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External Communication for Self-Driving Cars: Designing for Encounters between Automated Vehicles and Pedestrians

Impact Case Study

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Year of completion:	2020
Discipline/field:	Industrial Design
Type of Doctorate (e.g. PhD, DDes, ArtD)	PhD
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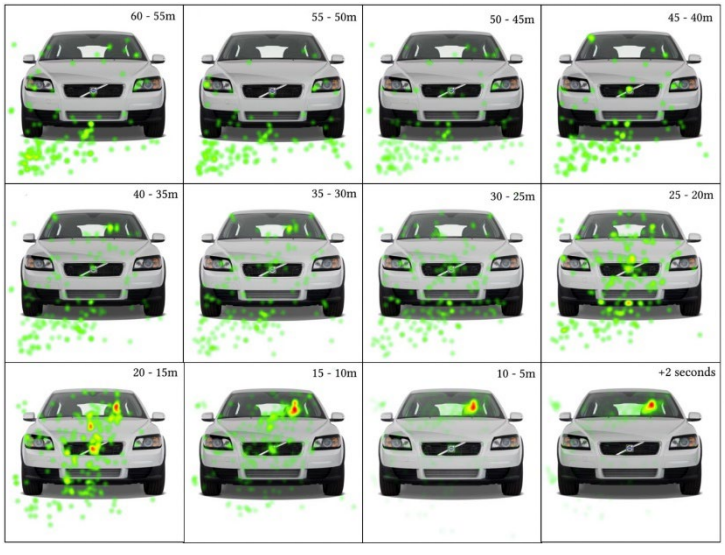
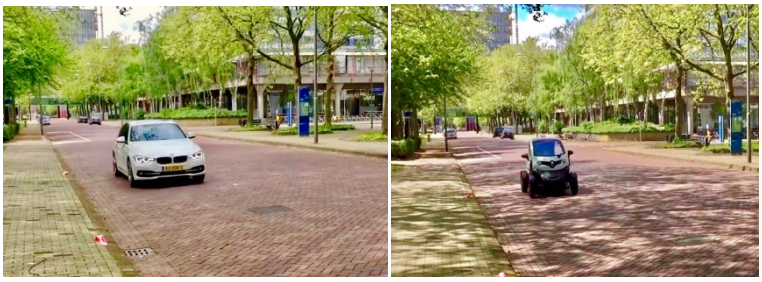
Abstract

Automated driving technology is developing at a steady pace, and is expected to permeate the society in the near future. It brings with itself the several promises such as increased traffic flow, better safety, and mobility for people with special accessibility needs. However, even if automated driving technology becomes mature for large scale deployment, it will be the human factors that dictate the success of the integration of automated vehicles (AV) in traffic and society. Public perception of automated driving technology varies considerably, ranging from enthusiasm and curiosity, to distrust and antipathy. In the context of this hesitation, sharing road spaces with automated vehicles – particularly in the nascent stages of this technology – may not happen organically. The design of a good AV-pedestrian interaction paradigm should consider the user perspective, and research is needed to



understand the perceptions and needs of pedestrians in order to contribute to a smooth transition to and a continued success of automated driving. It is commonly believed that there is explicit interaction between drivers of manually driven vehicles and pedestrians. Taking the driver out of the loop – as in Automated Driving – takes away this explicit interaction. This raises the question of how this communication gap can be addressed. The commonly proposed solution is to extend AVs with an external Human-Machine Interface (eHMI) to enable explicit AV-pedestrian interaction.



This research looks into the interactions between automated vehicles and pedestrians and aims to inform the design of an eHMI. The research aims to identify the aspects of interaction that drive road-crossing behaviours, and to uncover attributes of external communication through an eHMI that effectively facilitates this interaction. The work starts by identifying the theoretical requirements of a successful eHMI through a conceptual analysis and organizes the currently diverse space of eHMI concepts by describing a taxonomy and classifying said concepts. Subsequently, the work addressed six research questions in the context of pedestrians' interaction with vehicles in a road-crossing situation: (1) How critical is explicit communication in traffic interactions at present? (2) Where do pedestrians look to get the necessary information and make road-crossing decisions in front of an approaching vehicle? (3) How do pedestrians' interactions with AVs di er from that with ordinary, non-automated vehicles? Much of related research in the field assumes that an eHMI is a good solution to bridge the communication gap between AVs and pedestrians. To this end, we ask: (4) What is the contribution of an eHMI in facilitating a smooth

interaction, and what role does the vehicle's driving behaviour play? (5) What are the user preferences for colour and animation patterns in an eHMI? And particularly given that pedestrians seek different information based on the distance of an approaching vehicle, we ask: (6) What are the merits of phase-by-phase, distance-dependent communication of a yielding AV's intent? These questions were answered using a mix of methods commonly used in design research. The research culminates in evaluations and recommendations for properties of an external Human-Machine Interface (eHMI) for Automated vehicles.

