Article

A Study of Trends in Automotive Personalized HMI Design

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Abstract: ***Background:*** The development of China's automobile industry and the change of modern consumer demand have led to the innovation of personalized Human-Machine Interface (HMI) which has become an important research directions in the field of automobile design. Current findings indicate that most of the researchers' attention is mainly focused on the theoretical research and practical exploration of mass HMI design, whereas the demand for personalized automotive design is rapidly increasing. ***Purpose :*** This study aims to fill the gaps in academic research on automotive personalized HMI interaction design, to deeply excavate and summarize the laws and trends, and to provide more theoretical support and practical guidance for the field. ***Methods:*** This study adopts the literature research method, theory analysis method and case study method. The future trends are analyzed through examining relevant literature and theories both locally and internationally, combined with actual cases and design practices. ***Results:*** The study found that the core features of personalized HMI design focus on four aspects: high user involvement, high customizability, high degree of intelligence and good user experience. Future trends in automotive personalized HMI design include intelligence, automation, cross-platform, multimodal interaction, sustainability and environmentally friendly design. ***Conclusion:*** The future of automotive personalized HMI design will integrate the application of more advanced technology resulting in a more diverse, intuitive and convenient personalized automobile design in addition to growing awareness on environmental protection.

Keywords: Automotive Design; Personalization HMI; Design Trends; User Experience

1. Introduction

1.1 Research Background

The automotive industry is undergoing an unprecedented transformation due to the rapid development of Internet of Things (IoT) technology, Big Data, and Artificial Intelligence (AI) technology. Cars are no longer just a simple means of transportation but they are now gradually transforming into mobile living spaces and becoming an important part of the digital economy (Wang, 2023). In 2022, the China Auto Parts Industry Association (CAPIA) reported that market sales showed a U-shaped reversal, in which the production and sales of passenger cars reached 23.836 million units and 23.563 million units, respectively, and the year-on-year growth rate was 11.2% and 9.5%, respectively (Jia, 2023). This data fully demonstrates the rapid development of the automobile industry. At the same time, consumer demand for automotive personalized Human-Machine Interface (HMI) design has become the focus of attention in the industry.

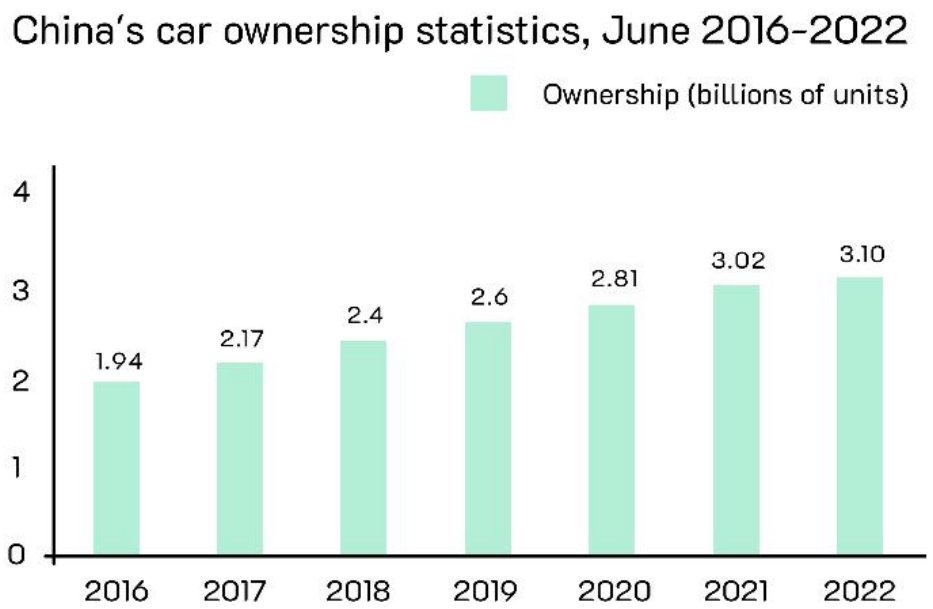


Figure 1: China's car ownership statistics, June 2016-2022

Source: www.askci.com

Despite the growing interest in personalized automotive design and the emergence of related studies, HMI design remains in the stage of continuous exploration and in-depth investigation, with research lacking systematic organization. This study will summarize and evaluate research on personalized automotive HMI design within the context of user demand. By combining technology and theory, we can gain insight into the development trend and provide new perspectives and ideas for future research on personalized automotive HMI design.

1.2 Research Purpose

This study aims to fill the gaps in academic research on automotive personalized HMI interaction design, starting from the comprehensive consideration to digging deeper and summarizing the laws and trends, providing more theoretical support and research information in the field, while also providing valuable guidance to automobile manufacturers. Combined with the current research situation locally and globally, the theoretical basis and key technologies of automotive personalized HMI design are analyzed and then integrated with case studies to provide new perspectives and ideas and to promote the development of the related industries in the direction of smarter, more scientific, and enhanced automobile design.

1.3 Research Methods

The main research methods used in this study are as follows:

(1) Literature research method: involves investigating an extensive quantity of literature to obtain relevant information on a specific research topic and then followed by systematic analysis of the subject matter. In this study, the method is mainly used to investigate the literature on automotive personalized HMI design both locally and internationally, to understand its characteristics and the current research status. Additionally, through the literature survey, the relevant applications of user experience and interaction design are summarized and organized. Explore the development trend. This method can effectively enhance the foundation established by prior manufacturers.

(2) Theoretical analysis method: an in-depth analysis of related theories and conceptual framework in order to understand the nature, characteristics, and laws of the

research object. In this study, the theoretical analysis method helps to establish the theoretical foundation of the study, guides the empirical research, as well as expands the theoretical understanding of automotive personalized HMI design. Furthermore, through the theoretical analysis method, the authors expect to provide useful references and insights for the development of the field of automotive personalized HMI design.

