Interface Design of Automobile Head-up Display from the Perspective of Human-Machine Interaction

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Abstract: Under the background of user-centered era, the traditional head-down display (HDD) is gradually being replaced by head-up display (HUD). As the carrier of HUD information presentation and the medium for direct interaction with drivers, the design research of HUD interface has become increasingly important and necessary in the research of automobile display system. From the perspective of human-computer interaction, this paper searches and summarizes relevant literature, and analyzes the research of HUD interface in three levels of information content, information level and information style related to user visual cognition, as well as the research of HUD interface in adapting to the physiological and psychological cognitive characteristics of different people, specific scenarios and other interaction elements. Finally，this paper concludes the process and common research methods of HUD interface design and prospects the future research direction.

Keywords: head-up display, interface design, human-computer interaction

1 Introduction

Head-up display, or HUD, is a display technology that uses the principle of optical reflection to map important information directly in front of the driver's field of vision. HUD can effectively reduce the driver's head down frequency and reduce the time of eye focus, so as to improve the driver's information acquisition efficiency, reduce cognitive load and ensure driving safety. With the development of new technologies such as automobile networking, artificial intelligence, and cloud computing, the human-computer interaction mode of traditional automotive interiors has undergone major changes. A large number of entertainment, communication, navigation and other information began to pour into the interior space of the car from external devices, and the information dimension of the car also became complicated, which made the car need more display devices to present information. HUD is one of the information carriers closely related to driving behaviour, and its huge market potential and optimistic application prospect have prompted many scholars to carry out multi-field and multi-dimensional professional research and technology upgrade. From the human-machine perspective, this paper summarizes and discusses the human-machine interaction interface of automobile HUD, summarizes its design process and common research methods, and puts forward the prospect of future research direction, providing a guide for the future design of HUD.

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2 Automobile HUD interface information design

HUD display interface information is increasingly rich, if the complex information is arranged on the HUD human-machine interface without rules, the interface will be easy to cause problems such as unclear presentation, unclear level, so that the driver cannot efficiently obtain key information, and thus affect the driving safety. Therefore, the design arrangement of human-machine interface information and the visual effect and cognitive feeling brought by the interface information to the driver are the key factors affecting the interface design effect. Current research on information design of automobile head-up display interface can be divided into three categories: information content, information level and information form.

2.1 Information content

In the intelligent era, the information content of the in-car interface is no longer limited to traditional driving information such as speed, rotational speed, gear, etc., even abandoned fuel automobile information such as fuel reminder and fuel consumption, and then expanded intelligent auxiliary information such as entertainment, communication, ADAS， and so on. In this context, the research on the information content of the automobile HUD interface has become the basis for organizing information architecture and arranging information forms. This paper divides the existing on-board HUD interface information into four categories: basic driving information, navigation information, safety assistance information, and entertainment information. Each category of information contains several information modules (**Table 1**).

Table 1. Summary of automobile HUD interface information.

Information Classification	Information Content
Basic automobile information	Speed information, gear information, rotational speed information, fuel/power, headlight status, steering information, energy recovery information, range, tire pressure, mileage, water/oil temperature, battery status, time information
Navigation information	Distance sign, destination information, current lane, fork choice, time information, turn indication, U-turn indication, lane change reminder, current road speed limit, special road conditions, congestion level, special location indication
Safety assistance information	ADAS Advanced driver assistance system information (ACC, AEB, BSD, FCW, LDW, ISA, PDS, NVS, AFL, TSR, etc.), signage reminders, door status, seat belt information, collision safety warning, outdoor temperature
Entertainment information	Music information, radio information, bluetooth status, communication messages, speech recognition, gesture recognition

2.2 Information hierarchy

The interface information of the automobile HUD is rich and huge, so it needs to be divided into clear and logical information levels, so that the driver can easily, timely and accurately obtain key information. The construction of clear information hierarchy is a key element to improve the usability of HUD interfaces, and is also an important part of constituting excellent human-computer interaction. Beck invited subjects with HUD experience to evaluate the importance of common information elements subjectively, and came up with level 1 information, namely four universal characteristics of important information: the need for frequent or continuous attention, the need for rapid perception and response, the need for correct information processing, and the failure to obtain it from the external environment [1].

