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TOWARDS A HUMAN-MACHINE INTERFACE GUIDANCE FOR IN-VEHICLE AUGMENTED REALITY HEAD-UP DISPLAYS

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Abstract. *Recently Augmented-Reality Head-Up Displays (AR-HUDs) has emerged as a next evolution of in-vehicle display technologies. Augmented image should be overlayed onto real-world objects providing alerts that can be viewed in the driver's line of sight. However, there are currently no guidelines that apply specifically to the Human-Machine Interface (HMI) for AR-HUDs. A review on existing literature on AR-HUD and applicable human factors and human-computer interaction guidelines was conducted, using the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) approach. Based on the literature, an initial set of guidelines for developing AR-HUD was derived. The guidelines are grouped into virtual image distance and field of view, brightness, projected information, and legibility. Research gaps are also discussed for future experiments. Taken together, this study is a starting point for developing the interface of AR-HUDs.*

Keywords: In-vehicle, AR-HUD, HMI, Guideline

1. **Introduction.** AR-HUDs are emerging as a next-evolution in-vehicle display technology for creating a better driving experience [1]. Utilizing real-time sensor data and advancements in Internet-of-Things and autonomous systems, navigational cues, and Advanced Driver Assistance System (ADAS) alerts could now be projected into the driver's field of view [2,3]. AR-HUD has the potential to increase attention to cued elements without adversely affecting attentional resources and reducing the ability to respond to environmental information outside the focus of attention [4,5].

To be defined as a true AR-HUD, unlike traditional HUDs, the augmented image should overlay onto real-world objects like other cars, pedestrians, and traffic lights [6]. According to Calvi et al. [7], improvement in driving experience could include, but not limited to, issues such as virtual traffic signs, lane deviation warnings, safe distance indication, environmental features, and potential interferences with other vehicles and road users, forward-collision warnings, driver's choice behavior [8].

However, displaying excessive information through AR-HUD can result in information overload [9]. AR applications might distract drivers, leading them to take their eyes off the road or engaging them in other tasks [10]. To prevent this, AR-HUD HMI design should be guided by human factors display design principles [9,11]. The utility and usability of the AR-HUD design will ultimately determine the usefulness of the product,

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which is to improve driving safety, driving performance, and driving experience. A comprehensive review about functionality requirements for traditional automotive HUDs has been conducted [11]; however, to our best knowledge, there is no guideline for designing AR-HUD interface to date. Park and Park did not discuss interface design for HUD, and more specifically, AR-HUD [11]. This study focuses on determining the interface design of AR-HUD.

The purpose of this study is to derive an initial set of guidelines for developing AR-HUD HMI design from existing literature and applicable guidelines and standards. Nine guidelines for AR-HUD virtual image distance, field of view, brightness, projected information, and legibility are proposed. A review on existing literature on AR-HUD was conducted to also map out potential future experiments. The article is divided into four sections. The first two sections present the introduction and methods used to propose the AR-HUD HMI guidelines. Based on the PRISMA approach, the proposed guidelines are presented in the third section. Section 4 discusses the guidelines based on the literature and suggestions of future research needs are presented. Finally, Section 5 concludes the paper.

2. Method.

In this study, the PRISMA approach was conducted to initially provide a comprehensive literature review. From reviewing the selected articles, the AR-HUD HMI guidelines were proposed. The search included research published in international journals, conference proceedings, technical white papers, and guidelines. The exclusion criteria are studies published prior to 2011 and published in other languages than English. The ScienceDirect, Scopus, and Google Scholar databases were utilized. The keywords selected for this literature search were Augmented Reality, Head-Up Display, and driving. Further exploration of topically related and interchangeable terms was conducted.

A total of 704 articles were identified from the four databases. After applying the exclusion criteria, a total of 43 relevant studies remained. Afterwards, the 45 studies were carefully reviewed to identify the ones relevant to making an HMI guideline of AR-HUD. Exclusion was performed to studies that were irrelevant or were focused on the hardware design or development. A total of 32 studies were identified. Human Factors and Human-Computer Interaction Guidelines were also examined, and 5 additional publications were found. As a result, a total of 37 studies were included in this review.

