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2021

Preprint:

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Designing for Prediction-Level Collaboration Between a Human Driver and an Automated Driving System

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Figure 1: Summary of the driver's prediction input into the iTFA AD system: Firstly, the automated driving is conducted by iTFA system while the GUI shows the ego vehicle's perception of surrounding traffic and the planned trajectory. Furthermore, if the system predicts the lane-changing behaviour, the corresponding vehicle will turn red. The driver can observe whether the prediction and plan are in line with their preference (picture 1). Secondly, if the driver wants to intervene in the prediction of the system, they can click the button while gazing on the vehicle indicating that it may change lane (picture 2 and 3). Thirdly, after the system has received the driver's input, sound feedback is provided; the GUI version of the indicated vehicle turns red and an arrow icon appears in the GUI(picture 4 and 5). Finally, iTFA re-plans the ego vehicle's trajectory and adapts the vehicle control accordingly (picture 6).

ABSTRACT

Although automated driving (AD) systems progress fast in recent years, there are still various corner cases that such systems cannot handle well especially for predicting the behavior of surrounding traffic. This may result in discomfort or even dangerous situations. Results from a previous Wizard-of-OZ study suggest that the collaboration between human and system at the prediction level can effectively enhance the experience and comfort of automated driving. For an in-depth investigation of the confluence between AD and driver, a prototype was implemented in a driving simulator driven by a functional AD system that has been partially validated on the public road. Furthermore, we designed and implemented a gaze-button input for intuitive vehicle referencing and a graphical user interface (GUI) for enhancing the explainability of the AD system. Three typical driving scenarios in which an AD could take advantage of the human driver's anticipation to drive more comfortable and personalized were created for subsequent evaluation.

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AutomotiveUI '21 Adjunct, September 9–14, 2021, Leeds, United Kingdom
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ACM ISBN 978-1-4503-8641-8/21/09.
https://doi.org/10.1145/3473682.3481873

CCS CONCEPTS

• **Human-centered computing** → **User interface programming**.

KEYWORDS

Cooperative driving; automated driving; gaze interaction; human-machine interaction

ACM Reference Format:
Chao Wang, Thomas H. Weisswange, and Matti Krüger. 2021. Designing for Prediction-Level Collaboration Between a Human Driver and an Automated Driving System. In *13th International Conference on Automotive User Interfaces and Interactive Vehicular Applications (AutomotiveUI '21 Adjunct), September 9–14, 2021, Leeds, United Kingdom.* ACM, New York, NY, USA, 4 pages. https://doi.org/10.1145/3473682.3481873

1 INTRODUCTION

With automated driving (AD), the human driver's control is gradually transferred to a computer system [3, 4, 8]. The human driver must remain in the loop as long as advanced driving assistance systems cannot reliably overcome corner cases. Even in SAE Level 4/5 automation, where driving safety should be ensured by the AD system, its driving style may not meet a human driver's preferences, which negatively affects the user experience. The accuracy and timely prediction of other road users' behavior is one of the major problem for AD systems [2, 6]. Often, humans are better at integrating multiple types of information for predicting future development of traffic situations that are complex or novel. For example, a human driver may be anticipating someone to open a door and exit towards the road if they see a car parked at the side of the road. In an AD system, it may simply be a parked car. As the dimensionality of the underlying feature space increases, an AD system's ability to make such advanced decisions becomes increasingly problematic [9].

In a prior study of Wang et al. [10], a framework for human-vehicle cooperation to guide concrete implementations of cooperative human-machine interfaces (HMIs) were proposed. Inspired by this framework, a system that allowed drivers to provide prediction-level intervention via gaze-speech input and audio output was designed and implemented in a Wizard-of-Oz setup. A study with this setup showed that the concept got high acceptance by participants. However, participants also reported that enhancing the transparency of the system, for example, showing the prediction and planning of the system and how it is influenced by human driver's input, may increase the trust and usability of the concept. Another limitation of the tested setup was that a Wizard-of-Oz setup may not match the consistency of a fully functional AD system in complex situations, even with a predefined and well practiced protocol.