Since there are differences among people, scenes and targets using HUD, the research on the interface information level should be based on these differences to effectively improve the interactive pain points under the target scene. Li Built a hierarchical HUD security prompt information model based on the element of security auxiliary information, determined the information weight accordingly, and completed the information organization and system interaction adaptive strategy of HUD [2]. Zeng Proposed the information organization strategy division based on four functional elements of navigation information: direction guidance, distance reminder, place name reminder and driving assistance [3].

2.3 Information form

The form of interface information includes the color, size, position, transparency and other visual information of interface elements, which is the core factor affecting the visual effect of interface. Due to the rich visual characteristics of human beings, such as the sensitivity of human eyes to different colors of light, the spatial resolution and grey resolution range of human eyes, visual adaptation, visual inertia, visual illusion, etc., the information form of HUD interface needs to make reasonable use of many visual characteristics, and make reasonable design and arrangement of information elements to meet the visual cognitive laws of most people.

Wang studied the impact of static and dynamic indication information in AR-HUD on the driver's situational awareness, and the results showed that static information improved the driver's ability to predict the environment, while dynamic information enhanced the driver's ability to perceive the environment [4]. Kandil studied the impact of AR-HUD interface design based on the external environment and the former windshield on the driver's environmental cognition, and clarified that the more concise and fixed screen carrier interface information has a more positive impact on the driver's environmental cognition than the more novel and dynamic environmental carrier interface information [5].

Research on HUD information color is the most abundant. Liu studied the color coding method of automobile HUD from the perspective of color adaptation, extracted HSV color values in different environments and matched them with HUD color values in corresponding scenes, so that HUD interface information could be most prominent under different environmental light colors, and ensured the driver's cognition and recognition efficiency [6]. Gabbard studied a perceptual matching method to check color mixing in HUD graphics, and verified the high performance of visual search tasks under blue, green, and yellow graphics [7]. Guan conducted a study on color classification strategy and ergonomic evaluation of HUD, and concluded that HUD interface with red background color and yellow and green foreground color has the highest search performance, and information with higher priority can be set to green and other information can be set to yellow during interface design [8].

3 Research on human-computer interaction of HUD interface

Human-computer interaction is the process of information exchange between the machine and the user in a certain interactive way to complete the determined task. The interface is the direct medium and dialogue interface for the two sides to transmit and exchange information, and is an important part of the interaction system. Therefore, the interaction research on the HUD interface is an indispensable part of the automobile HUD design research. The interface information mentioned above is the communication form and visual presentation carrier of the interface interaction system. However, in addition to the links visible to the user, an excellent interaction system should also consider the user's understanding of the machine, the user's behaviour characteristics, the availability of the machine, the interaction environment based on time and space, and other interaction elements and the underlying interaction logic that can build a complete interaction order. This paper summarizes the specific interaction flow between the user and the automobile HUD interface (**Figure 1**) and divides the existing HUD interface interaction research into the interaction research based on specific population, the interaction research based on specific space-time scene and the interaction research based on other interaction elements.

