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3D HUD Optical-Property Measurement for IEC and ISO Standard Developments

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ABSTRACT

In 3D HUD, 3D virtual image information related to navigation, vehicle condition, and safety is projected onto the road so that the driver can immediately recognize what is needed without changing the line of sight, thereby improving safety. Owing to this advantage, 3D HUD can be more effective for AR application area. This paper introduces objective optical-performance measurement items developed in the IEC 62629-62-11 and subjective evaluation items considered in ISO 21957.

1 INTRODUCTION

The AR technology, which shows virtual images simultaneously in the real-world background, is being deployed to wearable devices such as glasses and helmet, as well as non-wearable devices such as mobile devices and HUD. In this paper, the most promising area, HUD, amongst these applications is addressed. Previously, 2D HUD was mainly used, but the increased demand for AR representation has led to the need to develop 3D HUD. In order to visualize virtual information compatible with real-world objects in different locations, the depth information should be added to the virtual image.

The biggest differences between a traditional 3D display and a 3D HUD is (1) the reproduction image plane viewed by observers (actual 3D display vs. virtual image plane projected from actual 3D display by optical system) and (2) the correlation with real objects in viewing surrounds (non-correlation vs. correlation). These differences raise needs for the development of new measurement methods for 3D HUD. The optical-characteristics measurement methods are well defined in the IEC 62629-12-1 and 62629-22-1 for traditional stereoscopic and autostereoscopic 3D displays respectively. Contrary to the conventional 3D displays, the new measurement methods particularly in the aspect of geometry and spatial distortion are required for 3D HUD.

It is therefore attempted to develop optical-property measurement method for 3D HUD using binocular disparity concept and its results are suggested to the IEC 62629-62-11 standard development. This paper introduces the selection of the optical-property measurement items together with some subjective evaluation results.

2 INTERNATIONAL STANDARD DEVELOPMENT

A driver views the virtual-object displayed on the virtual image plane and 3D real-world objects at the same time (see Figure 1). The position of the virtual image plane is determined by the optical component design in the HUD. For 3D HUD, the 3D virtual objects are located in the front and rear of this virtual image plane whereas only 2D virtual objects on this virtual image plane for 2D HUD.

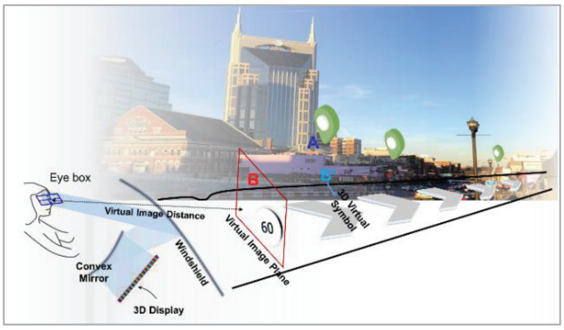


Fig. 1 The B symbol on 2D HUD vs. the stereo B' symbol with depth information indicating the real building A on the street.

The 2D symbol of B is presented on the virtual image plane of 2D HUD to indicate the building of A on the street whereas the stereo symbol of B' is presented with depth information for 3D HUD. The driver should alter visual focus between A and B for 2D HUD but does not need to switch visual focus between A and B' for 3D HUD since A and B' appear in similar distance.

The optical-performance assessment items are derived by considering the user requirements in HUD image observation, illustrating in Fig. 2. The seven measurement items have been suggested since 2018 to establish the IEC 62629-62-11 in order to ensure whether the two kinds of user-requirements are met: (1) projected virtual images should be properly aligned relative to user's eyes and (2) users should view clear projected images against real-world surroundings. Currently, the CD (Committee Draft) document is being developed in the IEC TC 110 (Electronic Displays). In addition, the subjective-evaluation method for 3D HUD is also progressing in the ISO TC 22 (Road Vehicles) SC35 (Lighting and Visibility) as an informative Annex in ISO TS 21957. The three measuring items have been proposed since 2019 to evaluate (1) how accurate the perceived distance of the virtual object is for users, (2) how visually comfortable, and (3) how different distance between virtual and its corresponding real object is for user to recognize both objects simultaneously.

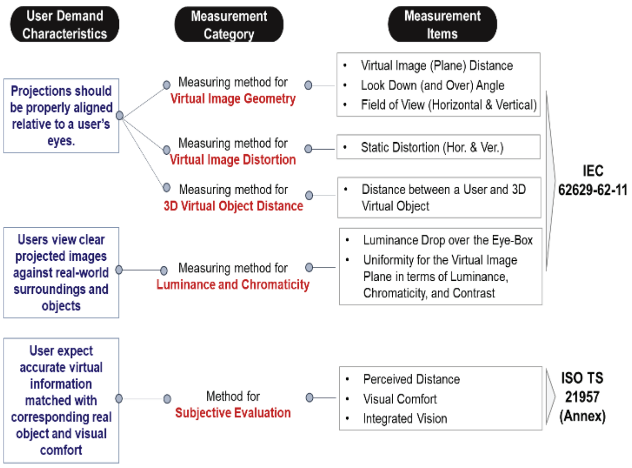


Fig. 2 Measurement items derived for IEC and ISO standard developments.

3 MEASUREMENT CONFIGURATION

The geometric relationship between an eye-box and a 'transparent virtual image plane' is shown in Fig. 3.

