Design Studies and Intelligence Engineering
L.C. Jain et al. (Eds.)

doi:10.3233/FAIA220702

Participatory Design of External HMI Based on Explicit Human-Vehicle Interaction Features

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Abstract. In order to explore the design strategy of participatory design approach in the design of external human-machine interface (eHMI), this paper at the theoretical level researches the relevant literature and typical interfaces of eHMIs, and sorts out the basic concepts of explicit human-vehicle interaction features theory. Through the user participatory design method, we summarized the key design points of the eHMI and produced a design prototype, and optimized the prototype according to the participatory design experimental results and actual needs to obtain a design solution. The design was tested and evaluated at the practical level, and a strategy for user participation in the design of the external human-machine interface was concluded. The results show that the participatory design approach can improve the usability and acceptance of eHMIs, reduce the cognitive differences in the presentation of interface content, and provide a reference for the design of out-of-vehicle HCI in future work.

Keywords. External human-machine interface, explicit human-vehicle interaction, participatory design, interaction features

1. Introduction

In recent years, advances in autonomous driving technology have led to more autonomous vehicles in existing traffic environments, and explicit human-vehicle interaction has been introduced into the existing research field in order to compensate for the possible lack of interaction between vehicles and pedestrians. In general, attitudes toward autonomous vehicles seem to be positive, yet further research is still needed in terms of the acceptance of explicit vehicle interaction methods [1]. The premise of self-driving car-pedestrian interaction is that the two form an effective communication, and from the vehicle's perspective, it is necessary to communicate critical information through explicit interaction methods [2]. Research has shown that external human-machine interface (eHMI) can be an important part of the explicit human-vehicle interaction process [3], so the design of external human-machine interface will become particularly important for improving communication between autonomous vehicles and pedestrians. This paper attempts to introduce participatory design methods into the

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design of external human-machine interface, and explore participatory design strategies for eHMI by combining explicit human-vehicle interaction theory and corresponding interaction features.

2. External human-machine interaction interface

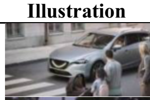
2.1. Literature Research and Case Studies

External human-machine interfaces are an emerging research area that has emerged with the development of research related to autonomous driving. A great deal of research has been conducted by academia and industry on solutions for safe and effective interaction between pedestrians and autonomous vehicles, and one important area of research is the external human-machine interface.

During vehicle-pedestrian interactions, the kinematic features of the vehicle are often the determining factor in the pedestrian's decision to cross the street. However, when a vehicle exhibits behavior that does not meet pedestrian expectations, pedestrians seek explicit interaction with the vehicle driver [4]. For autonomous vehicles, an effective alternative to driver interaction is an external human-machine interface that explicitly communicates information such as vehicle intentions to pedestrians in the form of displays, light bars, etc., to meet the interaction needs of pedestrians with autonomous vehicles. However, because there are many factors involved in the eHMI, there is no exact standard for how each factor should be presented, and differences in environmental factors or cultural backgrounds can lead to differences in individual understanding of the eHMI. Therefore, there is a need to improve the usability and acceptability of the external human-machine interface from the design level, and to reduce the cognitive differences in the content.

From the existing studies, the display mounted in the front radiator grille position of the vehicle is the more satisfactory form of the external human-machine interface. Therefore, this study selects five typical interfaces and summarizes the features from three perspectives: color, graphics and text content, as shown in the table 1.

Table 1. Analysis of typical external human-machine interface design elements

Case	Illustration	Text	Text Content	Color	Graphics
Semcon, 2016		/	Suggestion	White, yellow	Smiley
Toyota, 2017		Turning left	Vehicle intention	White	Arrow
Mercedes-Benz, 2017		Go ahead	Suggestion	Green	Arrow
Toyota, 2018		Turning around	Vehicle intention	White, green, blue	Arrow
Baidu, 2021		Please pass through	Vehicle intention, suggestion	Red, green, blue	Pedestrians, zebra crossings

2.2. Design analysis of text in eHMI

Existing research has found that text-based eHMIs are one of the most easily understood forms by pedestrians and are suitable for conveying short and clear messages [5]. The information conveyed through text of the eHMI can be divided into two categories, pedestrian-centric information (e.g., suggestion or instruction) and vehicle-centric information (e.g., vehicle status, vehicle intent) [6], with vehicle intent and suggestion receiving more attention from researchers.

