognitive load and situation awareness requirements of teleoperation tasks.
- Physical setup of teleoperated vehicles: We developed this physical setup, in contrast to driving simulations [9], to prevent the operator from disconnecting with reality and having video game like experiences. Because of the miniature aspect, it still allows for user errors, like crashing into the environment, which are not feasible with real vehicles.
- Teleoperation assistance and automation features: Built-in sensors on the vehicle, including cameras, micro-lidars and others enable the investigation of assistance features for remote operation.
- Open configuration and adaptation: The situation this setup allows for rapid use case development as the environment itself is built with paper cutouts and can simply be re-situated according to another driving task. Therefore, software development is needed when evaluating different environments. Code and templates for materials are provided open source.

3 SYSTEM AND ENVIRONMENT DESCRIPTION

In the following, an overview of the XR architecture of TeleOperationStation is provided, and physical vehicle and environment are described.

3.1 XR architecture

The remote automated vehicle management operator is equipped with different displays for remote management of fleets. In case a vehicle has to be directly teleoperated, VR glasses are used, in combination with the steering wheel (hardware and/or virtual representation via Varjo XR-3[1] or Oculus Quest 2[2] hand tracking). The VR environment is realized by Unity[3]. It consists of the video feeds, a floating user interface pane and the steering wheel. On a primary display, the visual information directly related to the visual scene is provided, including 360° camera streams and sensor-based proximity cues. This information is streamed from the four cameras and sensors mounted on the vehicle to Unity. Secondary displays contain additional elements, such as non-spatially oriented UI elements displayed on the floating 2D pane.

3.2 UI experimentation

User interface features can be made available on the primary or on a secondary display, based on the requirements from Graf and Hussmann [5]. Apart from information about the status of relevant vehicle parts (tires, light, weight), these include means for spatial orientation, such as a 360° remote view, and navigation. They can also include a marker indicating the vehicle heading (similarly to [4]), the display of the predicted driving lane and further landmarks. Furthermore, information on the respective driving task can be provided (such as time constraints, tasks to complete, task priority, as well as the projected need to shed tasks). Also, information on the quality of the communication line (about the available bandwidth and signal strength, the mobile carrier) and sensing reliability (camera status can be given.

3.3 The Vehicle

The vehicle consists of custom hard- and software. The chassis was 3D printed in a FDM (Fused Depositing Modelling) printer and

[1] https://varjo.com/products/xr-3
[2] https://www.oculus.com/quest-2/
[3] https://www.unity.com

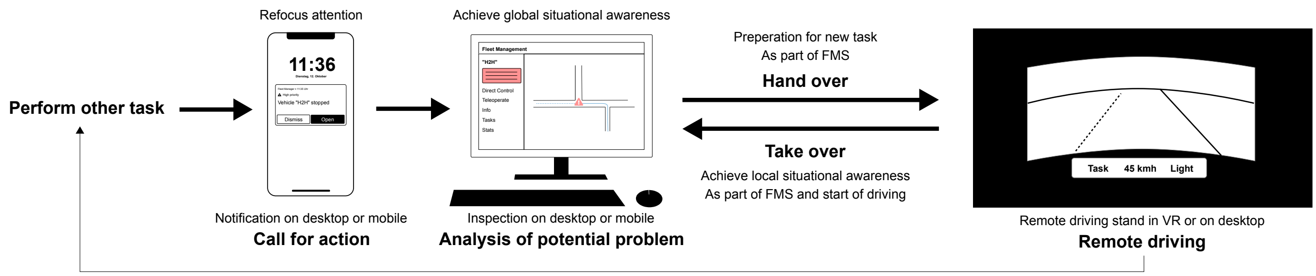

Figure 2: Cycle of automated fleet operations to be covered by the experience prototyping environment

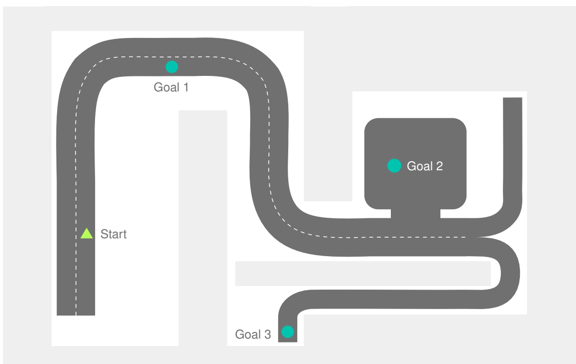

Figure 3: Example track with three different scenarios. The grey areas represent obstructions. Goal 1 is in sight. Goal 2 is behind three turns. Goal 3 incorporates a tight space and turns.

