Potential and Challenges of Augmented Reality in the Context of Automated Driving

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Abstract
In the next years, it is likely that automated vehicles (AVs) will be introduced into the market. Since AVs decisions are not always comprehensible, the driver/passenger may not understand why specific decisions are made, and therefore feel uncomfortable or even anxious. For a wide adoption of AVs, it is thus important that decisions are understood – which in turn leads to higher acceptance of AVs and trust in automation. To develop an understanding of the vehicle's actions, augmented reality (AR) technologies can be used. AR Head-Up Displays (HUDs) are already used commercially in some vehicles, e. g. to display navigational information. This approach can be further refined or extended to allow users to understand on which basis AVs make decisions. The usage of AR applications in the context of automated driving can generate a large value, but there are still several constraints in technology and some new problems that arise with the application of this technology during driving. This reflection paper states some fundamentals points which need to be considered before AR can be applied in vehicles. For better imagination, we use the example of trajectory visualization of surrounding AVs to explain the problems.

Author Keywords
Augmented Reality (AR), Automated Driving, Challenges of AR, Head-Up Display, Head-Mounted Display, Potential of

AR, Understanding of Vehicle Perception

CCS Concepts

•Human-centered computing → Mixed/augmented reality;

Introduction

An increasing number of vehicles are becoming equipped with automated driving systems (ADSs) and advanced driving assistance systems (ADAS). However, some proposed advantages (such as reduction of congestion, increased junction throughput or less emissions) can only be realized if such systems are widely adopted by large user groups. Some commonly cited barriers for automation include trust and acceptance; two hurdles that may slow the success of this kind of technology[11] [5]. In automated driving, human operators are put in charge of safety critical systems and thus operators' trust levels must be calibrated accordingly to prevent both overtrust (automation used beyond its capabilities) and distrust (automation not used at all) [12]. To foster trust in automation, it is important to provide timely feedback and feedforward messages about the system and its goals in the form of "why and how" information [3]. This way a shared mental model can be created where the intentions and decisions of the system are made transparent to the user [3]. In this context, it is important to design future in-vehicle HMI's that actively foster trust in the applied technologies. AR can be applied to visualize the functionality of autonomous systems [7].

In the transition from manual to automated vehicles, AR will be applied differently depending on the automation level. Some applications will get outdated over time and other applications will be required for newly introduced functions. For more complex tasks, AR indication may be needed over a long time period whereas other tasks may be learned and understood after a short period of time and therefor can be deactivated if the user wishes so. To use AV related AR applications properly in the near future, several limitations still need to be overcome, in general AR research as well as constraints which will occur due to the application field of automated driving.

Potential of AR in Automated Driving

Due to the increasing amount of in-vehicle information (provided by secondary tasks as using infotainment to listen to music, call, read e-mails, etc.) the drivers' attention is easily drawn away from their main task, namely, steering the vehicle safely. Further the level of attention during the driving task is unsteady [8] as for example driving in dense fog requires higher awareness of the situation than driving by daylight with a free view. A restricted perception range in combination with distraction due to secondary tasks is likely to pose a risk to the drivers' and others' safety on the basis of cognitive overload and a consequently weaker driving performance. Reduced situation awareness leads to human error which in turn can lead to accidents. Lack of situation awareness at high workload results in about 90% of accidents happening [1].

Since humans perceive about 80% of their environment visual the visual channel HMI can be utilized to merge and display driving relevant information in a way which decreases mental workload and distraction while driving. To achieve these results AR displays can be used which display information in the driver's direct line of sight. In partly automated driving AR applications can support the drivers and reduce the risk of accidents, in the transition phase to automated driving the focus will be shifted to a more explanatory purpose of correctly interpreting and understanding the operating principle of the vehicle.

Three kinds of AR displays are applicable in the context of driving, head-up displays (HUDs), windshield displays (WSDs) and head-mounted displays (HMDs). Each of these display technologies can be used to reduce mental workload and a more secure driving experience in terms of partly automated driving or support drivers of AVs in the process of understanding the vehicle's decision.