Therefore, a fully functional prototype, which integrates a real-world AD algorithm "intelligent Traffic Flow Assistant"(iTFA)[12]", for testing the concept of prediction-level cooperation was adapted for use in our driving simulator setup. In addition, to address the challenge of transparency and speed of the communication between driver and system, an interaction design based on gaze-button input and GUI output were implemented and added to our setup. This setup allows for in-depth investigation of human-vehicle cooperation on the prediction level.

2 INTEGRATING INTERVENTION INTO ITFA

Our AD system is based on the "intelligent Traffic Flow Assistant" (iTFA) [12], which has been used previously to demonstrate partially automated driving on public highways. It is a relative of the Honda i-ACC (intelligent Adaptive Cruise Control) system, which is capable of predicting cut-in behavior of other vehicles to improve the comfort of Adaptive Cruise Control [7]. The prediction model of iTFA can predict surrounding vehicles' behaviour in the next 8 seconds based on their relative positions and velocities. However, relative position and velocity are not the only determinants for a successful prediction in some conditions. As shown in Figure 2, in the perspective of iTFA, the truck drives normally on the right lane and will stay on its lane. In contrast, a human driver with a more cautious predisposition may come to a different conclusion. Such a driver might think that the big truck presents a high risk, especially in case it wants to change to the left lane. It might have only refrained from doing so due to low acceleration which makes finding an appropriate gap difficult. The driver predicts that the truck has a high probability of cutting in soon. With our adapted system, the driver can "inject" such a prediction into the AD system. The system takes this intervention into account and re-evaluates its driving plan accordingly, to minimize risk and discomfort from the perspectives of both the driver's and its own situation assessment. In the example scenario this could result in a smooth deceleration instead of an overtaking maneuver.

3 INTERACTION DESIGN AND IMPLANTATION

3.1 The driving simulator

The prototype was implemented in a driving simulation environment (IPG CarMaker [5]). The gaze-ray detection was performed by a remote eye-tracker system (Smart Eye Pro [1], picture 2 in Fig 1). Buttons were installed on the console next to the driver seat for explicit input from driver (picture 3 in Fig 1). The GUI was shown via a 14-inch screen in front of the steering wheel (picture 5 in Fig 1). A more detailed description of the system can be found in Wang et al. [11].

3.2 Gaze-button as input

In the prior study, gaze- and speech-based interaction was tested. According to the results, it was easy to refer to objects in the environment by looking at them, but not fast enough to explicitly confirm the selection through speech. Thus a physical button was implemented to confirm the gaze-based vehicle reference in the new setup. The eye-tracker was used to get the 2D-gaze intersection point on the physical screen of the simulator. By linking the virtual origin of the eye position in the virtual environment and the intersection point of the virtual screen, a 3D gaze vector in the virtual environment could be generated.

To avoid negative effects of distance-dependent amplification of potential gaze tracking errors, we did not use a gaze ray intersection with virtual vehicles as a selection criterion. Instead, the vehicle selection was based on the minimal angle between the gaze-ray and the vectors of ego-vehicle to each front vehicle (see Fig 3) at the moment that driver pressed the button.