was designed in Autodesk Fusion 360 to allow for four cameras to be attached. The four Arducam B0261 120° Field-of-View cameras are mounted on all sides of the vehicle (front, sides, back). Four cameras were chosen in contrast to one 360° camera to adapt to current vehicles which may not allow for one camera mounted on a platform on the top of the vehicle. Additionally, multiple VL53L0X ToF (Time-of-Flight) sensors are attached on the outside of the chassis which are used for proximity alerts in the interface. A Nema 8 stepper motor which is controlled by a TMC2209 stepper driver. All components are controlled be a Raspberry PI 4 which exchanges data with Unity via WebSockets and streams the USB camera feeds over Wi-Fi.

3.4 The Physical Environment

To allow for different use cases, an adaptable physical environment was built in which the vehicle can drive around in. Scaled down facades of houses and containers are printed as paper cutouts. These objects can be placed around a small area to built new tracks and environments. An example track is shown in Figure 3. This example track consists of three different driving tasks combined in one environment. The first task is the simplest and the goal is in direct sight of the operator. This allows the study participant in the role of an operator to understand the handling of the vehicle. The second goal is behind three bigger corners which may require the operator to look at the side video streams and the built in navigation system. The third goal additionally requires the operator to drive in a narrow corridor. To avoid crashing into the side the operator may find the proximity alerts useful.

4 INTERACTIVITY CONCEPT

4.1 On-site demonstration

The on-site demonstrator will consist of the operation station on a table as well as the remote-controlled vehicle in the physical driving environment on a floor surface of approximately 3x3m. There will be one presenter for the operation station and one for the driving environment. Visitors can stand in line for either one. They can choose to modify the physical driving environment and observe the remote-operated vehicle reacting to and driving within it, or operate the vehicle themselves. Both stations run concurrently and participants can make changes to the environment before or even during another visitor is operating the vehicle (to a limited degree and guided by the presenter). Visitors at both stations will be guided and introduced into using the system by the on-site presenters, so that each can be limited to the maximum of 5 minutes per visitor. A separate monitor will be placed on the far-end of the operation station table, which will show the VR view to all attendees. Equipment brought to the site will be a laptop computer, the miniature car, printed environments, a steering wheel, pedals, and VR glasses. The monitor for showing the VR view we would request from the organizers.

4.2 Online

The online-attendees will simultaneously see two live camera feeds next to each other, one showing the VR (in-vehicle) view, the other showing the driving environment and vehicle. The presenter (in the environment view) will explain briefly explain the motivation behind the demonstrator and then narrate the interaction (performed by a second individual as the operator) as it occurs. The virtual attendees will be able to see everything the operator sees, as well as the interaction with the environment. The introduction and live demonstration is intended to last approximately 4 minutes, to allow for one minute of questions from the attendees afterwards.

5 CONCLUSIONS AND OUTLOOK

TeleOperationStation is an interactivity demo to showcase challenges and potential solutions regarding design and experience of remote operation of an automated vehicle fleet. The virtual cockpit allows for effective prototyping of different control interfaces and can be extended with, e.g., mission status or task information for integration into a fleet operation cycle. The physical driving environment reduces the need for virtual environment modelling and provides an additional degree of tangibility. Physics also do not need to be modeled, since the vehicle and its environment are not virtual.

Through the immersion enabled by the extended reality setup, on-site and virtual visitors can gain novel insights and exchange. The system is ready to be used in its current state (and is actively being used within the AWARD project) but we also work on improving and extending it further, based on results and lessons learned from user studies. Thanks to the modular setup, extensions and modifications can be done with reduced effort and others who want to use or adapt it can choose to use all or only parts of it.

Conceptualized as a research environment, TeleOperationStation is intended to be openly used by anyone interested. All required components are available off the shelf, and instructions on how to assemble them are provided in an open repository. With public demonstrations such as the one planned for this conference, we expect a more successful uptake of safe and operator-friendly remote management technologies for automated transport.

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