- Vehicle intent: Mahadevan et al. showed that information about vehicle intent is more important for pedestrians than information about pedestrian detection [7]; Faas et al. similarly noted that conveying information about vehicle intent is more in line with the information needs of pedestrians [8].
- Suggestion information: Ackermann et al. showed that eHMIs that directly indicate crossing information are superior to those that display vehicle status information [9]; Stadler et al. also noted that eHMIs that convey advice information can improve the efficiency of pedestrian-vehicle interactions [10].

2.3. Design analysis of color in eHMI

Common colors in existing out-of-vehicle human-computer interaction interfaces include two main categories, red and green, which are commonly used in current traffic systems, and neutral colors such as cyan and white [11], which are not considered to have traffic implications. Bazilinskyy et al. showed that color has the greatest impact on the content of text that allows pedestrians to pass, when the color information is understood to act as a "reinforcer" [12]. According to the existing research, it is a reasonable color choice to refer to the color of traffic lights or adopt neutral colors such as cyan in the design of the external human-machine interfaces.

2.4. Design analysis of graphics in eHMI

The graphics used in the current external human-machine interfaces are more diverse, including pedestrians and crosswalks, which are common in traffic systems, as well as arrows, gestures and other graphics with instructional meanings. Stadler et al. have shown that graphics have the highest user satisfaction, high comprehension and low cognitive requirements [10]. In summary, existing studies suggest that anthropomorphic graphics or graphics with explanatory text are more reasonable forms of graphical interface presentation.

3. Theory of explicit human-vehicle interaction features

3.1. explicit human-vehicle interaction studies

For autonomous vehicles, explicit interaction usually refers to the vehicle's intention communicated through individually designed lights, displays or sound signals. Existing research has focused on five typical interfaces: driver cue simulation interface, textual interface, graphical interface, lighting interface and projection interface, but due to the limitations of technical means, cultural background and other factors, there is no unified design standard for explicit interaction in autonomous vehicles [13]. A generally agreed view, however, is that the presence of an external human-machine interface does enhance the interaction behavior of pedestrians with autonomous vehicles [4].

3.2. *explicit human-vehicle interaction features and definitions*

Youn-kyung Lim et al. proposed the concept of interaction features for the field of interaction design to describe the quality of interactivity and demonstrated experimentally that the use of interaction features can improve design outcomes [14]; Hao Tan et al. constructed the association between interaction features and user experience and validated it in design examples [15]. All of these studies show that the study of interaction features can provide theoretical guidance for design work. In this study, the explicit interaction subject focuses on the interaction between the car and the pedestrian, where the vehicle transmits interaction information to the pedestrian in the form of the external human-machine interface. Thus, the study defines the explicit human-vehicle interaction as the level of information transfer from the vehicle to the pedestrian through the external human-machine interface, and the higher the level of information transfer, the higher the familiarity and acceptability of the pedestrian to the eHMI, and establishes the explicit information transfer model based on this, as shown in Fig 1.

Therefore, this paper explores the explicit information needs of the external human-machine interface based on explicit interaction theory, and uses participatory design methods to explore the design needs of the eHMI to improve the usability and acceptance of the eHMI.

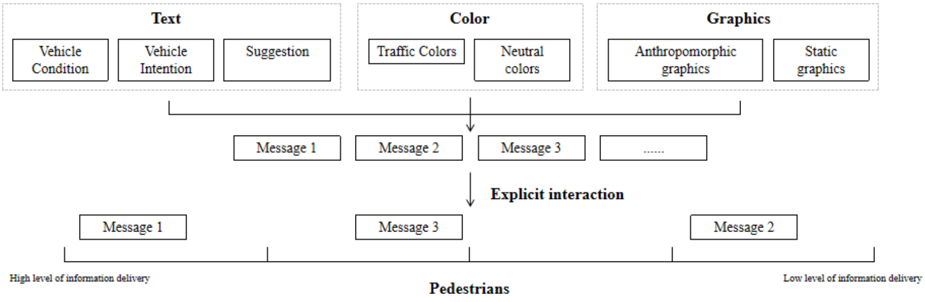


Figure 1. Explicit interaction information transfer model of external human-machine interface

