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Understanding Driver's Emotion and Attention in the Context of Augmented Reality Head-Up Display System

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ABSTRACT

As one of the primary psychological factors, the emotion of the driver affects the driving behaviour constantly. Negative emotions may lead to improper driving behaviour, threatening the safety of drivers, and even endangering society. Monitoring and regulating drivers' emotions while they are behind the wheel is crucial. It not only helps lower the risks on the road, but it also enables a novel approach to driver-car interactions. Augmented reality head-up display (AR-HUD), as a developing technology, has been invested in the innovation of automobile driving, with promising potential to support driving and change driver-vehicle interaction. While research on driver emotion is well developed, more study is still needed in the context of the AR-HUD system is still emergent for the future industry. The paper presents a systematic literature review to highlight recent research on drivers emotion in the context of the AR-HUD system. The paper explores the integration of emotional recognition technologies into AR-HUD systems, examining their effectiveness in improving drivers' mood and reducing the risk of accidents. This review also discusses the challenges and future directions in this field, proposing ways to optimize AR-HUD systems for better emotional awareness and road safety.

Keywords: Emotion, Affective computing, Driving, Augmented reality head-up display (AR-HUD), Human-centred interaction (HCI)

INTRODUCTION

Emotions are generally defined as human responses with specific patterns of psycho-physiological activity, either conscious or unconscious (Ekman & Davidson, 1994). From a biological point of view, emotions are related to the nervous system (Darwin & Prodger, 1998). The psychological theory of emotion directly links emotion to bodily manifestation, which includes the viscera and the skeletal muscles (James, 2009). And in neuroscience, emotions often relate to consciousness and decision-making (Damasio et al., 1990). Generally, emotions are categorized according to the six basic emotions theory, which are anger, fear, surprise, disgust, and joy (Strongman, 1996). According to Ekman's theory, these six basic emotions are universal and innate. One piece of evidence is the cross-cultural similarity in facial expressions of people from different cultures. There is also another classification approach for emotions with two continuous dimensions, which are valence and arousal

(Lang et al., 1993). Valence measures how good or bad an experience was. Arousal is a measure of activation that ranges from calm to extremely excited.

Understanding the relationship between emotion and behaviour has always been a research topic. Particularly, drivers' emotion is one valuable branch (Zepf et al., 2019; Underwood et al., 1999; Jeon, 2016; Nass et al., 2005; Mesken et al., 2007; Pecher et al., 2009; Roidl et al., 2014; Braun et al., 2020). According to the Yerkes-Dodson law (Yerkes et al., 1908), stating that task performance is interconnected with arousal, this behavioral principle has been applied to the driving context. Emotions can affect the cognition of drivers, which way may lead to dangerous situations. Many existing studies have proven that investigating the effects of emotion on driving performance, risk perception, and so on (Steinhauser et al., 2018; Jeon, 2016).

In order to investigate the context in which different emotions can develop, many works research the trigger of a driver's emotion. Commonly, the trigger can be divided into two kinds: inner triggers and external triggers (Zepf et al., 2019). The inner trigger refers to a person's characteristics. External triggers can be further divided into four categories: i) traffic and driving task, involving traffic lights, traffic density, etc. ii) HCI and navigation, involving route guidance, navigation settings, etc. iii) vehicle and equipment, involving air conditioning, etc. iv) environment and other, such as weather and sites.

Generally, researchers will choose an appropriate definition method according to the needs. Whichever is used, to detect different emotions, variant methods can be applied. Commonly, it can be divided into two kinds: obtrusive solutions and unobtrusive solutions. Obtrusive solutions involve tools such as fMRI (Phan et al., 2002; Ochsner et al., 2002; Lutz et al., 2014), EEG (Bos et al., 2006), ECG (Agrafioti et al., 2011), and other tools in contact with the human body. On the contrary, unobtrusive solutions mean detecting emotions by collecting signals that human conveys without contact. For example, behavioral signals such as speech (Dellaert et al., 1996; Nwe et al., 2001; Liu et al., 2018), facial expressions (Ekman, 1993; Keltner et al., 2003; Niedenthal et al., 2000; Yan & Yue-Jia, 2005; Pham & Philippot, 2010; Wallbott, 1991), and body gestures (Shan et al., 2007; Piana et al., 2014) are often used. In the automotive domain, unobtrusive solutions are commonly used considering the need not to interrupt the driver's performance during driving (Weber, 2018).