(3) Case study method: is a qualitative research method that seeks to understand complex phenomena by in-depth analysis of specific cases. The main application of this study is to analyze and examine the characteristics and factors of the existing successful cases, which will assist in future research on the trends of automotive personalized HMI design.

1.4 Research Content and Frame

This research can be divided into eight chapters, and the content of each chapter is as follows:

Chapter 1 Introduction, combined with the development of China's automotive industry and orientation, to clarify the research objectives, directions and methods, and to clearly explain the content and significance of the study; Chapter 2 Literature Review, to summarize the current domestic and international theoretical and practical achievements related to automotive personalized HMI design, to have an overview about the current status of the study, and to explore the key issues in the subsequent study; Chapter 3 Overview of automotive personalized HMI design, in this chapter the concept and definition of HMI design are clarified, along with its significance in the field of automotive design, followed by a comprehensive overview based on the concepts, characteristics and practical applications; Chapter 4: User Experience and Cognitive Psychology in Automotive HMI Design, this chapter comprehensively describes the concepts of user experience design and cognitive psychology, and explores the key of subsequent research; Chapter 5: Overview of Automotive Personalized HMI Design. This chapter comprehensively explains the concepts and application cases of user experience design and cognitive psychology, then proposes the interaction design strategy that combines the two and their specific applications, and deduces the future direction of automotive HMI design based on the application of design theory; Chapter 6 investigates the key technologies of automotive personalized HMI design, aiming to systematically summarize the existing technologies required for automotive personalized HMI design, including artificial intelligence and machine learning, virtual reality and augmented reality technologies, and the use of the latest technologies in automotive personalized HMI design. Exploring the fields of Learning, Virtual Reality and Augmented Reality technologies, and Voice Interaction and Automatic Speech Recognition technologies. Additionally, the exploration of the theory of automotive personalized HMI design in the context of the future state of technological development is done by studying and summarizing the use of existing technologies; Chapter 7 Future Trends of Automotive Personalized HMI Design. In this chapter, combined with the previous research and analysis, the use of interaction design theory, the future trend of automotive personalized HMI is explored, which is mainly divided into three points: the trend of intelligence and automation, the trend of cross-platform and multi-modal interaction, and the trend of sustainable and environmentally friendly design; Chapter 8 Conclusion, summarizing the conclusions and limitations, and discussing the subsequent development of the research work.

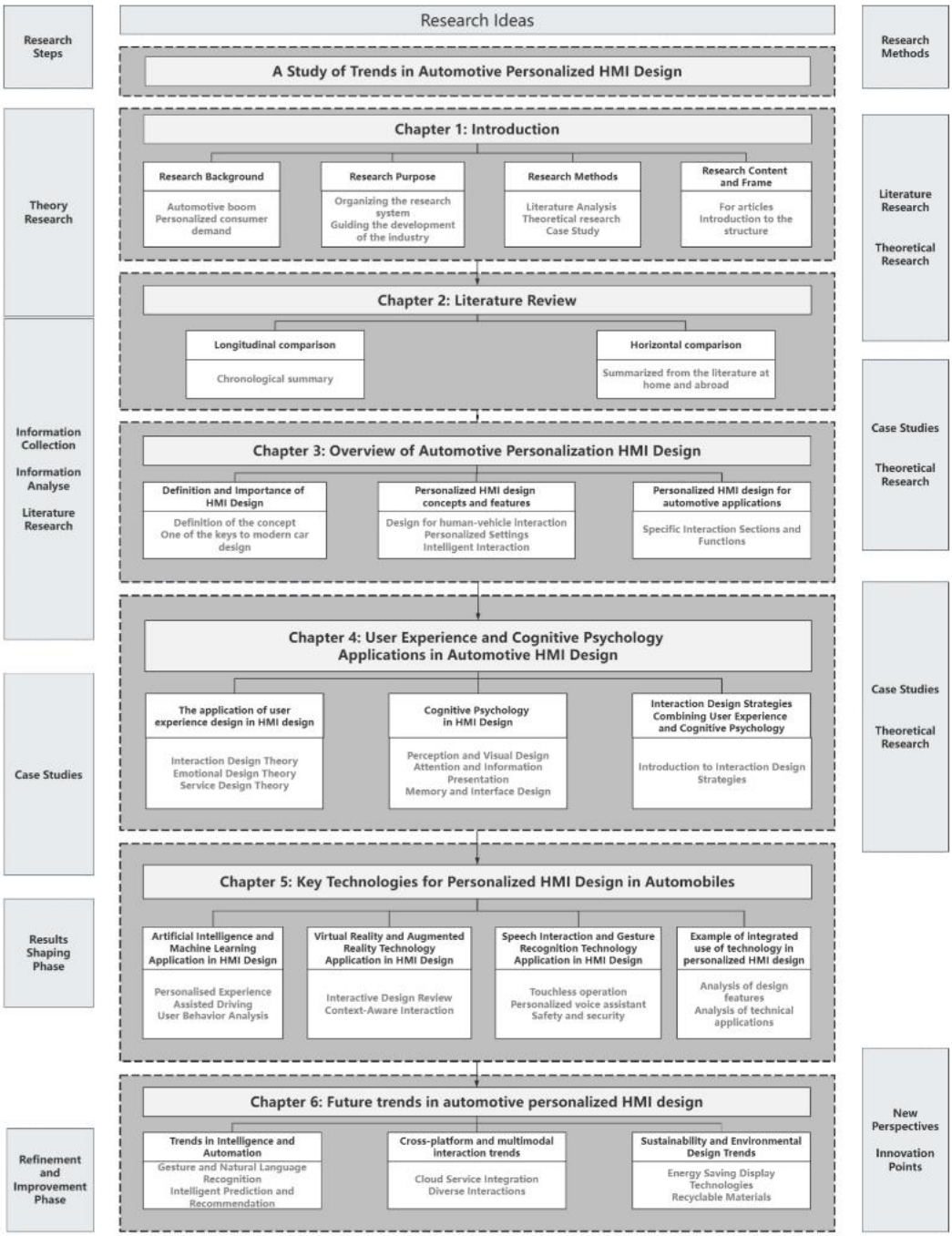


Figure 2: Frame diagram

2. Literature Review

The rapid development of the automotive industry and the transformation of consumers' customization demands have led to the innovation of automotive personalized HMI design and become an important research direction in the field of automotive design. This review will focus on the research on automotive personalized HMI design in recent years, discussing its development trend, key technologies, and the limitations of existing research, to provide references for future research directions.