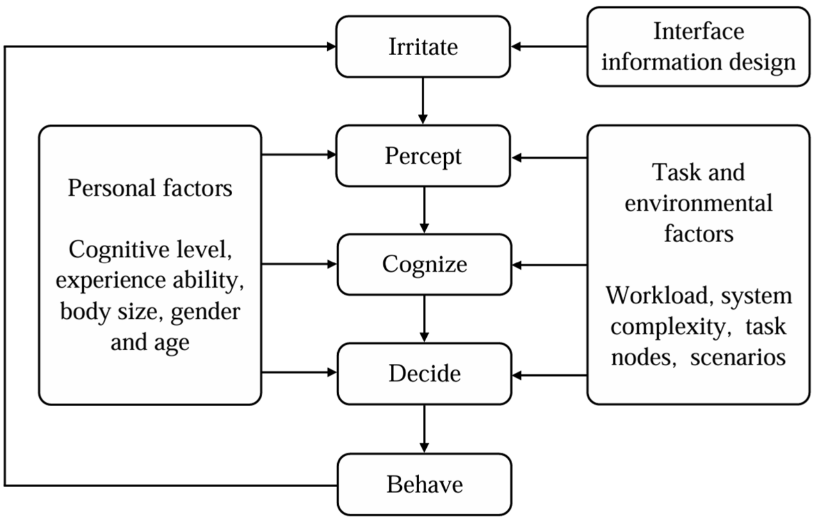

Fig. 1. Interaction flow between the user and the HUD interface.

3.1 Interactive studies based on specific populations

Different people have different body size parameters and physiological abilities, and also have different mental models. Due to the visual interaction between automobile HUD and drivers, drivers of different ages, driving ages and genders have certain differences in visual performance such as information visual needs, attention allocation and distraction risk, which are further related to drivers' behavioural performance such as reaction and decision time, automobile handling and information perception. This requires that the HUD interface should take into account the behavioural and cognitive differences between different users at the beginning of the design, so as to achieve inclusive design.

Zhang compared the HUD information needs of beginners and experienced drivers in different road environments, and concluded that beginners have different information needs for different road conditions, while experienced drivers have fixed information needs, both of which have higher requirements for navigation information [9]. Aydogdu applied HUD in the driving process of different groups to explore the changes in their driving ability, and the results show that HUD has a significant impact on driving ability, security and driving experience, and this impact is more intense in elderly drivers, students and women. When HUD is activated, women will feel safer [10].

3.2 Interaction research based on specific scenarios

The driving task takes place in a certain scene and has the dual properties of space transfer and time deduction. In a specific scenario, driving behaviour also has the dual availability attributes of scenario-driven and scenario-served. Based on scene recognition and scene ecology, the development of specific HUD interaction strategies for specific driving tasks is conducive to users' efficient completion of driving tasks. Charissis studied the spatial awareness and reaction time of drivers in low-visibility environment, and designed the HUD interface prototype [11]. In order to understand the speed impact of AR-HUD cues on drivers' recognition of pedestrians and the acceptability of visual cues for automatic intervention, Karatas developed an AR-HUD based on pedestrian reminder scenes, and proved its effectiveness for drivers' rapid recognition of potential dangers in the evaluation results [12]. Du focused on unmanned taxi, based on the explicit interaction theory, deeply explored the common scenes of users in taxis and the reasons for the demand for explicit information, and produced the design practice scheme applied to unmanned taxi, providing reference value for the design of unmanned taxi human-machine interaction interface [13].

3.3 Interaction research based on other interaction elements

Although specific people show different interaction characteristics in specific scenarios, the cognitive characteristics and interaction mechanism behind it are still worth exploring. Therefore, many scholars build HUD design framework based on user's cognitive rule and user's underlying logic drive. Nayara observed "unconscious blindness" during driving, in which the visual information presented by the AR HUD may be ignored if the driver's attention is focused on another activity other than the driving task. Based on this phenomenon, the authors evaluated the driver's eye distribution and visual ability, and designed an interactive interface to eliminate perceptual faults [14]. Kim noticed that HUD interface might cause cognitive damage to drivers' perception of road surface information. By treating different types of objects on the road as independent dynamic AOI, they summarized information elements that might cause cognitive damage and provided suggestions for the design of HUD information interface [15].