4. User Participatory Experiments and Analysis of external Human-machine interface

4.1. *Theoretical basis*

Participatory design originated in the workplace democracy movement in Scandinavia in the 1970s and has been developed as a practical design methodology by American companies [16]. Existing research shows that the application of participatory design methods in various fields has shown clear benefits [17], and that multi-user participatory design can completely define user needs, optimize user interfaces, and improve human-computer interaction, and other design outcomes [18].

Most existing studies have practiced and evaluated the design of human-machine interfaces through user participatory design methods, such as Mahadevan et al. who used participatory design methods to evaluate the usefulness of the outside surface of the vehicle for the question of whether autonomous vehicles can clearly communicate vehicle information to pedestrians [19]. It is now generally accepted that user involvement in the human-machine interface design process is of value [17].

4.2. Participatory design process

The study uses the research methodology of individual participatory design (PDInd), Spinuzzi divides the process of participatory design into three stages: initial exploration of work, discovery processes and prototyping [16], and for this study specifically, each stage is described as follows. (1) Preparation and exploration. The researcher recruits participants according to the needs, communicates with them initially about the process and considerations of participatory design experiments, and makes a follow-up plan and prepares the required materials. (2) Definition and design. This stage was conducted online, in which participants were involved in the design of the out-of-vehicle interface through individual participatory design workshops, and produced initial prototypes of the interface design. (3) Practice and Evaluation. Researchers and participants work together to produce interface prototypes of different fidelity and to define and evaluate the design.

Six subjects, three male and three female, with an average age of 24 years, were invited to participate in this user participatory design. Each had heard or learned about autonomous vehicles, and four had some experience with human-machine interface design. For epidemic reasons this experiment was conducted through the online design platform figma, as shown in the figure 2and before the experiment began the researchers prepared some images of the front of the vehicle with a blank eHMI and some labels describing the design elements in each canvas to facilitate the participants to construct their interface design concepts, as shown in the figure 2.

Figure 2. User-participatory design experiments based on the Figma platform

(1) The study began with a meeting of all participants, where the researcher conducted a semi-structured interview with the participants in order to explain to the participants the relevant background of the exterior vehicle interface design and to provide theoretical guidance for the subsequent participatory design.

(2) Each participant then entered into a separate meeting with the researcher, and participants began their design activities using the figma platform, during which they could seek technical assistance from the researcher. A brief presentation on the design

description is required to the researcher when the participant believes their design concept is complete.

(3) Once all participants had completed their interface concepts, the researcher initiated an online meeting in which all participants evaluated everyone's design concepts. The concept evaluation was conducted using a seven-point Likert scale, with higher ratings indicating a better fit for their situation, specifically "When I cross a crosswalk on an unsignalized road and encounter an oncoming vehicle with eHMI presenting such content, I choose to cross in front of that vehicle". Each participant rated each design concept, and the mean value was calculated for each design concept.

(4) After the evaluation, the researcher and the participants discussed the feasibility and acceptability of each eHMI design concepts, analyzed and summarized the presentation of the design elements.

(5) Finally, based on the meeting content and scores, the design of the workshop output eHMI concepts were defined, and the final scene renderings were produced by the researchers.

4.3. Experimental results

The external surfaces of the vehicles produced by the participatory design experiment can be divided into two categories: "vehicle yielding" and "vehicle passing", depending on the message conveyed. The results of the participatory design experiment are shown in the table 2, 3. The results show that the average rating of the eHMIs that conveyed the message of yielding was higher than 4, and the average rating of the eHMIs that conveyed the message of passing was lower than 3, which is in line with the expected results of the experiment, discussions are as follows.

