6. Virtual Reality Environments for Presentation, Elaboration and Evaluation of Autonomous Vehicles for Public Transportation in Singapore

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Autonomous vehicles (AVs) represent a major innovation for the automotive industry, but their potential impacts regarding their implementation on user perception, behaviour and acceptance remain hazy. Will it really improve future mobility and therefore our daily lives, especially when the technology of autonomous driving is implemented in the field of public transportation, like Singapore foresees? A challenge is therefore to figure out possibilities and opportunities, but also challenges for autonomous driving in the future. Since the technology of AVs is not mature yet, its impact on efficiency, comfort and safety can only hardly be predicted. For a successful implementation of AVs in Singapore, one open field, for example, is the investigation of users' perception and their behaviour in traffic with AVs in order to predict potential risks on the one hand, but also users' acceptance on the other. Based on these challenges, and especially with such a complex topic, how is it possible to remain innovative and work effectively within the conceptional phase of AVs for public transportation without losing time and costs on prototyping? How can justifiable and reliable data be collected in order to predict the impact of AVs in an efficient way?

Due to the fact that real life experiments, involving daily traffic of Singapore, pedestrians, passengers and AVs, are highly complex to set up, exceedingly expensive and potentially dangerous for human test objects, it is planned to use a virtual reality environment like CAVE (Cave automatic virtual environment) systems and Head Mounted Displays (HMDs) for setting up a virtual experiment test bed. Within this test bed, specific scenarios will be simulated with a fully immersion of the test object.

In this context, the main objective of the presented research is the development of a scientific method for elaboration, evaluation and presentation with the help of the virtual reality systems to replace building up a physical prototype. This includes preliminary tests that simulate real-life setups which are compared to actual real-life setups in order to measure the reliability and justification of the collected data within a virtual reality system. Furthermore, the scope covers the analysis of existing virtual reality systems to ensure the usage of the most fitting system for the stated project.

The case studies for the method are based on specific scenarios involving AVs as part of the public transport of Singapore and other traffic participants, such as pedestrians or passengers. One of these scenarios is how pedestrians and AVs can communicate in an active and/or passive way on a junction without traffic lights.

The research is part of TUMCREATE research in cooperation with Singaporean agencies and partners.

6.1. Introduction

Transportation is developing towards level 5 automation1. A study on autonomous vehicles (AVs) by Intel & Strategy Analytics (2017) predicts an economic opportunity of $7 trillion annual revenue by 2050, generated by businesses connected to level 5 AV technology. Furthermore, the study predicts that 585,000 lives could be saved between 2035 and 2045 thanks to this technology. The aforementioned technology is estimated to be implemented into daily traffic by 2030 (IHS, 2014).

Singapore's population grew from 3.5 million in the late 1990s to more than 5.4 million in 2014 (LTA, 2014). Furthermore, it is predicted that until 2030, population will increase to 7 million. An additional fact is that in Singapore, road space is limited. This means that infrastructures for mobility (like streets) only can be expanded to a certain extent. One way to tackle this growth within the circumstances is to enhance the local public transport system, such as the metro.

At TUMCREATE, a joint research institution of the Technical University Munich and the Nanyang Technological University Singapore, a gap was identified between the high speed and high capacity metro with its sparse proximity to destination and low speed and the low capacity bus system with its high proximity to destination. Within TUMCREATE, research is focused on filling this gap with a new public transportation system, the Semi Rapid Transit. The concept constitutes a whole transport system that is well integrated into the existing public transportation systems, as well as the infrastructure. Therefore, an interdisciplinary team consisting of Computer Scientists, Electrical- Mechanical- and Traffic Engineers, as well as Industrial Designers works on this road- based autonomous public transportation system, which is as flexible as busses, but still has a higher speed, thanks to features like autonomous mobility, virtual right of way, lane priority and decreased dwelling time.

6.2. Related Work

The "Design for Autonomous Mobility" department, with its team of Industrial Designers, is focused on the development of the newly proposed system with a user-centred design approach. Main topics are:

1. SRT Mobility Concept (e.g. SRT station, lane design, integrated mobility, payment)
2. SRT Vehicle Concept (e.g. interior and exterior design for autonomous vehicles (AVs) with universal design approach)
3. AV Communication Strategies (e.g. communication between pedestrians and AV)

Especially within the third research scope, validation of concepts is difficult since conducting experiments in real life conditions would imply great efforts in time and money spent, and would still remain potentially dangerous for test participants since AVs still misinterpret situations. One example that underlines this is a misinterpretation of the situation by a Tesla Model S in self-driving mode that resulted in a fatal accident (circumstances of the accident described by The New York Times, 2016).