2.1 Status of Domestic Research

Domestic research has contributed literature on automotive HMI design research, aiming to promote the development of HMI design theory and practice to improve driving safety and comfort.

Yu Mingliang (Mingliang, 2023) and others verified the feasibility of AHP and QFD methods in the HMI design of intelligent vehicles. Ma Yujia (Yujia, 2023), on the other hand, proposed a design method to solve multi-person multi-screen interaction in complex scenes and constructed a design process. Xu Meng (Meng, 2022) and others analyze and discuss the scene-based HMI design methodology with the goal of delivering the ultimate user experience. Yang Helong (Helong, 2021) further explored that art can be integrated into the design of automotive form, cabin, and HMI interface through the multidisciplinary integration of psychology, ergonomics, and aesthetics. Yu Fang (Fang et al., 2021) investigated the evaluation method of automotive HMI design based on team situational awareness. Yaying Li (Li, 2023) studied the evaluation method of female in-vehicle HMI design and implemented it in a practical setting.

Zhang Xinrui (Xinrui, 2024) proposed a new energy vehicle HMI design solution to solve the problem of load overloading of a single perception pathway in traditional HMI and emphasized the importance of multimodal interaction to enhance user experience. Lin Jiahe (Jiahe, 2024) proposed a design strategy for an automotive takeover request interface based on context awareness. Zhang Yuanchen (Yuanchen, 2023) researched a set of HMI human-computer interaction interfaces in line with brand aesthetics and scientificity for the practice object BYD Han EV. Huang Jinfei (Jinfei, 2022) proposed a set of design solutions to meet the multi-scenario HMI interaction interface and cockpit.

Meng Jian (Jian, 2022) team proposed a research project based on the four phases of intelligent cockpit product development, including cockpit definition strategy tool development, cockpit HMI prototyping tool development, cockpit iterative development simulation tool development, cockpit iterative development experience validation tool development, which promotes the construction of standards and specifications in the evaluation of intelligent cockpit experience.

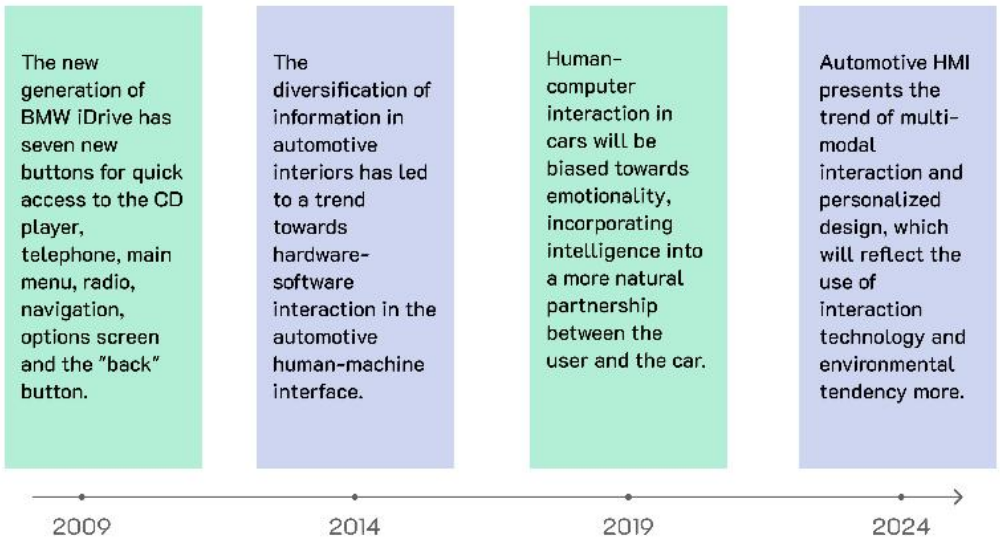


Figure 3: Automotive HMI Design Research Development Timeline

2.2 Current Status of Foreign Research

Foreign studies have highlighted the needs of different user groups for automotive HMI design and emphasized the importance of HMI design in enhancing driving safety and comfort.

Yang Hao (Hao, 2021) team employed Artificial Neural Networks (ANN) and Support Vector Machine (SVM) algorithms to quantify user experience by investigating the relationship between the design features of in-vehicle panels and the usability of the system, and ultimately identified the advantages of the SVM model in user experience learning of HMI design features, and provided a methodology for designing and evaluating the layout of the T-shaped dashboards. The team of Özbay H (Özbay, 2022) emphasized the importance of human control decision-making in automated driving cars and predicted future trends in HMIs in an AI-driven shared control environment.

Monsaingeon N (Monsaingeon, 2021) team highlighted the importance of HMI in self-driving cars by comparing the effects of two different HMIs on drivers, provided empirical support for HMI design, pointed out the potential benefits of multimodal HMIs, and proposed directions for further research. Li X (Li, 2020) investigated the ecologically safe driving HMI through simulation experiments and data analysis on driver behavior, mental workload, and visual demands, and concluded that the HMI can effectively promote ecologically safe driving behavior without imposing excessive mental or visual burdens on drivers.

