Title:
Validating HMI Design for Increasing User's Trust in Autonomous Vehicle

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Introduction:
Autonomous vehicles' application is supposed to enhance road safety and increase transportation efficiency[17]. The boosting development of Artificial Intelligence and the application of 5G mobile networks are realizing the full automation driving scenario from the technological end, but there are lots of problems of the user end still pending. One of the most crucial points is the trust of humans towards the autonomous vehicle (AV) system[2][3]. User's over-trust and distrust both may lead to safety problems [13]. In this study, a platform based on Virtual Reality technology is introduced as a tool to investigate the user's trust level towards two set of user interface (UI) organized in two methods. The novelty is that the interaction modalities of the new UIs are organized in a systematical way: one by function and the other by importance level.

The simulation scenario is created in Unity 3D, enabling four possible modalities of human-machine interactions (HMIs) to achieve an optimal trust level from the user: voice synthesis, sound effects, text on screens, Graphic User Interface (GUI). The motivation is to increase the transparency of the system's decisions and actions to the user. In this research, according to the function or importance level of each property, the information can be transmitted to the user in one or more HMI modes. Possible verification methods are also discussed to apply the tool, considering the current design and development procedure in the industry, in order to give constructive help to the researchers and practitioners in the field.

User's trust:
The importance of trust is dramatically increased in human factors in the past decade, especially in the field of automation, because people fail to rely upon it appropriately [13]. Results from the three studies conducted in the research of [8] indicate that trust is an important factor in understanding automation reliance decisions. They also found that user initially tended to consider that the automation system trustworthy and reliable, but after observing the errors that the automation system made, the users distrust even reliable behaviors unless an explanation was provided about the cause of the error. The secondary users' screens are believed to be helpful to build trust, where the user can interact with all the features provided by the service without losing control of what the car is doing at the same time[15].

A trust requirements Model is especially proposed in a research [10], which addresses seven key points as Trust Attributes for the adoption of self-driving cars: Security, Safety, Privacy, Reliability, Performance, User's Experience and Economic Value. In this model, there are also trust properties listed corresponding to each key point of trust attribute, which should be considered in the new autonomous vehicles developing process.

Changes in HMI:

The vehicle has been naturally defined as being controlled dominantly by human drivers since it is invented. Advanced Driver Assistant Systems (ADAS) has been always considered as a helper for the drivers to reduce or even eliminate human error[5], even if they integrate advanced functions such as Adaptive Cruise Control, Autonomous Intelligent Cruise Control, platoon driving, etc. In the autonomous vehicle, instead, the control of the vehicle is entrusted to Artificial Intelligence (AI). According to the classification of SAE International, the highest level of automation in the vehicle is defined as Full Driving Automation, Level 5[18], where all the driving subtasks (lateral and longitudinal vehicle motion control, and Object Event Detection & Response (OEDR)) fall to the autonomous driving system. The system will monitor the driving circumstances and make the decision for the user to react to the inroad events and interact with the user about its behaviors through the HMI system. Along with the evolution of vehicle automation, the Human-Machine Interaction mode changes from user-control to user-supervising, especially on the OEDR subtasks. The UI inside the car communicating the OEDR information will be crucial to increase the users' trust towards the autonomous driving system and have the confidence to complete their journey safely.

The aim of this research is to organize the interaction modalities in the HMI design of the fully autonomous vehicle in a systematic manner, in order to create a general method for the future works in the automotive field. Two approaches have been considered in the development of this method. The first one is based on the functions of the driving task and the second one is based on the importance of the communication content for the user. Their correspondence to the interaction modality is listed in Tab. 1.

Interaction modalities	*By function*	*By importance*
GUI navigation screen + AI Voice + AI Bar	System events, Emergency	Intention, Emergency
GUI navigation screen + AI Bar	In road movement	Cause of intention change
GUI navigation screen	External events	Potential Cause of Intention change

Tab. 1: Correspondence of interaction modalities and two organizations of information type.

User studies on HMI:

To evaluate the effectiveness of the proposed HMI interaction modalities in increasing driver's trust, a virtual reality scenario has been developed in Unity 3D (https://unity.com/). The driving scenario has been implemented onto the Head-Mounted Display (HMD) HTC Vice Pro, which has a visor of 6 DOF and a full-scale room tracking capability. The LeapMotion (https://www.ultraleap.com/product/leap-motion-controller/) controller was employed for the user's hands tracking, i.e. hands and fingers movements.

Virtual environment

The environment was relied on the AirSim project [19], built by Microsoft for the implementation and testing of cars and drones AIs. This package has different types of roads and environments (from urban to rural) inside, making it possible to test the car and user response to different road conditions (Fig. 1). An addon "Urban Traffic System" was employed in order to generate buildings, pedestrians and traffic flows inside the virtual environment. Different scripts were included in this addon for managing the crossroads interactions between the traffic lights and the pedestrians.

