Title:
Perspectives on User's Acceptance of Human-machine Interface in Autonomous Vehicles

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Introduction:

Autonomous driving technology has been significantly developed in the last years. However, several issues must be addressed to make it universally accepted. Through a literature review, this paper summarizes the existing research on the role of human-machine interfaces (HMIs)on users' acceptance in autonomous vehicles from the perspective of interaction design. First, the paper reviews the fundamental changes in the way users interact with autonomous vehicles focusing on: (i) the transfer of vehicle control between human drivers and artificial intelligence; (ii) the user experience of non-driving-related tasks (NDRTs); (iii) autonomous driving in public transportation; (iv) the impact of external HMI on vulnerable road users (VRUs). Then, the paper analyzes the concept of acceptability and describes the existing user acceptance model. Finally, the paper examines the future challenges for promoting a deeper exploration of the potential of autonomous vehicle interfaces design and proposes areas worthy of research to increase the user's acceptance of this technology.

The researched topic is located at the intersection of three main research fields: "Autonomous Vehicles," "Human-Machine Interface," and "User Acceptance." The resulting research field is interdisciplinary and covers various disciplines and scopes. Indeed, "Autonomous Vehicles" touches knowledge fields such as anthropology, marketing, physics, engineering, and information science. "HMI" is related to ergonomics, human factors, industrial design, computer science, and artificial intelligence. "User acceptance" deals with user research, interaction design, and so on. We explore the rationale and necessity of existing research areas and methodologies by aggregating them. Compare the innovation points of different research directions and the effectiveness of other methods to find valuable research directions in the future.

Methodology:

The research presented in this paper is a systematic analysis of the scientific literature. The analysis starts by identifying purposes, research questions, and gaps of previous research. The search strategy followed to identify the relevant publications was performing a keyword search through a combination of sequential and iterative searches, including search phrases, databases, and related publications. The retrieved publications have been classified for relevance and quality. [9] As a result, 206 pieces of relevant and valuable literature related to the research topic were identified. Identifying research gaps and inconsistent research results makes tacit domain meta-knowledge also explicit. The analysis of the obtained literature and data completes the writing of this literature review.
The proposed research can be summarized with the following five main steps:

- definition of the information sources and search strategy.
- identification within publications of purposes, research questions, and gaps.

- quality appraisal and data extraction.
- analysis of findings.
- writing of the review.

Results:
The literature is analyzed and synthesized by summarizing different concepts of various authors through the methods mentioned above. This section presents the analysis results, and all materials are divided into two categories: (1) research on HMIs inside and outside autonomous vehicles (2) development and application of user acceptance models. The results are elaborated in the following three aspects.

- Human-Machine interactions in autonomous vehicles
- Acceptability and user acceptance
- User acceptance model

Human-Machine interactions in autonomous vehicles

This section provides an overview of existing research on autonomous vehicles and human-machine interfaces (HMIs) for users inside and outside the vehicle, building on existing HMI classifications.
For autonomous driving scenarios, HMI refers to the devices enabling the connection between persons to the vehicles to achieve the purposes of complete human-computer collaboration. Researchers and engineers have developed a series of interfaces to make the collaboration between the driver and the vehicle much more flexible in recent years. Different theoretical frameworks and classification methods for autonomous driving HMI are proposed in the analyzed studies. Among them, two mainstream classifications emerge: one category is according to the function, and the other is according to the attributes.

According to its function, HMI in autonomous vehicles can be sorted according to the input and output types. The input type includes the vehicle's channels to receive the driver's input information, such as buttons, steering wheels, pedals, and touch screens. The output refers to the vehicle's channels to provide system status information to the user by transmitting multi-channel signals mainly based on visual and auditory stimuli (i e, displays, lights, and voice). In addition, the user here referred is not limited to the driver and passengers but also includes other road users outside the car.

On the other hand, it can be divided into explicit and implicit communication HMI according to its attributes. Explicit communication refers to the means to complete the information exchange between the car and the user through externally available information, which manifests explicitly as the external information obtained through multi-modal stimuli, such as lights, gestures, voice, Etc. Implicit communication refers to judging the vehicle’s state and perceiving the information through the inherent hidden details, such as the vehicle's trajectory. With the continuous improvement of the degree of automation, the types of HMI are also continuously subdivided. [1] To date, five are the different HMI types that autonomous vehicles possess: (i) Dynamic HMI (dHMI); (ii) Automation HMI (aHMI); (iii) Vehicle HMI (vHMI); (iv) Infotainment HMI (iHMI); (v) External HMI (eHMI).