Table 1: Summary of Literature Studies Abroad

Research Direction	Reference	Trait
HMI Interface and Cockpit Design Study	An Elderly-Oriented design of HMI in autonomous driving cars based on rough set theory and backpropagation neural network. Study of HMI in automotive ~ car design proposal with usage by the elderly ~.	The research results show that the elderly-oriented HMI design constructed by Kansei Engineering/ Rough Set Theory/ Backpropagation Neural Network can meet the sentimental needs of middle-aged. Proposed a UX based on-boarding/exiting and door shape, and established a new icon design based on door shape. Such an approach is expected to be effective in future automobile design.
HMI design in relation to driver attention and road safety	Investigating the impact of HMI on drivers' merging performance in an intelligent connected vehicle environment	The Guidance group further includes speed and voice guidance features.
Theoretical study of HMI design methods	Exploring relationships between design features and system usability of intelligent car human-machine interface.	In this paper, the usability of the T-shaped panel system with different design features will be identified and detected based on ANN and SVM models.

2.3 Limitations and Prospects of Existing Research

Despite the progress achieved in the field of personalized HMI design for vehicles, certain limitations remain, such as insufficient evaluation of the effectiveness of HMI design in enhancing driving safety and comfort. Furthermore, existing research may not have adequately considered that HMI interaction modes may need to be adapted and extended in response to technological developments. Future research should focus on these areas and explore how to better integrate user needs and technological advances.

3. Automotive Personalization HMI Design Overview

3.1 Definition and Importance of HMI Design

The design of Human-Machine Interface (HMI) involves designing and developing interfaces that facilitate interaction between humans and machines. In the automotive

field, HMI usually includes but is not limited to, navigation systems, audio controls, vehicle diagnostics, and driver assistance functions. By carefully designing the car's HMI, drivers can focus more on the road, reduce distractions and operational errors, lower the risk of traffic accidents, and gain competitive advantages for automotive brands in the marketplace.

3.2 Concepts and Features of Personalized HMI Design

Personalized HMI design is a design concept that is dedicated to providing tailor-made interaction experiences and interfaces for product users according to their individual needs. Its core lies in the user's preferences as the key to design, thorough exploration, and analysis of the user's driving habits, preferences, physical characteristics, and other aspects of the data, to provide users with more customized HMI design.

Personalized HMI design has many core features, one of which is the high degree of user participation. User feedback and involvement are crucial in the process of personalized design as they address the unique needs of the user, ensuring the accuracy and satisfaction of the design. This feature enables the users to make personalized adjustments to the HMI interface layout, functional settings, etc. to suit their preferences and driving habits, thereby enhancing driving convenience and efficiency. Another feature is the artificial intelligence and machine learning technologies and personalized HMI design to automatically learn and adapt to user behaviors and preferences and provide a smarter and more convenient interaction experience. The ultimate goal of personalized design is to provide a good user experience through in-depth excavation and analysis of user needs, resulting in interactive interfaces and functionalities that align with the user's habits and preferences. This approach aims to improve user satisfaction and loyalty to the product while also enhancing brand identity and word-of-mouth promotion. These features together constitute the core value of personalized HMI design, making it an indispensable part of the automotive industry.

3.3 Personalized HMI Design for Automotive Applications

Personalized HMI design is widely utilized in the automotive sector, with its core focus on providing a customized interaction experience through advanced technology and user insights to enhance driving convenience and comfort. At the same time, personalized HMI design is also a key to enhancing brand competitiveness, and automakers are taking it as an important direction for product innovation.

For example, Facecar has provided HMI design services for many well-known automotive brands, including Mastodon 917, Volkswagen CNS3.0, Avita, WEY, SAIC IM, Chery Explorer 06, Wuling KIWI, and Qichen.

Figure 4: Facecar Automotive HMI Design Service Client

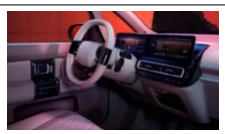
Source: http://www.facecar.org/

In Facecar's innovation project for SAIC Volkswagen HMI, in collaboration with SAIC Volkswagen's design, HMI, and styling teams facilitated the exploration of inspirations and user interviews addressing the needs of Chinese local users for intelligent networking, parking, sensorless payment, smart home integration, thereby centering the innovation and design with the user experience as the core. Through the preliminary user research, we have explored the visual preferences of local Chinese

users for HMI, analyzed the trends, and ultimately developed a visual design language of line and silk. This design successfully integrates the core elements of Volkswagen's brand identity into the mass-production HMI design, making the upcoming products even more worthy of anticipation for future models. These examples show how personalized HMI design may provide drivers and passengers with a smarter, more comfortable, and more convenient driving experience through user research, interaction design, visual design, and 3D kinetic design.

In addition, Facecar highlighted that new trends in in-vehicle HMI experience design include optimization of service scenarios, the integration of cross-industry and cross-channel value, service and marketing operations based on user and driving data, an enhanced user interaction experience, cross-platform multi-screen interaction, and multi-channel interaction. These trends reflect the key role of personalized HMI design in addressing user needs and enhancing user experience.

Table 2: Facecar Automotive HMI Design Services

Service Recipients	Picture	Service content
IM L7		Designed for the young user group using the slanting lines of the light luxury style.
M-Hero917		High-end off-road HMI experience design.
VOYAH		Provides the definition of a new generation of interaction frameworks.
CHERY TIGGO 06		Smarter and more convenient driving experience design.
WEY		A set of intelligent, efficient and intuitive HMI platforms is built.
AVATR		The combination of personalized experience with innovative graphics and interaction design creates an enjoyable and efficient driving experience.
KiWi EV		Starting from the real needs of the user, by understanding the driving habits of the owner, we can provide more intelligent traveling under different scenarios of car needs.

The application of personalized HMI designs in the automotive sector is continuously increasing. By providing tailor-made HMI designs, manufacturers have greatly enhanced driving flexibility, pleasantness, as well as brand competitiveness. By digging deeper into user needs and combining brand features, design service providers may deliver a smarter, more comfortable, and more convenient driving experience for both drivers and passengers. In the future, the development of new trends will ensure that personalized HMI design will continue to play a key role in addressing user needs and enhancing user experience.

4. Use Experience and Cognitive Psychology Applications in Automotive HMI Design

This chapter will discuss the application of theories related to automotive personalized HMI design, introduce the application of user experience design theory and cognitive psychology, and explore the interaction design strategy that integrates both disciplines. This study will analyze the application of design methods in automotive HMI design to explore the design strategy and the development direction of personalized HMI design.