Summary of impact beyond academia

While there are many design opportunities for the development of communication interfaces for Automated Vehicles, there are currently no standards in terms of the various aspects of design (e.g. message content, position/ location, colour, animation pattern, etc.) of external Human-Machine Interfaces (eHMI). The robust results from this thesis fed directly into the discussions and reports of the workings groups on Automated Vehicles Human Factors in the standardization organizations International Organization for Standardization (ISO) and United Nations Economic Commission for Europe (UNECE). These recommendations that emerged from this research are directly actionable by automotive Original Equipment Manufacturers in designing safe communication interfaces for future automated vehicles.

Underpinning research, context and summary of methodology

This research was conducted as a part of a project funded by the NWO (Dutch Science Foundation) aiming to develop mixed-mode cooperative automated vehicles. This work on the interaction between automated vehicles (AV) and pedestrians was executed as a handshake between two other projects on automotive human factors focusing on the interaction between AV and passengers.

The research started with a thorough literature review to get a bearing of the state of the art. Subsequently, in order to understand the context of the interaction between AVs and other road users, and to define the requirements of an effective information interchange, a thorough conceptual analyses of use cases, scenarios, and potential eHMI design attributes was conducted. Through such theoretical/conceptual analysis, several questions regarding the effectiveness of an interaction approach could be answered without having to conduct a thorough empirical study. In this process, a few design ideas were eliminated because they did not satisfy user-centred design requirements. Furthermore, brainstorming sessions and focus groups were conducted, both with domain experts and non-specialists to ideate potential solutions and scenarios.

True to the principles of User-Centred Design, the investigative efforts employed in this thesis placed a high importance on user feedback (in this case, pedestrians) throughout the process. In the course of this research, several user studies were executed to explore the research questions. These included observation studies to identify pedestrian behaviour in naturalistic conditions, as well as highly controlled studies in both laboratory and real-world settings. The studies incorporated a wide range of methodologies including interviews, surveys, questionnaires, and data

logging. Each empirical study was combined with subjective feedback from the participants which were used for qualitative analyses.

In line with our broad research question of determining the factors that are relevant for the design of an effective communication system to facilitate AV-pedestrian interaction, an immersive prototype of an AV was created using the Wizard of Oz methodology. This approach hid a human driver operating an ordinary vehicle under a 'seat suit' (a costume made to look like a car seat) to essentially promote an illusion that there is no driver in the vehicle, and subsequently to impress upon road users that the vehicle is self-driving.

In the course of the design-driven research project, several prototypes were developed for evaluating interface designs. The prototypes were used to answer specific design-related attributes of an eHMI. The goal of this work was not to design the 'ideal' eHMI, but rather to uncover insights on various aspects of design that would eventually contribute to such a design in the future, the prototypes were developed based on the research question being addressed. The prototypes ranged from low-fidelity abstract concepts on paper, video visualizations, to medium-fidelity prototypes incorporating 3D printed or laser-cut surfaces and using LED strips and matrices driven by Arduino that were mounted on real vehicles for testing. The interactions between an approaching vehicle and a pedestrian waiting to cross to road were empirically studied through a number of controlled experiments.

References produced by researcher from/during doctoral research

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Details of impact

Model of theoretical requirements of an effective communication between Automated Vehicles (AV) and other road users/ vulnerable road users (ORU/ VRU)

Set of guidelines to aid the development of new eHMI designs

Behavioural insights on pedestrians in present day traffic in road-crossing context

Behavioural insights on pedestrians with regard to the need and benefit of explicit communication (via an interface) in comparison to implicit communication (via vehicle motion and kinematics)

Pedestrians' road crossing willingness as a function of vehicle behaviour and external appearance.

Pedestrians' gaze patterns on an approaching (manually-driven) car to formulate an overview of information sought in road-crossing.

Comparison of pedestrians' gaze patterns for manually driven vehicle with an AV, with and without an eHMI to question the benefits of eHMI as well as the potential for causing distraction.

Insights on user preferences for eHMI colour and animation patterns in an eHMI in the traffic context and subsequent recommendation.

Validation of various modalities of communication using an eHMI for AV-pedestrian communication leading to the recommendation of a multi-phase communication model.

Direct input into the technical report by ISO into the standardization of AV signalling approaches, which serves as a foundation for OEMs. (report can be found here: https://www.iso.org/obp/ui/#iso:std:iso:tr:23049:ed-1:v1:en)

Direct input to the UNECE taskforce on Autonomous Vehicle Signalling Requirements (AVSR) session meetings, which form the backbone of European Commission regulations for automotive applications (https://wiki.unece.org/pages/viewpage.action?pageId=73925596)

This Case Study is an outcome of the D.Doc Project, funded by the European Union. Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union or the European Education and Culture Executive Agency (EACEA). Neither the European Union nor EACEA can be held responsible for them.