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Cognitive Ergonomics in Intelligent Systems: Screen Analysis and Design Proposal for Reducing Mental Load in the Design of User Interfaces of Autonomous Vehicles

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Abstract: This study aims to reduce the mental load of drivers and increase driving safety by designing user interfaces in autonomous vehicles according to cognitive ergonomics principles. Today, autonomous vehicles offer a usage scenario where the driver is only expected to intervene in critical situations and is in the role of observer or guest. In the design of user interfaces in these vehicles, cognitive ergonomics principles are of great importance and play a critical role to reduce the mental load of the driver and increase driving safety. In existing AR-based user interfaces, it is proposed to add new features to improve driving safety. In particular, detecting driver fatigue and displaying this information in the user interface will enable the driver to monitor the fatigue level and take necessary precautions. In this study, a design proposal for displaying driver fatigue level in an AR-based user interface is presented. In addition to improving driving safety, this proposal will contribute to a comfortable driving experience, personal health and well-being, analysis of driving habits and legal compliance.

Keywords: autonomous vehicles, cognitive ergonomics, intelligent systems, interface design

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1. INTRODUCTION

Autonomous vehicles can be defined as advanced automobile technology that has been given the ability to move without a driver driving the vehicle or with its own decisions by minimising human intervention. Technologies such as GPS, artificial intelligence models, sensors are used to provide mobility to these vehicles. The most important issue in the emergence of autonomous vehicles is to ensure safe driving by minimising driver errors. Autonomous vehicles are becoming increasingly widespread today and are preferred by users with many advantages. Many of the vehicles that are currently widespread around the world are vehicles equipped with mechanisms under direct user control. Although auto-controlled structures such as lane tracking system, collision avoidance systems, fatigue detection system, hill start support have been added to many of the vehicles in recent years, more user-active driving is still taking place. In autonomous vehicles, drivers are more in the role of in-vehicle guests or observers. In autonomous vehicles, drivers monitor variables such as whether the systems are working properly, speed and fuel status. In critical situations, the autonomous vehicle may ask the driver to take over driving control. Cognitive ergonomics is a concept that includes the processes of purposeful design of environmental factors in order to carry out the cognitive processes of the users on the system in the most efficient way. The combination of autonomous vehicles and cognitive ergonomics processes aims to reduce the mental load of users and increase driving safety. During driving, critical moments may occur when users need to take over driving control in emergency situations. In such situations, the driver's cognitive tasks come into play. Cognitive tasks require high concentration and instant decision-making skills of the driver. In such crisis management situations, the mental load of users may increase and stress levels may rise. The critical quality that autonomous vehicles should have is that the principles of cognitive ergonomics should be taken into account in the design of user interfaces, and a simple, practical and easy-to-use interface is expected to help users interact with these vehicles more effectively and safely. What is expected from cognitive ergonomics is to present critical information in a clear and understandable way, to optimise the information density and to keep the stress level to a minimum so that the cognitive capacities of the users are not challenged when designing autonomous vehicles. The information density in the interface during a driving process under the control of the user may overwhelm the user, prolong the reaction time and even cause errors.

2. CURRENT STATUS OF USER INTERFACES IN AUTONOMOUS VEHICLES

In autonomous vehicles, touch screens are preferred to communicate and interact with the user. On the touch screens, technical status of the vehicle, speed, route information, battery and fuel status, and status information about safety measures are presented. Touch screens are supported by voice command and voice feedback technologies. This technology is a great cognitive ergonomics tool to control driving comfort and safety without taking the driver's attention off the road in driving that progresses to the user's control. Amazon Alexa integration developed for these situations allows drivers to manage functions such as making calls, playing music, navigation control with voice control. Some of the autonomous vehicles also maximise the level of cognitive ergonomics by activating haptic feedback and physical controls. Haptic feedback systems are preferred to provide feedback to drivers in critical situations. Users can be warned by vibrating equipment such as steering wheel or seat. These systems are generally activated in cases of uncontrolled lane following, exceeding the speed limit, and fatigue detection. Some autonomous vehicles use Augmented Reality (AR) displays to provide drivers with additional information on the road. AR-based displays project onto the windscreen and provide the driver with information such as navigation instructions, speed limits and obstacles on the road. Such interfaces play an active role in reducing mental load by providing access to important information without taking the driver's eyes off the road. Figure 1 shows an image taken from driving a Mercedes S-Class vehicle.