Regulating drivers' emotions can be crucial for reducing traffic accidents and enabling new driver-car interactions. In a broad sense, regulation is defined as mechanisms used to strengthen, stabilize, or weaken responses (Gross, 2002). Specifically in driving contexts, different regulation approach is applied for different emotions from different triggers. For example, approaches usually try to bring emotional sympathetic resonance (Nass et al., 2005; Hernandez et al., 2014; Paredes et al., 2018) corresponding to inner triggers.

Different from a traditional head-up display (HUD), augmented reality head-up display (AR-HUD) projects graphics on top of the real world, allowing interaction with and augmenting real-world objects. As a new technology that just appears in the area, it has promising potential to improve driving performance and to keep the driver's attention focusing on the road. Existing research has been endeavoured to study in this field for future insight into industry (Gabbard et al., 2014; Schall Jr et al., 2013; Rusch et al., 2013). In this paper, we focus on the interaction between the driver and the vehicles. This review aims to highlight recent research on driver's emotion in the context of AR-HUD system.

METHODOLOGY

The systematic review focuses on the driver's mindless response (emotion or attention) in the context of the AR-HUD system. The systematic review method would strictly correspond to the guidelines set forth by Liberati et al. (2009).

Based on the objectives, studies meeting the following criteria were included: (i) drivers aged 16 years and older; (ii) focus on any emotions or attention; (iii) examined driver behaviours in the context of distraction and of ADAS or other vehicle automation systems; (iv) reported one or more of the following outcomes: driver performance, safety outcomes, distraction behaviours, driver trust, or situation awareness; (v) AR-HUD or any new techniques involved; and (vi) written in English. We excluded studies where target populations were not drivers or no any AR or advanced techniques involved. Literature review articles, non-empirical manuscript types and abstract only papers were also excluded.

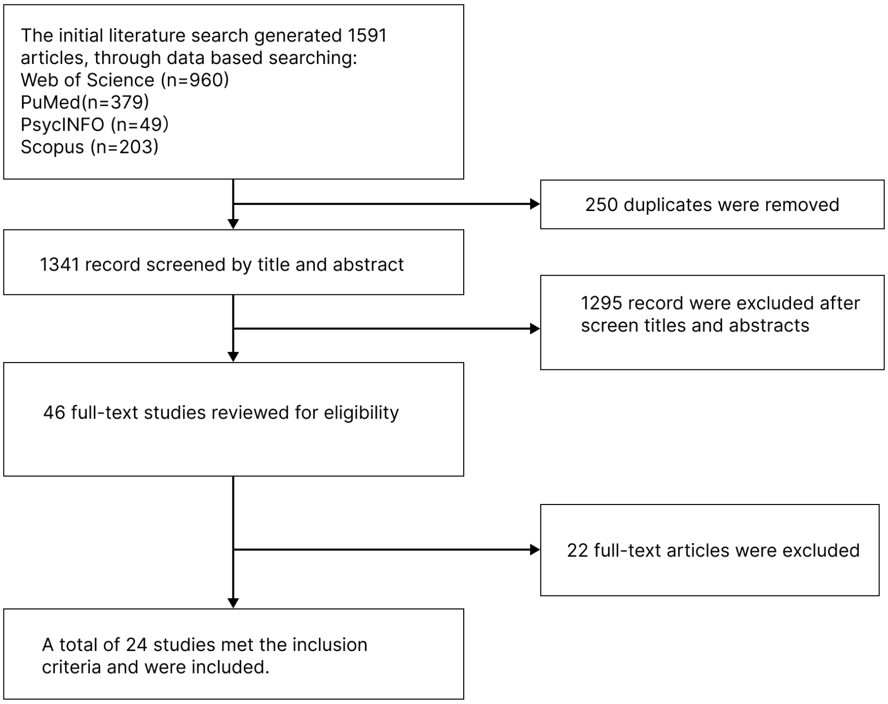
We searched the publication from four commonly used databases in this area, which are Web of Science, PubMed, PsycInfo, and Scopus. The publication dates were restricted between recent 6 years. The search based on three different concepts: (1) driving-related concepts, (2) AR-HUD-related concepts, and (3) emotion or attention. The final formulation is shown in Table 1.

Table 1. List of search keywords.