Fig. 1: A crossroad in the city in AirSim Project.

Virtual vehicle

The virtual car model in this study was created based on the Smart Vision EQ ForTwo, as shown in Fig.2(a). The interior layout of the car is defined in this way:

- User's seat towards the heading direction of the car;
- a central display indicating the essential information (i.e. Navigation);
- the secondary screens (user screens) conveying the personal entertainment features;
- an AI bar delivering messages of the onboard AI;
- a windshield screen showing the surrounding information.

With an addon "Bézier Path Creator", Beziers curves were generated in the 3D environment guiding the autonomous car to follow a certain movement cruise.

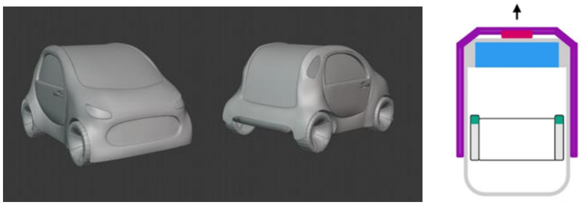

Fig. 2: Car model in the testing scenario, based on Smart Vision EQ ForTwo, (a) exterior model, (b) interior layout.

HMI design

The HMI in this study includes the interaction modalities identified in the previous section.

The visual interface extends over three types of screen devices: a central dashboard with touch screen capability (containing two user screens and the navigation screen), a dedicated glass display called AI bar (Fig.3) and the windshield screen. The user screen, placed in the dashboard monitor directly in front of each seat, contains all the information that go beyond the monitoring of the driving, allowing the user to have a complete control over the car's interior environment (panel on the right) and the entertainment functionalities (panel group in the center and on the left). This screen is meant to be private-use and can be customized with other third-party services (i.e., YouTube, Spotify, Twitter etc.) by connecting each personal account to the car dashboard, which will be very potentially applied in the full-automation taxi scenario. In this way, the entertainment inside the car is seamless connected to the one the users already enjoy on their personal devices, increasing their familiarity to the car environment and therefor increasing their trust.

Fig. 3: Layout of the central dashboard: one navigation screen in the middle, two user screens on the left and right, AI bar on the top.

Particularly, for the visualization of the navigation screen, it is suggested to use 3D visualization of the environment in a study that compared three types of visualizing methods: A world in miniature, a chauffeur avatar, the basic car indicators (blinking icons), because it gave more sense of security to the users. As shown in Fig. 3, the car per se and its surroundings are all visualized in this method.

Concerning the auditory interface, constant background noise has been added in order to avoid a persistent silence that could “draw out” the user from the virtual world. Moreover, during the trip, the user will be accompanied by a sound of the car engine, which consists of a looping tone pitching up or down depending on the vehicle speed. This acoustic effect has been added since, despite electric cars having almost silent engines, many car manufacturers today, e.g. Audi, Nissan, Tesla, etc. decide to use digitally generated tones and sounds to improve the safety of pedestrians [4]. An onboard AI character called ‘Kara’ is realized through the Cloud Text-to-Speech engine of Google (https://cloud.google.com/text-to-speech/), which is able to hear the user’s words and build a simple conversation with the user, by pre-establishing a series of “keywords” recognition inside the dictation. ‘Kara’ is defined to have a young female’s voice in order to give a more ‘human’ nature [14]. Auditory signals has some unique advantages, such as it is omnidirectional, which means that auditory cues can be received from any direction [1].

Validating Tools

In user studies, the assessment is usually considered from two levels: the subjective opinions and the objective reactions from both behavioral and physiological aspects. Questionnaires are employed in order to get a quantitative measurement of the usability and trust at the subjective level, for example: Technology Acceptance Model [9] measures four aspects, namely Perceived ease of use, Attractiveness, Trust and Intend of the HMI design; Trust in automation questionnaire [12], and Trust scale [16]. On the other side, users’ physiological data should be analyzed in order to investigate the fatigue and stress level for the evaluation of user comfort, and hence improve the HMI design by reaching a balanced state for the user[6]. Some physiological parameters have been included in the study, for instance, Heart Rate Variability(HRV), which is a sensitive and selective measure of mental stress[11], and Electrodermal activity, which is widely used in the investigations on driver’s fatigue and drowsiness [7].

<u>Conclusions:</u>

This study has proposed an evaluation method based on VR simulation to assess the design of HMI for full AVs. The simulations of AV HMI have been set up, following a series of rules to increase the user’s trust towards the automated driving system. By using virtual reality technology, it becomes possible to validate the HMI design in the early stage of AV development, which will be more efficient to achieve an optimal solution. The possible validation and evaluation methods are also discussed for the researchers and practitioners in the research area and industry to take a reference.