Figure 1. AR-based screenshot of a Mercedes S-Class vehicle driving (Youtube, 2024)

The three most important issues to be considered when creating user interfaces in autonomous vehicles are the difficulty of effective communication by overloading the user with information, difficulties in focusing users on important points due to complex designs, and mishaps that may occur due to incomplete feedback.

3. RESULTS

In AR-based user interfaces in existing autonomous vehicles, data such as navigation data, speed, fuel and battery status, lane alternatives are displayed to the user. One of the most important criteria of driving safety is the physical fatigue and attention status of the driver, which is critical in driving safety. Although fatigue detection is included in autonomous vehicles, it is not shown to the user in AR-based user interfaces and other interfaces. This is a situation left to the person's self-control and sensors. Continuous notification of this data to the driver allows both the driver to take precautions and other users in the vehicle to advise the driver.

Adding this feature to the AR-based user interface will contribute to safe driving by examining many topics such as comfortable driving experience, personal health and well-being, analysis of driving habits, legal compliance. When the fatigue detection system finds the driver's fatigue level high, it can automatically switch the vehicle to autonomous driving mode. This allows the vehicle to travel safely while allowing the driver to rest. Figure 2 shows a user interface design proposal that shows the fatigue detection level for the driver in an AR-based user interface to be designed.

Figure 2. Display of driver fatigue level in AR-based user interface

The motivation for proposing the introduction of this innovation can be listed as follows;

- Safety Protection Mechanism:
  The visual display of the driver's fatigue level on the AR-based interface allows the driver to monitor his/her physical condition in real time. In this way, as soon as the driver realises that the fatigue level has reached critical levels, he/she can consciously stop the vehicle for a rest break or switch the vehicle to automatic driving mode. This feature increases driving safety by preventing accidents that may occur when fatigue is not recognised or neglected. Considering that fatigue prolongs the driver's decision-making time and slows down the reaction speed, it is vital to provide instant access to this information.
- Differences with Existing Systems:
  Existing driver fatigue detection systems usually process data from sensors and provide passive warnings to the driver, which are usually just an audio or visual warning. However, these warnings do not present the degree of fatigue or how the fatigue level changes in

detail to the driver. The interface proposed in Figure 2 aims to overcome this lack of information. The continuous visualisation of the fatigue level gives the driver more control and allows him to consciously manage his fatigue state. Furthermore, this system allows the driver to recognise the situation not only to himself, but also to the other passengers in the vehicle, which creates a collective sense of safety.

- Proactive Safety Enhancement:

The system not only detects fatigue, but also has the ability to put the vehicle into automatic driving mode when the fatigue level reaches a critical threshold. This is a proactive safety measure that is often missing in existing systems. While other systems simply warn the driver, this design proposal aims to prevent fatigued driving by taking a step that directly affects driving safety.

- Enabling Driver Involvement:

The constant visibility of the fatigue level allows the driver to be more involved in the situation and reduces the possibility of unconsciously falling into a dangerous situation. In existing systems, the driver may not realise his/her fatigue status, but in this new interface, the driver can both see his/her own status instantly and if this situation worsens, the system can prevent possible accidents by automatically activating.

These advantages emphasise the importance of fatigue detection in an AR-based user interface and significantly improve both safety and the driving experience. A system that monitors driver fatigue and makes appropriate recommendations can make a big difference on long journeys or in challenging driving conditions.