Concept	Keywords
Driving	driv* OR car OR vehicle OR automotive
AR-HUD	ar OR augmented* OR (head* AND display)
Emotion	emotion OR stress OR attention OR affect*
Area	hci OR interaction OR design

Search results were downloaded to Endnotes. The inclusion and exclusion criteria were applied to select studies for the review. The initial search generated 1591 potentially relevant articles, as shown in Fig 1. After removing 250 duplicates, 1341 papers remained. Of those, 1295 were removed based on reading the title and the abstracts, leaving 46 papers for further reading. Finally, after reading the full text, there are 24 articles left in this review.

Two authors independently screened the titles and abstracts in the initial review to determine the relevant papers in the field of driver's emotion under AR-HUD system. A union result of the two is included for the full texts assessment. Then, the full texts of the final chosen papers were assessed. Any disagreement in the whole process was discussed involving a third author until a consensus was reached.



We analysed and synthesized the selected articles, extracting information including author, abstract, research field, research motivation, research design and methods, AR-HUD technology, research methods, and significant findings of the review research question. By comparing this key information, we further explored the innovation of each article in the research and application of driver's emotion under the AR HUD system, or their impact in related fields. At the same time, we also focused on the challenges and future research directions mentioned in the article, to better understand the development trends and potential of this technology. Finally, we summarized the common issues and differences that emerged in the study, providing more in-depth insights and suggestions for subsequent research.

RESULTS

The final 24 studies were identified further by the objectives, which are (i) the superiority of AR-HUD where research shows strong advantages compared with traditions; (ii) the AR-HUD interface design, where research conducted insights towards future AR-HUD interface design for better supervision while driving; (iii) the adaptive system, where new interaction was proposed.

SUPERIORITY OF AR-HUD

Currently, many studies have demonstrated the advantages of AR-HUD over traditional methods. The existing research on the superiority of AR-HUD systems is often reflected in their positive impact on driving behaviour and safety, although Frémont et al. (2020) mention that drivers perform best without any visual assistance because they would be more focused on tasks. Research has shown that the AR-HUD system can significantly improve driver's attention and behavior during driving activities (Mendoza, 2020; Aydogdu et al., 2020; Luzuriaga et al., 2022; Heo et al., 2022), especially in reducing cognitive load, enhancing attention to dangerous driving situations, and reducing the impact of environmental conditions. In addition to the AR-HUD system in daily driving scenarios, its advantages are also reflected in the military (Bielecki et al., 2020), agriculture (Pei et al., 2020), and other fields. Bielecki et al. (2020) discuss the use of the AR-HUD system to improve the ability of combat vehicles and soldiers by maintaining a comprehensive understanding of tactical situations during mission execution.

However, the impact of AR-HUD on drivers is also influenced by various factors such as experience. Research has shown that AR-HUD's effects are more pronounced among elderly drivers, students, and women. These groups feel a significant reduction in driving burden when activating AR-HUD, especially women who feel safer during AR-HUD activation (Aydogdu et al., 2020; Luzuriaga et al., 2022). In the subjective evaluation survey of the AR-HUD system conducted by Cheng et al. (2023), it is also found that the subjective acceptance of drivers is significantly influenced by driving experience and gender. Furthermore, the effectiveness of AR-HUD varies between daytime and nighttime (Cheng et al., 2023). In nighttime driving situations, the AR-HUD system significantly improves driver attention and reduces cognitive load. However, in the daytime driving scenario, the impact of the AR-HUD system is not significant.

In measuring attention, eye tracking is commonly used alongside subjective evaluations to assess drivers' focus. By analyzing eye tracking data, researchers can gain insights into how drivers allocate their attention to visual stimuli, among other aspects. Cheng et al. (2023) used eye tracking technology in the experiment to analyze and evaluate the driver's perception of the driving environment, as well as their attention allocation and response when facing risky driving situations. Additionally, Pečečnik et al. (2022) mentioned in their article that monitoring changes in pupil size is an indirect method to evaluate drivers' attention needs and distractions. Experiments have shown that HUD can enhance driving performance and pupil response. When attention is focused, pupils dilate to allow more light to enter the eyes, thereby improving visual acuity and attention. Conversely, when attention is diverted, pupils constrict, reducing the amount of light entering the eyes.