Table 2. Statistics of user-participatory experimental results for interface type I

Design concept (vehicles yielding)	**1**	**2**	**3**	**4**	**5**	**6**	**average score**
1		6.00	5.67	6.33	5.67	5.33	5.80
2	4.00		4.33	4.33	4.00	4.33	4.20
3	5.33	5.67		5.67	6.00	6.00	5.73
4	5.00	6.00	5.67		6.00	6.33	5.80
5	4.00	4.33	4.67	4.33		4.33	4.33
6	4.67	4.00	4.33	4.00	4.33		4.27

Table 3. Statistics of user-participatory experimental results for interface type II

Design concept (vehicle passing)	**1**	**2**	**3**	**4**	**5**	**6**	**average score**
1		1.00	1.33	1.33	1.33	1.67	1.33
2	2.67		2.67	2.67	2.67	2.67	2.67
3	1.67	1.33		1.33	1.33	1.00	1.33
4	1.33	1.00	1.33		1.00	1.33	1.20
5	2.00	2.67	2.33	2.67		2.67	2.47
6	2.33	3.00	2.67	3.00	2.67		2.73

In terms of text content, participants generally believed that the level of information conveyed on the eHMI that conveys advice is higher than that of the interface that conveys vehicle intent, which was interpreted as a higher level of comprehensibility because the advice message can directly instruct pedestrians. However, some participants indicated that explicit interaction messages should only convey the vehicle's own intent and avoid conveying directional information to pedestrians because there are other road users in real human-vehicle interaction scenarios, and pedestrians may be involved in accidents with other road users by following the advice messages on the eHMI, which is consistent with existing research [20]. Therefore, the text content of the external human-machine interface should mainly convey vehicle-centered information.

In terms of color, the color metaphor in the referenced traffic system was considered to have a higher level of information transfer, where one participant showed concern about conflicting information perspectives when the interface color was green for the external human-machine interface that conveyed the vehicle's intent, which could be misleading to pedestrians. While the other five participants indicated that although the color and text conveyed information from different perspectives, both conveyed the same message of "vehicle yielding", and the color information only acted as a "reinforcer" of the text information [12], so there was no conflict. Therefore, the color information on the eHMI can be adopted from the existing traffic system.

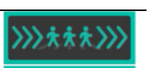
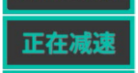
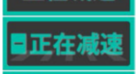
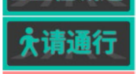
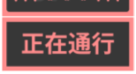
In terms of graphics, anthropomorphic graphics are considered to have a higher level of information transfer, which is consistent with the findings of Fridman et al [21]. The participants indicated that graphics in the design of the external human-machine interface should have high recognizability and comprehensibility features that do not impose an additional cognitive burden on the pedestrian. The combination of text and graphics was rated higher than a single graphic interface, which could be interpreted to mean that adding textual explanations to graphics could help understand the meaning of the graphics. Therefore, anthropomorphic graphics should be used primarily in the design of eHMI, and a combination of text and graphics should be used.

5. External Human-Machine Interface Design and Evaluation

5.1. Design practice

Based on the user participatory design experiment result of the external human-machine interface design concept and evaluation results, the study defined the design of the eHMI, as shown in the table 4. And from this, the questionnaire of "External Human-machine Interface Design Evaluation" was designed and distributed through the web platform. The questionnaire was in the form of a seven-point scale, with higher scores indicating the respondents' stronger intention to cross the street in front of the interface. 8 types of external human-machine interfaces were presented in the questionnaire, and these interface concepts were presented by scene renderings, as shown in the figure 3.

Table 4. Description of the main design elements of external human-machine interface

Information	Text	Information Perspective	Color	Graphics	Illustration
Vehicle yielding	/	Pedestrians	Green	Walking posture pedestrian + arrow	
	Slowing down.	Vehicles		Horizontal line	
	Slowing down.	Vehicles		Horizontal line	
	Please pass.	Pedestrians		Walking posture	
Vehicle passing	/	Pedestrians	Red	Stationary pose, arrow	
	Passing	Vehicles		Arrow	

Passing	Vehicles	Arrow	
Please wait.	Pedestrians	Stationary posture	

Figure 3. External HMI scene renderings

The questionnaire was distributed through the online platform, and 209 valid questionnaires were collected. Among them, 53.7% were male and 46.3% were female, 94.7% were in the age range of 18-30 years old. The table 5 gives a statistical description of the questionnaire response options.As can be seen from the table, the scores of the eHMIs that conveyed the message of yielding were all greater than 4 while the scores of the eHMIs that conveyed the message of yielding were all less than 2, indicating that the external human-machine interfaces designed in this experiment all presented a better level of information transfer.