Each display type is suitable for the usage in AV context but to a different extent. HUDs for example are already used in some vehicles to inform the driver about e. g., current speed limits, navigation directions, etc. For this the information is displayed in the direct line of sight using a projector. Since the display area is rather small it is well suited for static information which has no need to be aligned with the physical environment. Windshield displays (which represent a larger variant of HUDs) will be likely to cover the whole windshield in the future. Extending these HUDs to the whole windshield is a promising approach to place information more precisely in the driver's/passenger's field of view [6]. With WSDs it is possible to place information dynamically on top of the physical environment since it covers a much larger viewing area. At the moment WSDs are not available yet. Another alternative are head-mounted displays which allow to place information in the users' field of view regardless of their viewing direction. This approach allows to place information dynamically but also to place omnipresent static information which is displayed screen-fixed and therefor independent of the driver's viewing direction.

Summarized it is possible to render information at a fixed location (screen-fixed) or dynamically, depending on the environment (world-fixed) [4]. Information as vehicle velocity or amount of fuel are examples for screen-fixed information, whereas for line assist or a pedestrian warning system a dynamic concept in a world-fixed approach is suitable.

AR applications are reasonable for manually operated vehicles (with ADS or ADAS) as well as for AVs. While the driver is still in control of most actions of the car in partly automated driving, AR can be utilized to support the driver and on this way lead to less accidents and a higher road safety. This comes in handy especially in extreme weather conditions as fog, snow or heavy rain where the driver's range of view is restricted. Drivers/passengers may feel to be in danger as also their knowledge of the surroundings is limited. Even though data obtained by a optical sensor, i. e., camera, may be unusable, data collected by other sensors, e. g., radar, lidar, etc., can be used to preserve knowledge of the surroundings of the own vehicle. Indicating oncoming and preceding vehicles as well of possible hazard in scenarios in extreme weather conditions significantly increases the trust level of the drivers in the applied support functions/automated driving functions [13]. There is evidence that AR displays reduce the mental workload while driving and also significantly diminish distraction due to secondary tasks (looking onto the dashboard or middle console) the time the driver is looking away from the road is decrease due to shorter viewing distances [9][10]. In the transition phase to fully automated driving more and more automated driving functions will be added over time. A large part of these functions will be highly complex and thus difficult to understand for the drivers/passengers. Since the understanding of the vehicle's decisions is the crux of accepting AVs it is important to create a basic understanding of the underlying principles. AR technology can be used to display the vehicle's perception for a more transparent view on the AVs' functions.

Fully Automated Driving: Indication of Trajectories

Enhancing the driver's field of view by presenting an abstraction of what the vehicle can "see", could increase driver trust and afford a better understanding of the vehicle's capabilities and intentions. Understanding the rationale for a vehicle's current and projected behavior are significant factors that influence driver performance in dynamic situations [2]. We hypothesize that this understanding becomes more important as, for example, predictions of future traffic could lead to ambiguous situations (shared driving lanes adapting to traffic volume, junctions without traffic lights for increased throughput, etc.). For this purpose, Augmented reality head-up displays could be utilized to examine how presentation of enhanced visual information may evolve over time since, for example, some visual aids will become less relevant with increasing system experience.

When approaching complex junctions, new drivers may need different information than those that are experienced with the automated system. This different information may be designed to specially develop a shared mental model over time. Since experts will have established a shared mental model of the autonomous car's behavior, other information may be more useful/effective. Thus, we might speak of an adaptive support system that aims to provide the most relevant and salient information to drivers' given both their experience and the current driving context.

An example of a driving scenario which may confuse the drivers/passengers in a fully automated vehicle are junctions with a high throughput. Figure 1 shows an example case for a junction.