In addition to its impact on attention, the AR-HUD system has also been shown to have a positive impact on driver's emotion. Detjen et al. (2020) demonstrate that virtual windshield systems have a positive effect on reducing stress and increasing passenger safety by allowing participants to watch videos including a car accident scene in a real but stationary car. Similarly, Kim et al. (2023) indicate that the AR-HUD system can effectively alleviate driver's nervousness, thus positively affecting their emotions. Furthermore, Morra et al. (2019) utilized electrodermal response (GSR) to measure participants' emotional responses, finding that the design of the AR-HUD interface can significantly alter participants' electrodermal response levels.

Although AR-HUD can effectively improve driver's attention and have a positive impact on emotions, it is worth noting that AR-HUD can also bring negative effects. As mentioned by Wang et al. (2022), the use of AR-HUD may increase the driver's attention blind spots, especially in the absence of enhancements for unpredictable events, which may pose a potential threat to driving safety.

AR-HUD INTERFACE DESIGN

AR-HUD, as an emerging technology, has seen significant investment in automotive innovation. The benefits of AR-HUD systems, such as reducing driver cognitive load and enhancing driving safety, underscore the importance of AR-HUD interface design in future vehicle-human interactions. Research into AR-HUD interfaces is actively advancing. Zhang et al. (2022) conducted experiments to investigate the information needs and priorities of novice and experienced drivers in various road conditions, informing AR-HUD interface design. Furthermore, Frémont et al. (2020) noted that most participants preferred bounding box prompts over pedestrian panel prompts because bounding boxes better help determine the position of pedestrians, whereas pedestrian panels may prompt unnecessary braking. To ensure vehicle safety, Dou et al. (2022) designed the interface's content color to balance the driver's visual sensitivity and fatigue, thereby directly impacting driver performance. Li et al. (2021) also suggested that a HUD system with blue as the primary color can serve as an effective aid, thus enhancing driving safety. The arrow-pointing AR-HUD interface and the virtual shadow AR-HUD interface have been shown to reduce driver visual dispersion more effectively than non-AR-HUD interfaces (Jing et al., 2022). It is also noted that the effectiveness of different AR-HUD interfaces varies in specific scenarios, indicating that interface design should be tailored accordingly. Yu et al. (2023) noted that driver's needs for AR element information vary across different scenarios, with their subjective attention differing among information types. Morra et al. (2019) observed that incorporating more information into AR-HUD interface designs can reduce participants' stress and enhance their trust in autonomous driving. Hecht et al. (2022) introduced an emotional information auxiliary element, and experiments indicated that participants' attention to the road remained relatively stable when this element was included. Bielecki et al. (2020) investigated how AR symbols and multimodal methods could effectively reduce driver cognitive load. Additionally, Wang et al. (2022) demonstrated through experiments that multimodal warning signals enhance driving performance more than single-modal signals, linking the addition of visual or auditory signals to driving performance improvements.

ADAPTIVE SYSTEM

The adaptive system based on AR-HUD is one of the development trends of the future industry. Frémont et al. (2020) proposed a new adaptive system that provides visual cues based on the driver's alertness, which can better adapt to the driver's attention and emotional state, thereby improving pedestrian driving awareness in dangerous situations. Wojtkowski et al. (2022) proposed an attention-based adaptive system and demonstrated its effectiveness in maintaining safe driving. Bautu et al. (2020) has developed a system to assist drivers in managing and driving related information, in order to improve their attention and safety. The system can filter out notifications from third-party applications, such as social media, email, and instant messaging, to reduce driver interference. In addition, the system can also provide information about weather and traffic conditions to help drivers make better decisions.

CONCLUSION

This review summarizes the literature on the interaction between driver unconscious responses and AR-HUD systems. From the literature, it can be seen that most studies focus on driver's attention and driving performance in the context of AR-HUD, verifying the effectiveness of AR-HUD in improving driving safety. However, there is little research on drivers' emotions in the context of AR-HUD. Studying how AR-HUD affects drivers' emotions is not only important for providing new insights into the industry, but also for maintaining steady development in the entire field. Correspondingly, detecting and regulating emotions within the driving environment is crucial. Designing visual information for AR-HUD systems that effectively identify emotions in various driving scenarios is important. Furthermore, incorporating system feedback and adaptive adjustments holds significant potential for future industry advancements. Based on these studies, reasonable methods can be proposed to monitor driving emotions in the context of AR-HUD. In the future, other sensors and machine learning models can be used to more accurately detect the emotion of drivers, further improving the personalization and adaptability of autonomous driving. For instance, the driver's emotions can be detected solely through facial expressions, and the AR-HUD interface can be adjusted accordingly to improve driving safety.

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