The human-computer interaction discussed above mostly stays at the visual level. However, multi-sensory and multi-channel interaction can achieve multi-device collaboration and cross-device scene migration by means of its diversity, accuracy and inclusiveness in the face of different groups of people, occupying a place in the field of interaction. Wang introduced a seamless multi-sensory interaction design space and applied it to automotive HMI through the integrated view of temporal cognitive dimension and space, and provided a design case study to explain its practical value [16]. In addition, some scholars grasp the key steps in the interaction process, starting from the interaction node, to optimize the design of HUD interactive interface. For example, Han starting from the key node of human operation to machine takeover, studied the technical principle and system framework of AR-HUD takeover mode, designed the interactive interface, and demonstrated the feasibility of the interactive interface from two aspects: emergency takeover and ordinary takeover [17]

4 Design process and common research methods of HUD interface

Based on the existing research results, this paper summarizes the design process of automobile HUD interface into three stages: demand research stage, design stage and evaluation stage (**Figure 2**).

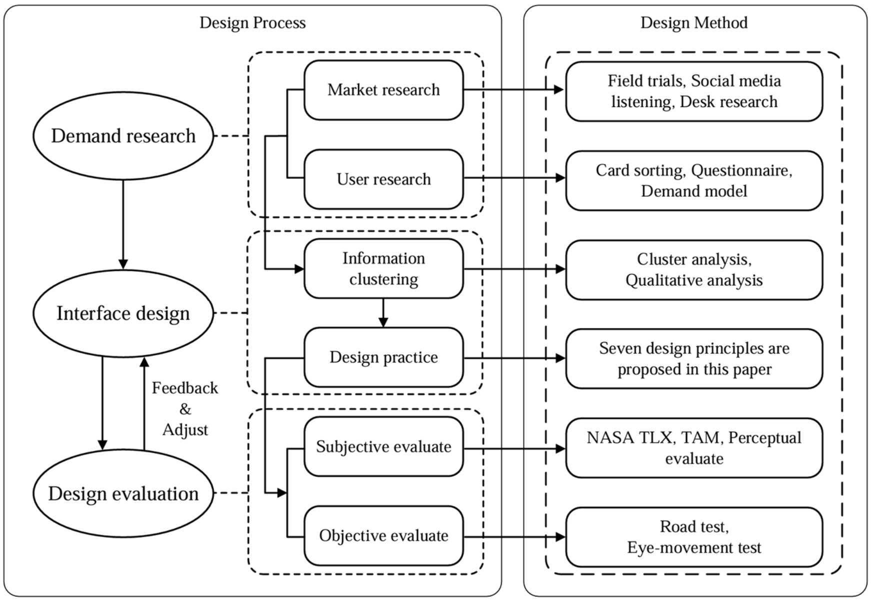

Fig. 2. HUD interface design flow.

The demand research stage can be divided into user research and market research. According to the positioning of the design object, researchers should have insight into the market demand, analyze the existing emerging technologies and application fields, investigate and understand the industry situation, determine the market positioning of the product, and strive for technical advantages. Common market research methods include field trials, social media listening, desk research, etc. At the same time, researchers should interview and communicate with target users, listen to their needs and motivations, understand their behavior patterns and psychological activities, so as to quickly build user portraits and master product pain points. Commonly used demand research methods include card classification, questionnaire survey, IPA model, etc. The requirements selection process should be as comprehensive and precise as possible in order to guide the next design work.

The interface design stage can be divided into two steps: information clustering and design practice. The designer first needs to cluster the collected research information and grade it according to its importance, which lays a foundation for the subsequent selection of interface information content, division of levels and design of forms. Common information clustering methods can be realized by cluster analysis and qualitative analysis software such as EZ-sort and Nvivo, or by user emotional evaluation and user collaboration. Secondly, the designer needs to process the key information elements of the interface in a form that conforms to aesthetic experience according to the user cognitive law, and complete the design of the HUD interface. This article provides seven general design principles for the design of HUD for reference:

(1) Information priorities need to be ranked according to importance, important information should be fully displayed and in a prominent position. And information about driving safety must be the highest priority.

(2) The information content is best not to be static, and dynamic information is not easy to make the driver feel sleepy and tired. Urgent information needs to be displayed in an eye-catching and dynamic manner.