It seems to be a feasible approach to display information of the vehicles' trajectories in a kind of introductory phase to allow the driver/passenger to get used to the function. As

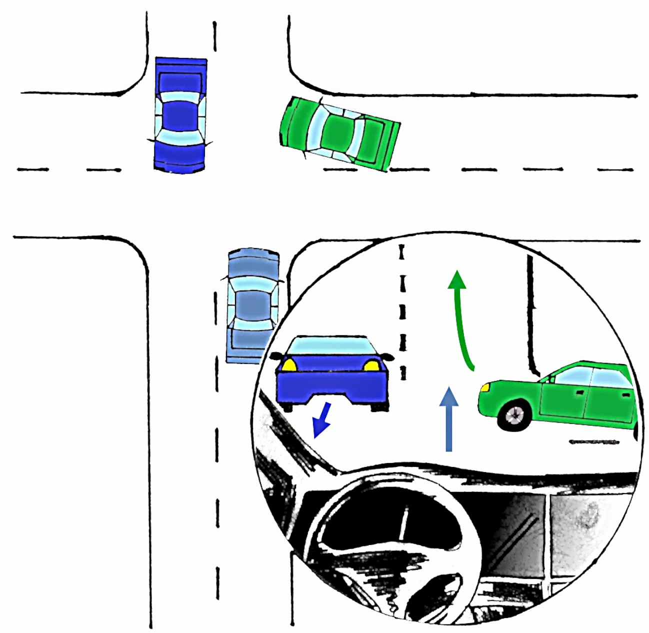

Figure 1: Sketch of the underlying principle: To maximize throughput on a junction, cars pass in a hardly predictable manner, which could irritate vehicle occupants and decrease trust in automation. AR HUDs or WSDs that display others' (and as well the own) future trajectories may increase trust by conveying information that suggests systems are accurately perceiving complex and dynamic environments.

soon as the user understood the function the trajectory information can be omitted.

Challenges of AR in Automated Driving

For simple AR applications information of the surroundings (e. g., in form of depth data) need to be gathered. Based on this, virtual objects can be placed as an overlay on top of the physical environment using an AR display.

In order to exploit the full potential of AR technologies in combination with automated driving there are still challenges to meet. The main aspects which currently still limit future-oriented AR applications in vehicle are first of all the computational power, followed by perception issues and the decision of which information is important to be displayed without overloading the display.

Computational Power

- Vehicles are safety critical systems and therefore every split-second counts for reacting correctly. For this reason low latency is crucial to deliver safety critical information in real time to the driver.
- Since information regarding the surroundings are obtained by multiple sensors the data often is fused to achieve a higher understanding of the situation. This data is then processed to create content displayed by AR technology. The preparation of data is expensive.
- A future vision is V2V communication which will be used for a higher understanding of the surrounding but comes with a immense data volume.

Perception Issues

- The AR application needs to be viewable regardless of lighting conditions.
- Important environmental information should not be occluded with superimposed information.
- In a world-fixed approach the information has to be placed in the correct perspective. For this the tracking of the surrounding needs to be combined with the tracking of the drivers' head/eyes. Disturbance variables as vehicle vibrations, e. g., due to engine movement, or shocks due to the road surface need to be considered.
- Current HMDs only cover a small field of view due to technical restraints. This may lead to missing urgent information i.e. using a HMD with world-fixed information which is displayed outside the displays boundaries and thus outside the area where information can be perceived.

Information

- In partly automated driving AR technologies are likely to be used to reduce mental workload. For this a possible information overload needs to be prevented.
- To increase trust in AVs the vehicles' perception has to be prepared in a way to grant transparency and understanding of ADS and ADAS.
- Not all information needs to be displayed all the time, some information, i.e. less complex, constantly used functions as line assist and ACC, only need to be introduce for a short time period and can be skipped after the drivers/passengers understood the function (in terms of an adaptive experience based shared mental model).

Physical problems

- Constantly focusing between the physical environment and the projected superimposition is likely to trigger eye strain which can lead to fatigue, which is dangerous while the person is still the main operator of the vehicle.
- Using HMDs over a longer time period can be cumbersome and lead to headaches.

This listing states some of the aspects that need to be considered to allow successful implementation of AR technologies for driving.

Conclusion

AR seems to be perfectly suited to enhance understanding of AVs. AR technologies can already be applied in the transition phase to fully automated driving, since they are capable to increase road safety by displaying the vehicle's perception. Once the driver is mainly in a mainly observing position AR can be utilized to explain the operating principles and make them transparent to the passengers of AVs. Still multiple problems need to be addressed to exploit the full potential of AR technologies, e. g., display technologies need to be developed further, computational power needs to be increased to process and prepare data.

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