4.1 Application of User Experience Design in Automotive HMI

User experience encompasses the inner sensations that users encounter when using a product and their overall perception and evaluation of it. A user-centered design approach focuses on shaping a user experience that is both engaging and efficient. User needs and reactions should be the key considerations at all stages of product development. This means that designers must comprehensively consider every detail of the interaction between users and products, deeply understand users' psychology, behavior, and preferences, and make design decisions accordingly (Yang, 2015). User research is a crucial part of UX design, which is an indispensable step in order to deeply explore users' needs. Through user research, designers can deeply understand users' potential needs, inner expectations, and habitual behaviors, and continuously absorb users' feedback, to provide design direction. At the same time, designers must consider the usability and ease of use of the product, which also plays an important role in the user experience. In many cases, the key factor in user experience is its simplicity, ease of use, and intuitive understanding, especially in the automotive HMI design for road driving scenarios.

With the development of the automotive industry, the basic needs of users are gradually satisfied, prompting automotive manufacturers to focus on the enhancement of user experience. In automotive HMI design, the core principles of user experience design are also applicable and the optimization of interaction feedback and interaction process is particularly important. Therefore, designers need to consider every detail of the interaction between the user and the car to ensure that the user can easily understand and use the various functions of the vehicle, and get a pleasant experience while driving.

The Mercedes Me mobile client launched by Mercedes-Benz is a very typical case. By connecting and expanding the car HMI interface terminal, users can access a comprehensive intelligent mobile service platform, which covers a wide range of functions and services from basic vehicle information control to entertainment content and life information. The client also provides more than ten special services for the Chinese market to further meet the multiple needs of users, fully reflecting the personalized design that respects the unique needs of users.

Figure 5: Mercedes me mobile client

Source: Mercedes-Benz official website

Through the study of user experience, designers in the automotive HMI design, can gain deeper insights into user needs, improve the user experience, better fulfill user needs, and improve product service.

4.2 Cognitive Psychology in Automotive HMI Design

Cognitive psychology is a broad field that explores all aspects of how humans process and understand information. Broadly speaking, it covers all aspects of human cognition, while from a more specific point of view, it focuses on the science of information processing, similar to the study of the way computers process digital information, but the difference is that this discipline focuses on the study of how human beings receive, analyze, store, process, categorize, and retrieve information, and explores the mechanisms involved in order to research rational methods of information processing and integration. In short, cognitive psychology focuses on the process of how humans acquire information, process information, and express information, and is therefore also known as information processing psychology (Guo, 2020).

Automotive human-computer interaction interface is one of the important media for users to acquire and process information while driving. Therefore, cognitive psychology plays a key role in the design process.

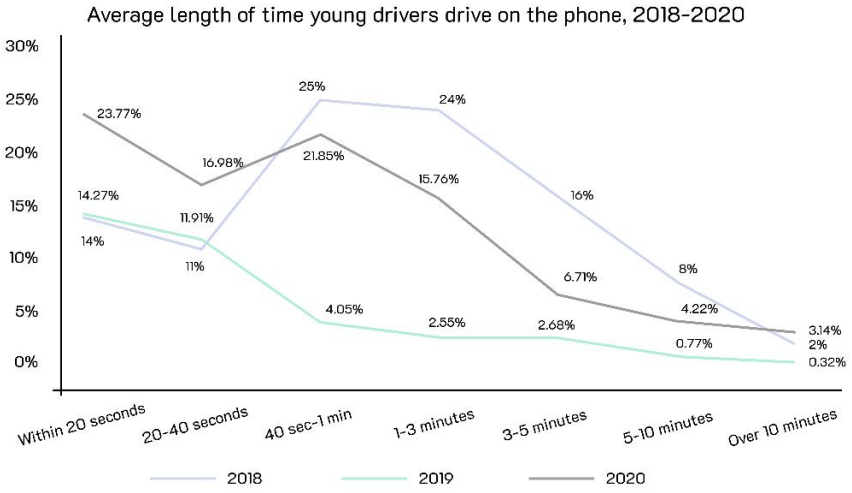


Figure 6: Average length of time young drivers drive on the phone, 2018-2020

Source: White paper on distraction and traffic accidents among Chinese youth 2018-2020

In automotive HMI design, designers need to consider how users receive information through their senses, such as sense of sight, sound, and touch, and how this information is processed and remembered by the brain. For example, research in cognitive psychology has found that humans have a limited capacity for attention and memory when processing information, so HMI design must be simple and clear to avoid information overload. For example, Tesla's Autopilot system helps users easily understand and operate the car's autopilot functions through an intuitive interface and concise commands, this design is based on the principle of "reducing cognitive load" in cognitive psychology and is also under the framework of the concept of "user-centered design." This philosophy emphasizes that the design should be centered around the needs and expectations of the user, ensuring that they can complete the tasks easily and efficiently. Based on the theory of cognitive psychology, it is easier for designers to understand how different types of visual elements affect the user's attention, and this knowledge can help designers choose the appropriate interaction and visual layout in the interface design to improve the efficiency and safety of the user's operation in the driving environment.

4.3 Interaction Design Strategy Combined with Theory

Interaction design is a design practice that focuses on creating and shaping man-made systems. It explores the construction of practical functions and emotional experiences between people, products, external environments, and systems and also covers the emotional elements that convey these functions, as well as their deeply interconnected interaction behaviors. Compared with traditional design disciplines that focus more on form, interaction design is different in that it emphasizes the exploration of the essence of content and design arrangements. Information and interaction design is an emerging discipline with the rapid progress of Internet technology (Du, 2018).