References:
[1] Bazilinskyy, P.; de Winter, J.: Auditory interfaces in automated driving: an international survey, PeerJ Computer Science, 1, 2015, e13. https://doi.org/10.7717/peerj-cs.13.
[2] Bélanger, F.; Carter, L.: Trust and risk in e-government adoption, Journal of Strategic Information Systems. 17(2), 2008, 165–176. https://doi.org/10.1016/j.jsis.2007.12.002.
[3] Benenson, R.; Fraichard, T.; Parent, M.; Benenson, R.; Fraichard, T.; Parent, M.: Towards urban driverless vehicles To cite this version : HAL Id : inria-00115112, 2008.
[4] Bräunl, T.: Synthetic engine noise generation for improving electric vehicle safety, International Journal of Vehicle Safety, 6(1), 2012, 1–8. https://doi.org/10.1504/IJVS.2012.048531.
[5] Brookhuis, K. A.; de Waard, D.; Janssen, W. H.: Behavioural impacts of advanced driver assistance systems–an overview, European Journal of Transport and Infrastructure Research, 1(3), 2001, 245–253.
[6] Carsten, O.; Martens, M. H.: How can humans understand their automated cars? HMI principles, problems and solutions. Cognition, Technology and Work. 21(1), 2019, 3–20. https://doi.org/10.1007/s10111-018-0484-0.
[7] Cernat, R. A.; Speriatu, A. M.; Taralunga, D. D.; Hurezeanu, B. E.; Nicolae, I. E.; Strungaru, R.; Ungureanu, G. M.: Stress influence on drivers identified by monitoring galvanic skin resistance and heart rate variability, 2017 E-Health and Bioengineering Conference, EHB 2017, 2017, 261–264. https://doi.org/10.1109/EHB.2017.7995411.
[8] Dzindolet, M. T.; Peterson, S. A.; Pomranky, R. A.; Pierce, L. G.; Beck, H. P.: The role of trust in automation reliance, International Journal of Human-Computer Studies. 58(6), 2003, 697–718. https://doi.org/10.1016/S1071-5819(03)00038-7.
[9] Fred, D. D.: User acceptance ofinformation technology: system characteristics, user perceptions and behavioral impacts, Springer-Verlag, 2012.
[10] Hakimi, H.: Trust Requirements Model for Developing Acceptable Autonomous Car, Journal of Electrical and Electronic Engineering. 6(2), 2018, 59. https://doi.org/10.11648/j.jeee.20180602.14.
[11] Hjortskov, N.; Rissén, D.; Blangsted, A. K.; Fallentin, N.; Lundberg, U.; Søgaard, K.: The effect of mental stress on heart rate variability and blood pressure during computer work, European Journal of Applied Physiology. 92(1–2), 2004, 84–89. https://doi.org/10.1007/s00421-004-1055-z.
[12] Jian, J.-Y.: Foundations for Empirically Determined Scale of Trust in Automated Systems, 1998.
[13] Lee, J. D.; See, K. A.: Trust in automation: Designing for appropriate reliance, Human Factors. 46(1), 2004, 50–80. https://doi.org/10.1518/hfes.46.1.50_30392.
[14] Lee, S.; Ratan, R.; Park, T.: 2019. The Voice Makes the Car: Enhancing Autonomous Vehicle Perceptions and Adoption Intention through Voice Agent Gender and Style, Multimodal Technologies and Interaction. 3(1), 2019, 20. https://doi.org/10.3390/mti3010020.
[15] Miglani, A.; Diels, C.; Terken, J.: Compatibility between Trust and Non-Driving Related Tasks in UI Design for Highly and Fully Automated Driving, Proceedings of the 8th International Conference on Automotive User Interfaces and Interactive Vehicular Applications Adjunct - Automotive'UI 16, New York, New York, USA, 2016, 75–80.
[16] Moghimi, M.; Stone, R.; Rotshtein, P.; Cooke, N.: The Sense of embodiment in Virtual Reality, Presence: Teleoperators & Virtual Environments, 25, 2 (2016), 81–107. https://doi.org/10.1162/PRES.
[17] Organisation, W.H. 2015. Global Health Observatory (GHO) data: Number of road traffic 640 deaths. (2015).
[18] SAE International 2018, Taxonomy and Definitions for Terms Related to Driving Automation Systems for On-Road Motor Vehicles.
[19] Shah, S.; Dey, D.; Lovett, C.; Kapoor, A.: AirSim: High-Fidelity Visual and Physical Simulation for Autonomous Vehicles, 2018, 621–635. https://doi.org/10.1007/978-3-319-67361-5_40.