4. LITERATURE REVIEW

A systematic review examined the role of AR technology in autonomous vehicles between 2012 and 2022 and found that vehicles equipped with this technology are more accepted and trusted by users (Kettle et.al., 2022). Fatigue while driving is recognised as an important cause of accidents, and this is also the case in autonomous vehicles. In particular, machine vision and deep learning are effective tools for detecting signs of fatigue in the driver's facial expressions. These technologies increase driving safety by detecting fatigue, warning the driver and switching the vehicle to autonomous mode when necessary (Fu et.al., 2024). Driver fatigue is one of the most important factors threatening driving safety. Therefore, detecting and managing driver fatigue in autonomous vehicles is of critical importance. In recent years, fatigue detection systems based on technologies such as machine learning and deep learning have developed significantly. These systems detect signs of fatigue by analysing drivers' facial expressions, eye movements and physiological signals and provide warnings to the driver based on this information. In particular, systems based on multimodal data fusion provide more comprehensive and accurate fatigue detection by integrating information from different data sources. These methods, when integrated with autonomous driving modes, offer an effective solution to increase the safety of drivers and prevent accidents that may occur due to fatigue (Peng et al., 2022; Guo et.al. 2019). Studies on the detection of driver fatigue and distraction to improve safety in autonomous vehicles show that the use of systems based on multimodal data fusion is becoming increasingly common. These systems make fatigue detection more accurate and reliable by combining different data sources. For example, Mandal et al. (2016) reported that high accuracy rates were achieved in the detection of driver fatigue by analysing eye movements. Li and Chung (2013) suggest that heart rate variability is an effective method for fatigue detection based on wavelet analysis. These findings emphasise the critical role of technology to ensure safe driving in autonomous vehicles. In recent years, research on autonomous vehicles and driving safety has particularly focused on driver fatigue and distraction. Advanced sensor technologies and artificial intelligence algorithms play a critical role in ensuring safe driving by detecting driver fatigue. For example, research by Xie and Chen (2018) shows that fatigue can be detected in the early stages by detecting the driver's yawning movements. Similarly, Shah et al. (2018) present important findings on simulating autonomous vehicles with high accuracy and analysing fatigue symptoms through these simulations. These studies on driver fatigue detection generally focus on multimodal data analysis and deep learning models. These technologies combine data from different sensors to provide more accurate fatigue detection and improve driver safety. For example, research by Vu et al. (2019) revealed that real-time fatigue detection can be performed using deep neural networks and that these systems make significant contributions to driver safety. Such advanced detection systems have been developed and implemented to improve the driving safety of autonomous vehicles.

Table 1. Comparative literature summary revealing the importance of the study

Author(s)	Year	Objective of the Study	Methods and Techniques	Contribution to Literature
Fu, S., Yang, Z., Ma, Y., Li, Z., Xu, L., & Zhou, H.	2024	Comprehensive review on advancements in driver fatigue and distraction detection.	Review of intelligent detection methods using machine vision, deep learning, and physiological signals.	Provides a detailed assessment of current detection technologies and proposes future research directions.
Kettle, L., & Lee, Y.-C.	2022	Systematic review of AR technologies in vehicle-driver communication.	Review of AR visualizations and their impact on situational awareness and driver performance.	Highlights the potential of AR to enhance driver trust and safety in automated driving systems.
Peng, K., Fei, J., & Yang, K.	2022	Development of a multi-attentional semantic segmentation approach for LiDAR data in autonomous vehicles.	LiDAR data analysis using a multi-attentional semantic segmentation model.	Introduces a new approach to LiDAR data segmentation, improving object detection in dense environments.
Guo, J. M., & Markoni, H.	2019	Detection of driver drowsiness using hybrid CNN and LSTM models.	Hybrid approach combining CNN and LSTM for analyzing driver facial features.	Demonstrates the effectiveness of hybrid models in enhancing drowsiness detection accuracy.
Mandal, B., Li, L., Wang, G. S., & Lin, J.	2016	Detection of bus driver fatigue using visual analysis of eye state.	Visual analysis focusing on eye state for detecting fatigue.	Shows the importance of eye state analysis in fatigue detection, particularly for bus drivers.
Li, G., & Chung, W.-Y.	2013	Detection of driver drowsiness using wavelet analysis of heart rate variability and SVM.	Wavelet analysis of HRV combined with SVM classifier.	Illustrates the efficacy of HRV analysis in combination with SVM for accurate drowsiness detection.
Xie, Y., Chen, K., & Murphey, Y. L.	2018	Real-time detection of driver yawning using deep neural networks.	Application of deep neural networks for yawning detection.	Proposes a robust method for real-time yawning detection, improving in-vehicle safety systems.
Shah, S., Dey, D., Lovett, C., & Kapoor, A.	2018	Development of a high-fidelity simulation environment for autonomous vehicles.	Simulation environment development combining physical and visual factors.	Offers a comprehensive simulation tool for testing and validating autonomous vehicle systems.
Vu, T. H., Dang, A., & Wang, J. C.	2019	Real-time detection of driver drowsiness using a deep neural network.	Application of a deep neural network for detecting drowsiness in real-time.	Validates the use of deep learning techniques for accurate and real-time drowsiness detection.