Gillian Crampton Smith, known as the pioneer of interaction design, has pointed out that the goal of interaction design is to create interactive products that can be integrated into people's daily work and lives (Su, 2007). The core concept followed in this design field is the principle of human-centered design. Based on this principle, human-machine interaction (HMI) interfaces should be designed from the user's perspective to ensure that the system conveys information in a way that the user can understand. Therefore, the interaction design of HMI should be human-centered to meet the needs and expectations of users (Zhang, 2024).

The integration of user experience with cognitive psychology within the principle of interaction design can improve the personalized HMI design of automobiles. The study of user experience and cognitive psychology in driving scenarios concludes that for automotive HMI design, the following interaction strategies can be combined:

(1) Emotional feedback

The integration of affinity and emotional design elements along with interaction methods, enables the product to trigger the user's empathy and recognition, and then enhance the user's trust and loyalty to the brand. This emotional connection is an important factor in establishing and maintaining long-term customer relationships (Lan, 2024). Incorporating reasonable humanized feedback in HMI design, can assist drivers in controlling their emotions while driving, stabilize the driving state, and also strengthen the emotional connection with the vehicle.

(2) Multimodal interaction

Multimodal interaction integrates visual, auditory, tactile, and other sensory modes, effectively transmits emotions, and enhances the sense of intimacy between the user and the cockpit system. In some cases, multimodal interaction has more advantages than unimodal interaction. For example, for warning messages, combining visual and auditory or visual and tactile communication methods can capture users' attention faster than single-sensory warnings (Zhang, 2024). Automotive HMI design has its uniqueness, integrating multiple functions in the cockpit itself, and at the same time, it is more necessary to combine multiple senses in road scenarios, which can be better carried out through the reasonable arrangement of multimodal information transfer.

(3) Convenient Operation and Simple Process

In the driving scene, because it involves road safety and various other concerns, the requirements for automotive HMI design are very different from the interaction design in other scenarios. In various automotive contexts, it is necessary to enhance the user experience, the interaction process, and the operation of the simplified design. On the driver's side, according to different scenarios, important information on the interface should be highlighted, while unnecessary information and visual elements should be hidden to reduce the cognitive burden and operational pressure on users (Ren,2020).

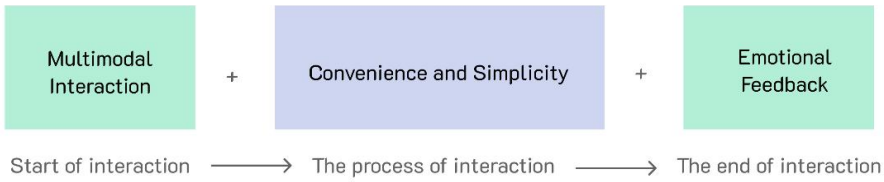


Figure 7: Interaction Design Strategies Combining User Experience and Cognitive Psychology

Interaction design is essential in automotive HMI design, as it focuses on the functional interaction between the product, the user, the environment, and the system, while also emphasizing the conveyance of the emotional experience. This approach can enhance users' trust and loyalty to the brand and improve the overall driving experience through humane and emotional design elements and multimodal interaction.

5. Key Technologies for Automotive Personalized HMI Design

5.1 Artificial Intelligence and Machine Learning in HMI Design

In 2015, significant progress was made in the field of artificial intelligence. Qin Jingyan suggests that the advent of the big data era has significantly expanded the definition and application scope of interaction design. The design framework has shifted from an isolated state to a more integrated and interconnected design undergoing significant evolution across multiple aspects such as design patterns, information structures, technology use, design methods, and interaction contexts (Qin, 2015).

In the human-machine interaction (HMI) of automotive smart cockpits, the machine learning model facilitates the rapid identification of the user state and dynamic changes in the surroundings, enabling the system to actively respond to the needs while accurately predicting the behaviors and intentions, thereby achieving an active interaction mode (He, 2023). There are many research cases of applying AI to real-world scenarios, such as:

AI-based driver behavior analysis. Researchers developed a machine learning model that analyses drivers' physiological signals (e.g., ECG, conductance activity, respiration, etc.) to classify driver states into four categories: alertness, attention, affective state, and situational awareness, and generates a global metric reflecting the overall psychophysiological state of the driver. The AI partner uses this metric to tailor its interactions with the driver to better support the drivers, such as providing more visible warning messages when fatigue is detected.

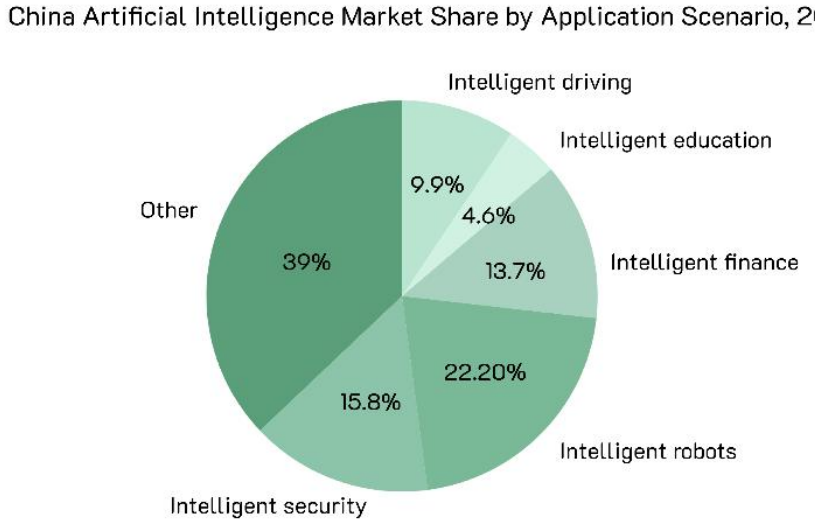


Figure 8: China Artificial Intelligence Market Share by Application Scenario, 2019

Source: Yiguan Analysis

Machine learning in personalized settings. The research team plans to develop a multimodal whole-body interaction model that combines haptic, visual, and voice interaction. Depending on the driver's state (e.g., stressed, fatigued, etc.), the level of information delivered as well as the type and number of modalities used to interact with

the driver can be adjusted, for example, voice prompts can be used to alert the driver to road conditions in case of driver distraction.