Table 5. External human-machine interface design evaluation statistics

Information	Interface Content	Strongly Disagree	2	3	4	5	6	Strongly Agree	average score
Give way to vehicles	depiction	7	13	21	96	48	14	10	4.18
	Text (intention)	4	7	10	59	82	27	20	4.77
	Icon + Text (intention)	3	4	4	48	93	34	23	5.00
	Icon + Text (suggestion)	1	1	2	0	92	15	98	5.96
Vehicle access	depiction	127	23	45	12	0	0	0	1.70
	Text (intention)	148	45	5	8	3	0	0	1.44
	Icon + Text (intention)	152	41	7	7	2	0	0	1.40
	Icon + Text (suggestion)	153	46	5	4	1	0	0	1.34

5.2. Design strategies

Based on the above assessment, combined with the results of participatory design experiments and the findings of existing literature, design strategies for the external human-machine interface are derived: (1) Present a vehicle-centered information perspective. (2) Deliver unambiguous and unified information content. (3) Coordinate the implicit and explicit information interaction. The details are discussed below.

(1) Present a vehicle-centered information perspective. The results of the participatory design experiment show that the eHMI in the form of image-text combination with the same information perspective shows the best level of information transmission. Considering of road rules and ethical principles, the eHMI should convey its own intentions to avoid misleading pedestrians. For key design elements, the presented text and icons should maintain the same information perspective; on the other

hand, color acts more as a reinforcer, so the color metaphor in the traffic system can be invoked to keep in line with the kinematic features of the vehicle.

(2) Deliver unambiguous and unified information content. Comprehensibility and acceptability are the key evaluation dimensions for the design of the exterior of the vehicle. Specifically, the use of text should be simple and concise, such as "slowing down", "passing", etc., while graphics need to take into account their intrinsic semantics, user familiarity and other factors. In addition, the design elements of the interface should be standardized to ensure the uniformity of information content and to reduce the negative impact on pedestrians due to differences in regional culture or level of understanding.

(3) Coordinate implicit and explicit information interaction. In the whole process of human-vehicle interaction, there are both explicit and implicit interactions, so the information expressed by the vehicle through explicit interaction must be consistent with the implicit interaction. Existing research shows that the human-vehicle interaction process can be most effectively facilitated when the explicit interaction (eHMI) and the implicit interaction (vehicle kinematic features) of the vehicle are coordinated and work in concert [4], so that the eHMI could be used as an additional aid to the human-vehicle interaction to improve the level of information transfer in interaction process and help pedestrians better understand vehicle intent.

6. Conclusion and outlook

Based on the current research status of external human-machine interface and explicit human-vehicle interaction, this paper sorts out the key design elements of eHMI with external display as a carrier and the explicit human-vehicle interaction features, and introduces a user participatory design method into the design of eHMI to focus on user experience and information transfer level. A design strategy to improve the usability and acceptance of eHMI is proposed, as well as a user-participatory eHMI design method. In the future, further exponential development of related technologies in the field of autonomous driving is bound to occur. How autonomous vehicles can more clearly convey key interaction information to pedestrians, eHMI based on explicit human-vehicle interaction is an ideal solution. Future research should consider more comprehensively the specific impact of various factors on the human-vehicle interaction process in complex traffic situations, unify the standardized design of the external surfaces of the vehicle, and establish external human-machine interface that can flexibly respond to complex traffic environments.

Acknowledgement

This research was supported by Zhejiang Provincial Key Laboratory of integration of healthy smart kitchen (Grant No. 2014E10014), Humanities and Social Sciences of Ministry of Education Planning Fund (Grant No.21YJA760075) and National Defense Science and Technology Foundation Strengthening Program Technology Field Fund (Grant No.2020-JCJQ-JJ-047)

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