5. CONCLUSIONS

Cognitive ergonomics principles are fundamental in the design of user interfaces for autonomous vehicles, as they directly impact both driving safety and user experience. In autonomous vehicles, the driver's role shifts from being an active operator to a passive observer or supervisor, which introduces new challenges in maintaining safety and minimizing mental fatigue. AR-based user interfaces are particularly valuable in this context because they present critical driving information, such as navigation, speed limits, and hazard warnings, without diverting the driver's attention away from the road. This seamless integration of information minimizes cognitive overload, ensuring that the driver can stay focused on essential tasks without feeling overwhelmed. Moreover, the inclusion of advanced features such as fatigue detection within the AR-based interface goes beyond traditional alert systems by offering real-time monitoring of the driver's physical and mental state. Fatigue detection systems can analyze physiological signals, such as eye movements and facial expressions, to determine when the driver is becoming drowsy. This information, presented clearly on the AR display, allows the driver to take preventive actions, such as taking a rest or switching to autonomous mode, before fatigue leads to dangerous situations. The ability to proactively manage fatigue not only improves safety but also reduces stress, leading to a more comfortable and enjoyable driving experience. Incorporating these cognitive ergonomics-driven features into user interfaces can significantly enhance the overall well-being of drivers. By making critical information easily accessible and actionable, these systems empower drivers to make better decisions, fostering confidence in both the vehicle and their own driving capabilities. This confidence is particularly crucial as more drivers transition from conventional vehicles to autonomous models, where trust in the system is a key factor in adoption. The simplicity, practicality, and user-friendly nature of advanced AR-based interfaces also play a pivotal role in promoting the widespread adoption of autonomous vehicles. As these interfaces are designed to be intuitive and easy to use, they reduce the learning curve for drivers transitioning from traditional vehicles. This usability factor is crucial in encouraging a broader demographic of users to embrace autonomous vehicle technology. In turn, this can accelerate the integration of autonomous vehicles into everyday life, transforming transportation systems globally. In the future, the deep integration of cognitive ergonomics principles will not only optimize the user experience but also form the foundation of safer and more efficient transportation systems. These systems will leverage the power of human-centered design to ensure that both safety and comfort are prioritized, making autonomous driving a more reliable and accessible option for a diverse range of users. The result will be transport networks that are not only technologically advanced but also aligned with the cognitive and emotional needs of their users, contributing to the future of sustainable and intelligent mobility. This extended version further emphasizes the significance of cognitive ergonomics in enhancing both safety and user experience, while also underscoring the broader implications for the future of transportation systems.

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It should be written as short as possible and expressing the contribution made without giving the number.

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Author Contributions
All studies were carried out by the corresponding author.

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The authors have no conflicts of interest to declare.

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