Therefore, at TUMCREATE, VR is used as a platform for usability tests for concept generation and evaluation of communication concepts. Furthermore, it is investigated how VR can be a platform for concept presentation to an audience.

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[1] In contrast to level 0 automation, which means the human driver has to perform all aspects of the driving task, level 5 automation means that humans do not overtake or influence any task in any driving situation, but act solely as passengers (SAE, 2014).

VR is already being used in the product development process, especially when physical prototypes are not available or the tests can lead to hardware damage or injuries (Berg & Vance, 2016). In certain situations, like for instance training time for pilots, VR can be even more effective than the “actual” training (Mihelj, 2014). With Virtual Reality, conditions like the weather can be changed easily and design variants can be tested and compared without great effort.

VR can be enabled through systems like, for instance CAVE (CAVE Automatic Virtual Environment) (Cruz-Neira, 1992) or Head Mounted Displays (HMDs) (Sutherland, 1968).

This leads to the overall research question: *“How can VR environments support the design process for presentation, elaboration and evaluation in the context of autonomous vehicles for public transportation for Singapore?”*

6.3. Method

Together with the Computer Scientists in the department of Area-Interlinking Design Analysis (AIDA) of TUMCREATE and ARS Electronica Linz, Austria, the department of Design for Autonomous Mobility created a VR platform for elaboration, evaluation and presentation of autonomous driving for Public Transportation in Singapore. For this purpose, the so called Deep Space 8K, a high resolution CAVE system in Linz, Austria, was used.

It consists of two projection areas, one on the wall and one on the floor. Both areas have dimensions of 16 to 9 meters and a resolution of 8000 pixels in width. Thanks to the 8 4k projectors, virtual content can be displayed in 3D and with a 120 Hz frame rate. The floor area is equipped with laser tracking. Together with a HMD this constitutes the Interactive Virtual Research Lab. In this virtual immersive and responsive environment it can be observed how humans interact with a partly real, partly virtual vehicle, and their responses to various AV communication strategies can be easily sensed, tested and verified using the 3D virtual immersive environment. This would not be possible otherwise, unless we make working prototypes with additional sensors and test them in real world situations, which consume far more time, effort and funds. This research tool enables an impressive visualisation and live experience of vehicle concepts, mobility systems and operation strategies at a city scale which is understandable to scientists, students and people from various backgrounds. The setup can be used for research. It is ideal for data exploration and design review without complete isolation from the real world. Additionally, it limits the necessity of physical prototypes and experiments in real-life conditions while it is still capable to validate concepts. As an immersive experience with a shared experience, the Interactive Virtual Research Lab also enables the visualisation of validated concepts in an innovative way (TUMCREATE & Ars Electronica Future Lab, 2017).

6.4. Case Study for Singapore's Public Transportation

One of the case studies for the application of the Interactive Virtual Research Lab is the communication between pedestrians and AVs in situations where there is no traffic light. This includes for example zebra crossings. Since AVs do not have a driver anymore, misunderstandings in and/or misinterpretation of crucial situations become potential issues. Currently, pedestrians communicate directly with the driver of an approaching car. This happens with communication strategies like eye contact and/or gestures (Šucha, 2014). The Interactive Virtual Research Lab is used as platform for the validation of Human Machine Interaction (HMI) concepts. In this case, the visibility and comprehensibility of semantics that are used for HMI with AVs in a multicultural environment like Singapore are tested. To represent the population of Singapore, the recruitment reflects a multicultural distribution between Chinese, Malays, Indians and others. Additionally, a wide array of age groups is represented (children, adults, seniors) and the gender distribution is equal.

To validate the concepts, test objects conduct usability tests inside the Virtual Research Lab with equipped HMD. Methods like error analysis, taking the time to complete a task, and reaction time measuring give insights about the behaviour in the aforementioned scenario. This is supported by interviews before and after conducting the experiments.

6.5. Outlook

As a next step, a calibration of the setup will be conducted in order to ensure the validity of the collected data. To do so an example scenario will be tested within the Interactive Virtual Research Lab, as well as in real life conditions. After the tests, the results are compared for congruence of outcome. Thus, the overlap defines the validity of the collected data.

Furthermore, the transferability of concepts to other cities and/or countries will be tested. The used case of Singapore is a special one, due to the city's rapid population growth and limited road space. With the help of the Interactive Virtual Research Lab, the transferability of for instance HMI concepts to other cities/countries can be tested.

Finally, the VR method as a whole will be tested in terms of transferability. This means that the application is not limited to autonomous mobility but has the potential to be applied in several fields.

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