3. Results.

A total of 9 HMI guidelines were identified from reviewing the literature on AR-HUDs. The guidelines are grouped into four categories: Virtual Image Distance (VID) and Field of View (FoV), brightness, projected information, and legibility. Discussions on each guideline are presented in Section 4.

3.1. Virtual Image Distance (VID) and Field of View (FoV).

Guideline #1: VID should be at least 6 m.

Guideline #2: FoV should be more than 10°.

3.2. Brightness.

Guideline #3: In a bright daytime, brightness for AR-HUD should be more than 10,000 nits.

3.3. Projected information.

Guideline #4: In normal conditions, the AR-HUD should only present speed, navigation cues, lane lines, and distance from stop line.

Guideline #5: In intersections, the AR-HUD should highlight the correct road lane, augment landmark boxes and spatial referencing on other vehicles, bicycles, and pedestrians, and provide audiovisual warning messages for collision alert.

Guideline #6: In highways and high speeds, the AR-HUD should highlight the current road lane, provide distance information to nearby cars, speed limit information, and provide audiovisual warning messages for collision alert.

Guideline #7: After congestion, the AR-HUD should highlight the correct road lane, augment landmark boxes and spatial referencing on other vehicles, bicycles, and pedestrians, and provide audiovisual warning messages for collision alert.

3.4. **Legibility.** Guideline #8: Letter guidelines. The size of text should be 12-20 arcmin for general text and 30 arcmin for headings. The stroke/height ratio should be 0.08-0.2 for normal size and 0.1-0.2 for small writing. The aspect/length for alphabetic characters should be 0.65-0.8. Recommended font is San Serif with height/outline thickness ratio within 0.08. When using outline, outline thickness for small letters should be within 0.35 mm. Shadow direction should be 25°-155°. Stroke/shadow thickness is recommended to be 70%. Lastly, line spacing should be 3 arcmin.

Guideline #9: Color guidelines. Change highlight color to red when a vehicle, bicycle, or pedestrian is less than 5 m from one's car. Use red to indicate highly urgent messages, yellow to indicate cautionary information, and green to indicate normal operations or safe conditions. Refrain the use of green-red, green-blue, yellow-red, yellow-blue, purple-red color combination. It is recommended to not use more than four different colors for semantic coding.

4. Discussion.

4.1. **VID, FoV, and brightness.** The graphics in traditional HUDs are projected to the vehicle's windshield; however, AR-HUD graphics should overlay onto real-world objects. Figure 1 depicts the difference between the interface requirements of traditional HUDs and AR-HUDs. One important purpose of an AR-HUD is to identify threats by directly marking it within the driver's FoV. To achieve this purpose, the VID requirement is at least 6 m [12,13]. Previous publication by Texas Instrument [12] stated 7 m to be minimum; however, it was revised to 6 m in [13]. VID more than 6 m is good for user experience because, starting at this length, the eyes are less sensitive to discrepancies in physiological distance cues and will perceive that the AR information is more strongly fused with the real world. Optimal VID is between 12 m to 15 m and the benefit of less