Although there is some degree of overlap between them, the definitions of these five HMIs are described in detail by Bengler et al.

Acceptability and user acceptance

Two concepts, "acceptability" and "acceptance," are commonly used to study people’s attitudes towards new technology. There are also specific differences between these two.

Acceptability is the characteristic of being subject to acceptance for some purpose. A thing is acceptable if it is sufficient to serve the purpose for which it is provided, even if it is far less usable for this purpose than the ideal example. It is used to refer to the public's acceptance, recognition, internalization, obedience or disregard, violation, evasion, resistance, and other behavioral responses to something or technology. A thing is unacceptable (or has the characteristic of unacceptability) if it deviates significantly from the ideal to the point that it is no longer sufficient to serve the desired purpose or if it goes against that purpose. In this article, “acceptability” is the prospective judgment of

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potential users towards a technology to be introduced in the future. It implies that the potential users have not yet experienced the technology [5]. Applying this concept to the design means that the designed artifact should be suitable for people of different abilities, without specific changes or modifications. Acceptability in design has four characteristics: recognizability, operability, simplicity, and inclusiveness. [2]

"Acceptance" is the opposite of rejection, indicating a favorable decision to use innovation. [3] In design, the concept of "user acceptance" often appears in research. It represents potential users' judgment, attitude, and behavioral response to the product after trying it [6] . There are three measurement standards for testing user acceptance in the market economy: (i) general acceptance; (ii) willingness to pay (WTP); (iii) behavior intention (BI). [4]

Research on acceptance can indirectly improve users' desire to buy and has a particular role in promoting the commercial value of autonomous driving technology. Many studies have shown that user acceptance of autonomous driving results from four decision-making steps. First, have access to autonomous vehicles. Second, form a positive attitude towards autonomous vehicles. Third decided to adopt a self-driving vehicle and finally, the actual use of self-driving vehicles.

User acceptance model

In interaction design, the user's acceptance of new technologies and products can be used to predict user behavior, which will affect consumers' buying behavior. Research on this concept helps establish and implement a new design and reduce consumer resistance to new products or technologies when they appear [7] .

The public's acceptance of autonomous driving technology and cars is essential. Although AVs can provide a potentially effective solution for improving road safety, their benefits can only be realized when the public accepts AVs. The surveys show that the public's willingness to use or purchase AVS is usually low.

Improving the public recognition of this technology, an issue that scholars in autonomous driving have started addressing in recent years is crucial to determine the user's acceptance before any technology is fully developed. Usually, a user acceptance model is first developed then tested, influencing the design and implementation process, thereby minimizing the risk of user resistance or rejection. The development process of the user acceptance model is as follows (see Figure. 1.).

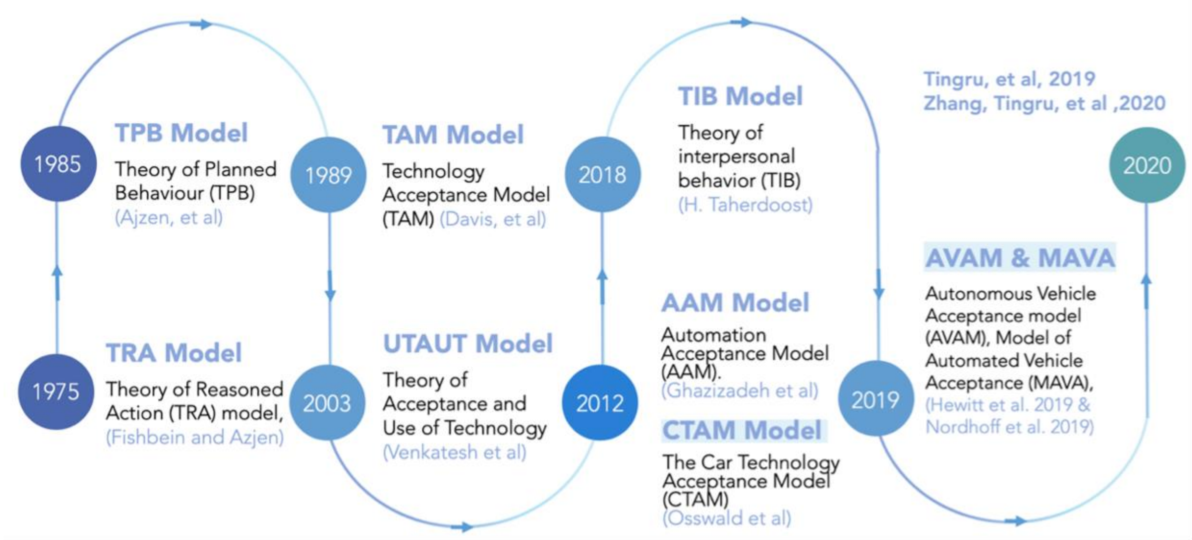

Fig. 1: User acceptance model development history.