(3) The display color of the HUD should be a high-saturation color, and the high-saturation blue, green and yellow will help the driver to extract information.

(4) The display color and brightness of the HUD should take into account changes in the background and lighting, and it is best to make adaptive changes according to the environment in order to present a high contrast state with the surrounding environment. At the same time, be careful to prevent HUD information from blocking road information.

(5) HUD information should not only have visual stimuli, it is best to combine with other sensory stimuli such as hearing or smell to achieve multi-modal interaction.

(6) HUD should be able to record the presets of multiple different drivers, so that different drivers can quickly set preferences when using it. The default content includes the physical position of the HUD, display style, display content and other information.

(7) Designers should make use of aesthetic principles to ensure the simplicity and unity of the interface while realizing the aesthetics of the interface.

The design evaluation of automobile HUD can be carried out through two aspects: subjective evaluation and objective evaluation. After the interface prototype is designed, the designer can use the NASA TLX multidimensional evaluation scale, user perceptual evaluation, TAM technology acceptance model and other perceptual evaluation methods for users to evaluate the design results subjectively. Road tests and eye tracking experiments are commonly used to collect objective data. Designers can re-examine and modify the design results through the evaluation results, and strive to achieve the optimal interface usability.

5 Future research prospects

5.1 Immersive interactive experience based on scene services

AR-HUD is a technology that superimposes virtual reality. If the virtual field of perception and information coexist, the user's media consciousness will be relieved and immersed in the augmented reality environment. To a certain extent, this media scene is separated from the real time and space and reconstructs the spatial pattern. As traditional means of transportation gradually transition to intelligent mobility space, drivers are more inclined to use the space in the car as an independent third space in addition to home and office. On this basis, designers need to closely integrate service design with usage scenarios, and make full use of artificial intelligence and network interconnection to enable users to obtain immersive interactive experience. Multi-screen is the design trend of interior HMI in the future. Multi-screen in-car information interaction tends to be multi-modal. The design of automobile HUD should also take into account the collaboration and interaction with other screens to improve the information processing efficiency under multi-task flow.

5.2 In-depth exploration and development of multi-sensory channels

Current multi-channel studies based on automobile HUD mostly focus on audio-visual combination and gesture or voice control, but there are few studies on the interaction of sensory channels such as smell and touch. With the improvement of virtual algorithms, the development of neuroscience and the deepening of brain machine research, the design of automobile HUD with multi-sensory channels is no longer a fantasy. For example, HUD can be combined with other wearable devices to share information and cooperate, and key information can be transmitted to users by means of vibration, taste and sound through wearable devices such as smart watches and head-mounted display devices to enable multi-sensory interaction.

5.3 Construct high simulation experiment platform

In the real road driving, the driver's perception of the target distance is longer than the actual situation, while the indoor test results are just the opposite. It can be seen that there are significant differences between the HUD simulation experiment and the real road test results. If the simulation experiment data in a low-fidelity environment is adopted, the driver may misjudge the information in the real environment, leading to potential dangers. Therefore, the design, research and evaluation of automobile HUD should strive to improve the scientificity of human factor testing, and it is suggested to build a high-fidelity test platform and develop a simulation scene library to meet different needs. At the same time, the design evaluation system should be improved to ensure the authenticity and usability of the research results.

6 Conclusions

As an important part of automobile HMI in the information age, HUD has positive significance for future intelligent driving by optimizing driving experience and improving driving safety. This paper reviews the current research status of automobile HUD interface design from the perspective of human-computer interaction, and discusses interface information design and automobile-machine interaction based on user, time and space, cognitive psychology, multi-channel and other auxiliary scenarios. In view of the existing research results and shortcomings, three future research directions are proposed: immersive interactive experience, multi-sensory channel and the construction of high simulation experiment platform. The research in this paper can provide a reference for the human-machine interface interaction design of the new generation of HUD, and it is expected that more researchers will put new perspectives, new technologies and new methods into the design and research of automobile HUD.

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