Intelligent voice assistant and natural language processing. Researchers have proposed an ambient light display system that communicates the severity of the current situation to the driver and described a conversational agent that the driver can interact with to obtain more information about the current situation, such as asking about current road conditions or vehicle status (De Salis, 2020).

In current research, it has been found that AI can reduce the likelihood of accidents by analyzing driver behavior and vehicle status, predicting potential safety risks, and providing early warning or assisted driving features. It can also improve the user experience by collecting user behavioral habits and physiological data to personalize interactions. However, it is also a challenge to seamlessly integrate AI technology into automotive HMI design and ensure the security and privacy of user data.

5.2 Application of Virtual Reality and Augmented Reality Technology in HMI Design

Virtual Reality (VR) is a form of media constructed from an interactive computer simulation that senses the user's position and movements and provides or enhances multi-sensory feedback, thus creating a mental immersion as if one were in a virtual environment. Simply put, VR creates a completely computer-generated world in which the user can only experience the virtual environment and cannot see the real world (Liang, 2019). In automotive HMI design, VR technology can be applied to immersive driving simulation, virtual interactive experience, and interactive interface design.

Figure 9: Virtual Reality

Source: https://unsplash.com/images

Augmented Reality (AR) is an extension of virtual reality technology, which is able to combine computer-generated virtual information (e.g., objects, images, videos, etc.) with real environments and allow users to interact with them. In short, AR adds virtual elements to the real world, allowing users to observe the real environment as well as experience virtual content (Liang, 2019). In automotive HMI design, AR technology can be applied in the areas of real-time navigation and information display, maintenance and assembly instruction, and vehicle information display.

Figure 10: Augmented Reality

Source: https://unsplash.com/images

Virtual Reality (VR) and Augmented Reality (AR) technologies are increasingly attracting industry attention in the area of automotive HMI personalization. These

technologies provide users with a more immersive and intuitive interaction experience by simulating or augmenting real-world environments. For example, Audi exhibited its in-vehicle VR experience "Experience rides" at CES 2023, where visitors had the opportunity to sit in the back of the Audi e-tron and e-tron Sportback and experience in-vehicle VR in an immersive way, allowing users to experience how the vehicle drives in different road conditions before purchasing the car. This experience not only enhances users' confidence in purchasing but also improves the brand image.

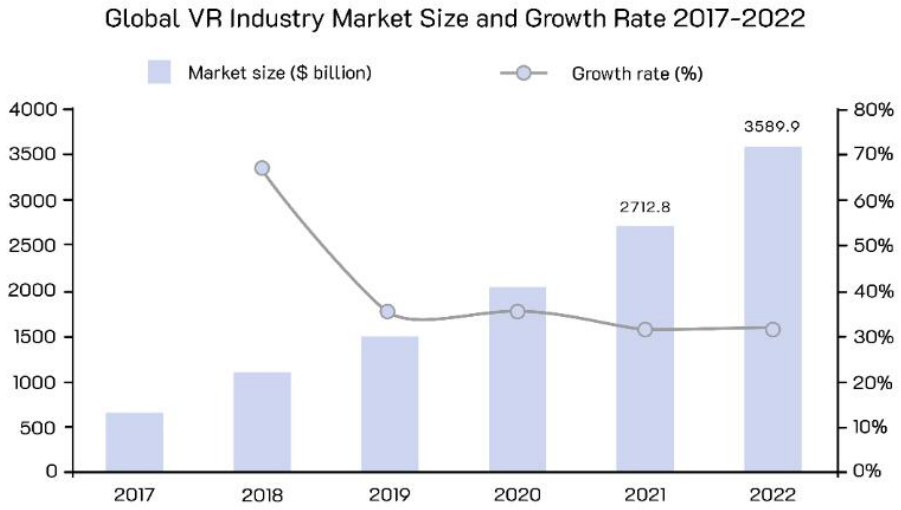


Figure 11: Global VR Industry Market Size and Growth Rate 2017-2022

Source: www.huaon.com

Similarly, the application of AR technology in HMI design has also attracted much attention. With AR technology, drivers can access real-time information about the vehicle's surroundings without leaving the driver's seat. For example, in early 2022, South Korea's Hyundai Motor released a new pure electric platform based on the E-GMP platform to build the SUV IONIQ 5. This vehicle utilizes AR technology to display information directly into the driver's field of vision, facilitating a more intuitive understanding of the driving route and the surrounding environment. This innovation effectively addresses the problem of the traditional in-vehicle screen, which hinders the driver’s ability to monitor road conditions while engaging in interactive operation.

5.3 Application of Speech Interaction and Automatic Speech Recognition Technology in HMI Design

Speech interaction technology combines a variety of advanced technologies to provide a convenient and efficient interaction experience for drivers and passengers, mainly including Automatic Speech Recognition (ASR), Natural Language Processing (NLP), and Text To Speech (TTS) (Yu, 2021). The threshold of voice interaction technology is relatively low, however, numerous established cases exist nowadays.

For example, NOMI, an in-vehicle intelligent voice assistant launched by Azera Motors, was first equipped in the Azera ES8 model in 2017, and NOMI takes "Understand Me" as its design concept, and strives to provide users with intelligent, emotional, and humane cockpit interaction experiences through the reasonable use of Automatic Speech Recognition, Natural Language Processing, and Emotion Recognition technologies. NOMI's intelligent and humanized design enhances the user experience, strengthens driving safety, and reflects Azera's leading position in the field of intelligent vehicles (Qiu, 2024).

Gesture recognition, as one of the most intuitive ways of human communication, plays an important role in HMI design. It is mainly divided into 2D and 3D gesture recognition. Two-dimensional gesture recognition means recognizing stationary gestures, such as waving hands, comparing numbers, and other simple movements. 3D gesture recognition, on the other hand, recognizes complex gestures and requires the support of 3D cameras and other advanced sensors (Liu, 2023). In recent years, gesture interaction in the field of in-vehicle interfaces has seen a booming development, gradually moving from the theoretical research stage to the application practice, and from conceptual exploration to the reality on the ground (Lee, 2022).