Influencing users' decisions and making them more receptive to new technologies can help businesses and researchers find better ways to design products. It also helps evaluate and predict users' reactions to new technologies and products. Through our literature review, we analyzed the most popular user technology acceptance theories and models: TRA, TPB, TiB, Tam, UTAUT, and AAM, as well as their extended models. Researchers used them many times to understand and predict users' behavior and influence the consumers' purchase behavior, which is worthy of study. [7]

Although the model's research has improved our acceptance and understanding of AVS, most of the research is limited to the overall perception of autonomous driving, analyzing which cognitive factors impact the user's acceptance and focusing on each factor proportion and relationship. User acceptance surveys for specific driving functions and interaction modes have not been fully tested.

Challenges and Future Works:

User-acceptance studies of several future works for HMI are estimated in this section. As a high-end intelligent robot with wheels, the role of autonomous vehicles in the use of technology has become more prominent. Trust and perceived risk are the two most common reasons users do not accept AVS. [8] When cars are given autonomy, their communication with people becomes more and more critical. Machine perception, information classification, human-computer interaction, etc., are autonomous vehicle design research focus. It is imperative to use user acceptance models as the basis for user behavior research.

Future research on user acceptance of autonomous driving technology should focus on a specific level of automation. Moreover, the challenges that affect user acceptance will include security and privacy, trust and transparency, safety and performance, capability and control, and positive experience. Designers should focus on clear communication of the system benefits (usefulness) and usable implementation of features (perceived ease of use) and trust, safety, security, control, comfort, fun, social, and well-being factors in automated vehicles. That will help to overcome biases (anxiety, the feeling of low safety, bad attitudes towards usage, and low task-related self-efficacy) regarding AVs.

For in-car HMI, with the gradual deepening of automation, the impact of the transparency of the HMI on user acceptance cannot be underestimated. The issue of vehicle control transfer is undoubtedly essential. However, it is an essential issue to synchronize automated data and information to enable users to understand the system's operating status more clearly. After all, humans have a reaction time and cannot enter immediately after taking over the task.

Future research directions should pay more attention to displaying the HMI's vehicle status. On this basis, improve some NDRTs interaction to improve user trust and experience further. In addition, with the reduction in driving activities, the role of vehicles will shift from operating experience to public transportation. Sharing autonomous cars will become a trend. At that time, the distribution and conversion of control rights for different users in the vehicles will become the focus.

On the other hand, the information exchange between vehicles and Vulnerable Road Users (VRUs) is the focus of research for HMI outside the car. To date, the researchers compared the effects of different forms, types, and locations of eHMI on user behavior. However, the results are not the same due to the various experimental and data analysis methods. Furthermore, the current research is mainly conducted in general scenarios, and the attention to scenarios and users is not great.

Future research should be more in-depth and comprehensive, such as comparing the impact of different vehicle types (e.g., cars, buses, etc.) and appearance on the information interaction between eHMI and VUR. From the perspective of inclusive design, a survey can be distributed to different user groups and in various extreme weather conditions (such as fog, rain, snow, thunder, etc.) to evaluate the ease of use of different eHMIs. This will help to have a deeper understanding of the influencing factors of user acceptance.

Conclusions:

This research conducted a literature review on the human-machine interface and user acceptance of autonomous driving.

In driving scenarios with increasing automation, HMI is an essential way for users inside and outside the vehicle to understand and communicate with autonomous vehicles and has a considerable impact on the user acceptance of this technology.

In this study, starting from two scenes inside and outside the vehicle, we summarized different scholars' research contents, focus, and experimental methods. Accordingly, we compared the effects of various HMIs on user behavior and the experience's impact. Then, we defined the concept of "acceptability" and user "acceptance" and explained the evolution of the user acceptance model in time. Finally, we reviewed the research challenges to be addressed in the future, when the internal and external design of HMI should also consider many human factors.

In brief, this research has comprehensively analyzed the user acceptance of the human-machine interface of autonomous vehicles. It aims to guide the design of human-centered AVs to improve human behavior and cognition and increase user trust and acceptance of the technology.

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