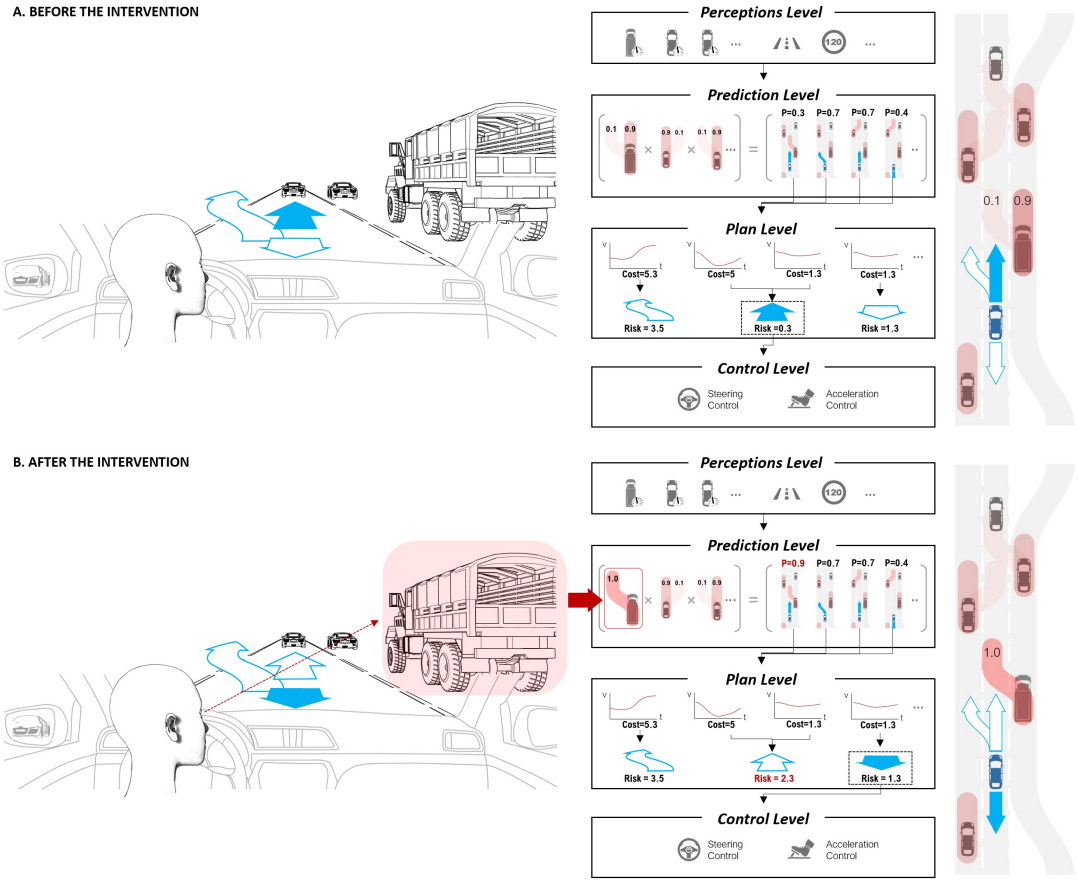

Figure 2: Adaptation with human driver's intervention on iTFA. [11]

3.3 GUI as output

In the previous study by Wang et al.[10], users reported that they wanted a higher level of transparency and explainability regarding the AD system and gaze-based vehicle selections. Therefore, we developed an interface that visualizes the detection of surrounding objects, the planned trajectory and the prediction other vehicles' behavior. The whole interaction flow is described in Fig 1.

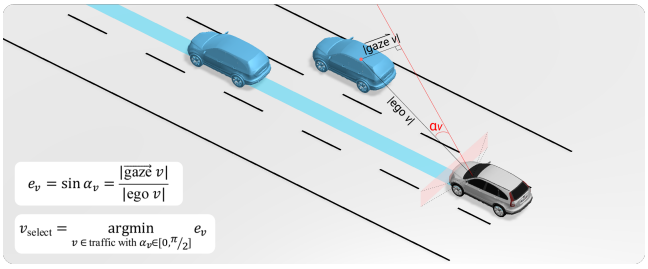

Figure 3: Gaze-vector and distance-based vehicle selection method

4 SCENARIOS AND FUTURE WORK

Three highway scenarios, in which the drivers can freely inject their prediction into the iTFA system at any moment, were created for further testing: The first scenario is a typical iTFA use case: the ego vehicle is driving on the center lane and a fast car in the right lane is approaching a slower truck. The iTFA system can predict the fast car's lane-change behavior several seconds ahead. There is no need for driver to intervene with the system's behavior. In the second scenario, a sports car is driving behind a slow truck in the right lane. iTFA does not predict the car overtaking behavior as it keeps the same speed as the truck. A human driver may think that the sports car will change lane soon or later as normally sports car drives fast. Due to this added context, a human driver may come to a different expectation about the future than the iTFA on its own. In the third scenario, the ego-vehicle is approaching an entrance lane with a van that is about to enter the highway. However, due to lacking map information, the system does not predict the van's merge-in behavior only based on the velocity.

Using a real AD system, we implemented a concept of predictions-level intervention with a real-world AD system. Our next step is to run a study to investigate whether prediction-level cooperation

improves driving experiences and whether the transparency of the system can be improved through the added GUI.

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