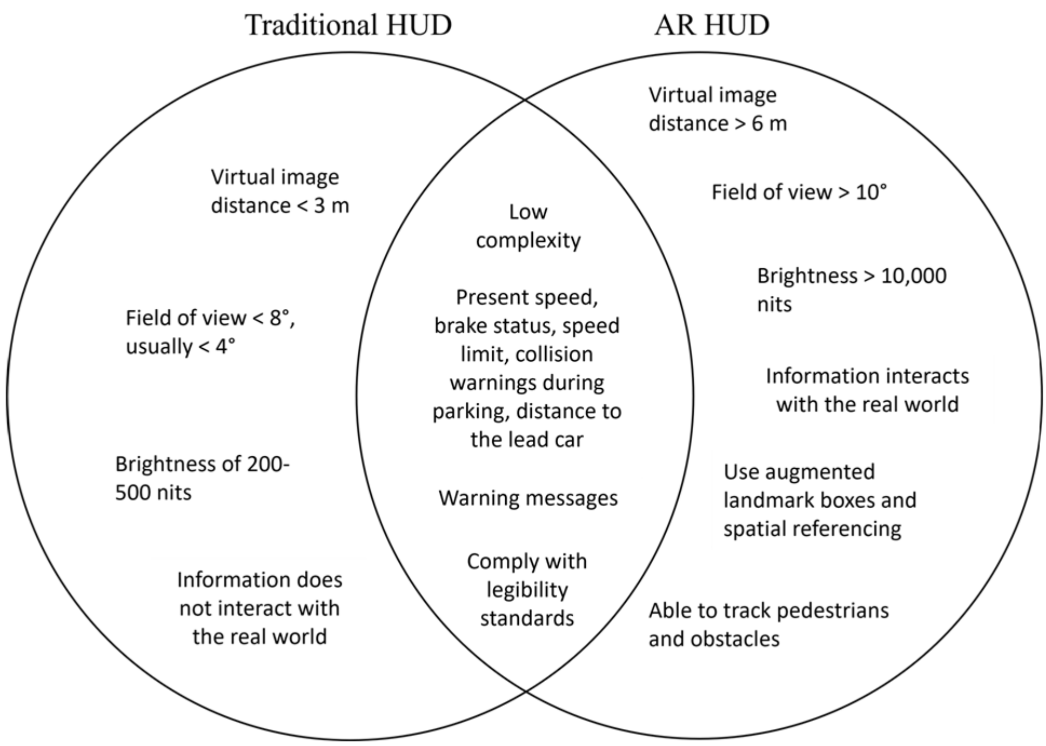

FIGURE 1. Comparison of traditional HUD vs AR-HUD requirements

misalignment of the augmented graphic from longer VIDs is diminished beyond this range [13]. Further experiments on different VIDs to driving performance are needed.

Corresponding with VID, an FoV will result in better driver experience. To present augmented graphics on the road, other vehicles, pedestrians, and buildings, a narrow to medium FoV in current HUDs is not enough. At least 10° is needed and this corresponds to Ren et al. [14]. We propose further study is needed to investigate the relationship between different FoV and different age groups to AR-HUD usability and driving performance.

AR-HUD projects graphics onto real-world objects in front of the car. Therefore, a high requirement for brightness is needed for the graphics to be clearly seen. For outdoor applications, the required luminance is more than 10,000 nits [15-17].

Naturally, driving in a bright, dark, raining, and snowing environment will change the required brightness requirement. Research comparing these different environment settings and different brightness levels should be done in the future.

4.2. **Projected information and legibility.** In general, for dynamic task like driving, the complexity of the AR-HUD display should be as simple as possible, and information should be presented when needed [18,19]. Previous studies have highlighted speed, navigation cues, lane lines, pedestrian crossings [7], and distance from the stop line as important information [20]. Therefore, in Guideline #4, other information is suggested to not be presented to minimize the display complexity.

However, in intersections, cognitive load is higher, especially in mixed traffic scenarios [20-23]. Distance from stop line, vehicle's approach speed and type of intersection were important factors in drivers' decisions [20]. It is also interesting to note that in highways, advertisements and the natural environment represent the visual elements that most distract the driver [24]. After congestion, the driving behavior tends to be more aggressive and prone to accidents [25]. Therefore, we propose Guidelines #6 and #7.

In a navigating task experiment, to increase the driver's attention to obstacles, using augmented landmark boxes is recommended, compared to only using arrows [26,27]. On top of that, spatial referencing of an unspecific warning symbol consistently improved driver's reactions [28]. Animating warning messages or graphics is proved to increase driver's attention [29].

Effective uses of color can help a driver to group information, code information, attract their attention more quickly, and facilitate interpretation via the use of population stereotypes [29]. Letter guidelines comply with ISO 15008, SAE-J283, TRL-PA3721/01, FHWA, and Naujoks et al. [30-34]. The color guidelines were based on FHWA and Naujoks et al. [33,34]. We argue that these standards are applicable to AR-HUD. Nonetheless, it would be worthy to conduct future research to validate these legibility guidelines specifically for AR-HUD and how it affects different age groups [35].

5. **Conclusions.** This study proposes nine guidelines and presents a suggestion of future research needed for AR-HUD human-machine interfaces. This set of guidelines is a starting point towards future standards for the development of AR-HUDs. Existing research on AR-HUD is limited, and based on the findings, future research that is needed is the following: Experiment on different VIDs to driving performance, investigate the relationship between different FoV and different age groups to AR-HUD usability and driving performance, comparing different environment settings and different brightness levels, and to validate legibility guidelines specifically for AR-HUD.

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