The sixth-generation iDrive system introduced gesture recognition technology in the BMW 7 Series models, allowing drivers to control vehicle functions through a variety of preset gestures. For example, by opening the palm to the right and waving it to end a phone call, moving a single finger back and forth to answer a call or confirm an operation, and pausing or playing music when using two fingers to remain stationary and pointing forward (Feng, 2020).

Table 3: Application Cases of Speech Interaction and Gesture Recognition Technology

Company Name	Picture	Product Name	Technical Features
XPeng Motors		XiaoP	Voice recognition, natural language processing
Mercedes-Benz		ChatGPT	Large language model
BMW		Sixth-generation iDrive system	Gesture recognition

According to the above actual case application, we can see that the application of Automatic Speech Recognition technology and gesture recognition technology in automotive HMI design enhances driving safety and convenience while providing users with a more intelligent and personalized driving experience.

5.4 Example of Integrated Use of Technology in Personalized HMI Design

Equipped with four screens, the intelligent cockpit and interior experience of IM L7 is a typical representation of the comprehensive use of interaction technology in automotive personalized HMI design. The four screens in the cockpit are the center screen, the dual center control screen, and the passenger screen, of which the center screen is mainly used for most of the interactive operations, including navigation, music playback, answering phone calls, etc.; the dual center control screen is responsible for the display of specific vehicle information, while the passenger screen focuses on the audio-visual entertainment in the cockpit. The different screen functions are assigned for users to understand and utilize, and the HMI design follows the simplicity principle of interaction design, which can well satisfy the personalized and unique needs of different passengers in driving scenarios.

Figure 12: IM L7

Source: https://www.immotors.com/website

The IM L7's Smart Cockpit is also able to provide users with an exceptionally intelligent and humanized cockpit interaction experience through Automatic Speech Recognition and Natural Language Processing technologies, the key to which lies in the innovation of voice control capabilities and computer interaction logic processing algorithms. This makes IM L7 perform quite well in helping drivers to be able to focus more on the road and reduce manual operation, improving driving safety.

The design team of IM L7 intelligent cockpit has achieved success at the level of one-to-one personalized and unique user experience by giving full consideration to user needs and driving safety from a situational point of view during the design process, through the layout of the four screens and the functional partitions to achieve the purpose of improving driving convenience. The upgrading of the Automatic Speech Recognition algorithm and the enhancement of the natural language processing technology has also made the interaction more intelligent and humanized, paying full attention to the personalized user needs, improving the interaction logic, and enhancing the user experience.

6. Future Trends in Automotive Personalized HMI Design

6.1 Trends in Intelligence and Automation

The future automotive HMI system will automatically adjust and optimize the interface layout, function settings, and operation logic to better align with user needs through artificial intelligence, machine learning, data analysis, and an increasing trend towards greater intelligence and automation. For example, the system is capable of automatically adjusting the positions of seats, mirrors, and steering wheel according to the driver's habits and preferences, even before the driver gets into the car to complete these settings. Additionally, it can learn the user's entertainment preferences, and automatically recommend music and movies that match with the passenger's tastes which can be automatically played at the right time. Furthermore, it can also anticipate the driver's needs and actively provide relevant driving information and advice to avoid the driver's active operation, such as navigation, weather forecasting, and data analysis to reduce driving risks through better human-vehicle cooperation with the assistance system.

6.2 Trends in Cross-Platform and Multimodal Interactions

The integration of automobiles and mobile devices such as smartphones and tablet PCs is expected soon. Future automotive HMI systems will facilitate seamless connectivity and data sharing between multiple devices, with more emphasis on cross-platform and multi-modal interaction. Mobile phone applications enable drivers to control the vehicle's navigation, and music playback and answer mobile phone calls through the car machine system. Future advancements may rely on the remote control of the mobile aspect of automatic driving systems. In addition to the traditional touchscreen interaction in future cars, human-computer interaction methods will increasingly diversify. The future automotive HMI system will better support Automatic

Speech Recognition, gesture recognition type of interaction, eye tracking and facial muscle recognition and other interaction methods may also be installed.

6.3 Sustainability and Environmental Design Trends

The future of automotive personalized HMI design in the context of increasing environmental awareness will prioritize sustainability and environmental protection, based on the different preferences and needs of car owners and passengers. HMI system will utilize a unique energy-saving strategy, through the use of more efficient display technology and energy-saving hardware equipment to reduce energy consumption, addressing the interactive needs of activation and dormant state transitions. To meet the user's energy-saving needs it will also have the ability to display real-time energy consumption and driving efficiency, thereby assisting and motivating drivers to adopt more environmentally friendly driving habits. Furthermore, future automotive HMI designs will prioritize material selection and recycling to mitigate environmental effects.

7. Conclusion

This study thoroughly explores automotive personalized HMI design emphasizing its importance in enhancing the driving experience and user satisfaction through specific cases. It also explores future trends such as intelligence and automation, cross-platform and multi-modal interaction, sustainability, and eco-friendly design, which demonstrates the direction of development of automotive personalized HMI design. Personalized HMI design has great potential and application value in the automotive sector. With the continuous progress of science and technology, it is expected that personalized HMI design will have a more important role in the automotive industry, enhancing the driving experience of both drivers and passengers through greater intelligence, comfort, and convenience.

The limitations of this study are the potential lack of depth in the analyses of some cases and the uncertainty associated with the prediction of future trends. Future research could further expand the range of cases, conduct an in-depth analysis of the design details, and strengthen the prediction and validation of future trends.

This study provides new perspectives and ideas for automotive personalized HMI design, as well as a reference for future research and practical applications. The continuous progress of technology and personalized HMI design will play a more important role in the automotive industry, enhancing safety, comfort, and convenience for both drivers and passengers.

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