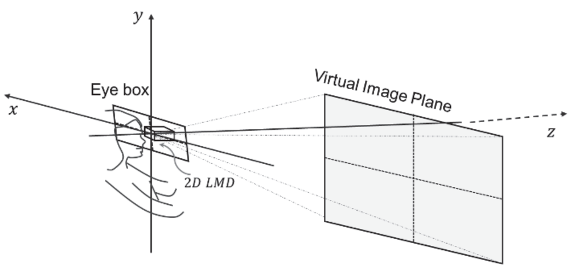


Fig. 3 The geometric relationship between an eye-box and a virtual image plane

If user's eyes are placed in the eye-box, it is assumed that the user can view the entire virtual image with natural rolling movement of the eyes. The measuring devices of 2D LMD (Light Measuring Device) should be setup within the eye-box position. A 3D virtual object can be presented in front or rear of the virtual image plane. A 3D coordinate system of the xyz indicated in Fig. 3 is defined in order to figure out the positions of the 3D virtual object and the virtual image plane from the eye box. The geometric location and distortion information of a 3D virtual object and the virtual image plane can be estimated from the corresponding pixel-position information in the acquired 2D image-plane of 2D LMD. The detail computational procedure regarding this concept is not given in this paper since the technical contents of the IEC 62629-62-11 are under revision process.

4 MEASURING 3D VIRTUAL OBJECT DISTANCE

4.1 Objective Measurement

The depth reproduction of the 3D virtual object is important to provide viewers with accurate distance information for corresponding 3D real object in the real world. Vehicle-related information can be displayed in front of the virtual image plane, and at the same time the information relevant to navigation or objects on the road can be expressed in the back. The measurement condition is shown in Fig. 4 to assess the distance of the 3D virtual object located in the front or rear of the virtual image plane.

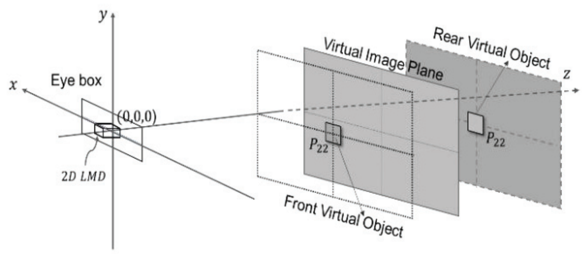


Fig. 4 Measuring condition for the 3D virtual object distance for the virtual object in the front or rear of the virtual image plane

The virtual image plane is located at 4.5 m away from a viewer for the 3D HUD used for the experiment in this work. The measured distance result can be reported in terms of diopter for the rear virtual-object: $D_{3D\ object}$ = 0.179 diopter that is calculated by dividing the distance (5.6 m) by one. Actual distance values of the displayed 3D virtual objects can be deviated from original designed values. To quantify this deviation, the distance measurement method proposed in IEC 62629-62-11 can be utilized.

4.2 Subjective Measurement for Perceived Distance

If a driver can view a navigation symbol reproduced by 3D HUD at the same distance where the next turn is actually placed, this is the most preferable. The 3D HUD should therefore display the corresponding 3D virtual content such as arrow at the same distance as the real turning location. The assessment methodology and its results are introduced here for the distance perceived by an observer in the augmented surrounding (see Fig. 5) composed of real objects and their corresponding virtual objects.

The exemplary evaluation configuration is illustrated in Fig. 5. The following procedures are applied:

a) selection of the target distances to be assessed from both the front and the rear positions of the virtual image plane (at 4.5 m), for instance, one front position of 3 m and fiver rear positions of 8, 15, 30, 40, 50 m from the user;

b) siting the real square panels at the target distances;

c) preparation of the respective virtual-object image (arrow in Fig. 5) by considering the inter-pupillary distance of each observer; and

d) the observer is asked to adjust the distance of the virtual object to the position of the real square panel.

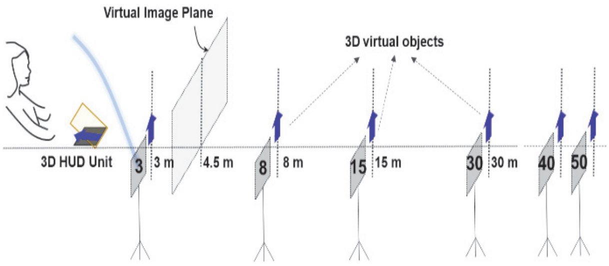


Fig. 5 Experimental configuration for the perceived distance in 3D HUD

The perceived distance results are shown in the diopter and binocular angle dimensions in Fig. 6 (a) and (b) respectively. Reflecting that determinable deviation is not the same in the actual distance [1], it is recommendable to analyze the observations in different distances in the domain of diopter or binocular angle. The virtual objects are viewed to be placed at 0.385 diopter (2.6 m), 0.129 (7.8 m), 0.07 (14.4 m), 0.035 (28.6 m), 0.027 (36.6 m), and 0.023 (44.8 m) (in median values in Fig. 6(a)) that are slightly closer in the observer direction compared with the actual target-object locations at 3, 8, 15, 30, 40, and 50 m. The minimum to maximum ranges in the perceived distance in Fig. 6(a) and in the binocular angle in Fig. 6(b) at 15 – 50 m fall into similar size. These findings indicate that recognition degree against 3D virtual objects is similar in the distance range of 15 – 50 m with comparable minimum to maximum diopter sizes. The longer distance than the farthest distance of 50 m used in this experiment will be evaluated later.

There are various cues contributing to our depth perception. Figure 7 introduces the depth cues that vary in their effectiveness at different distances [2]. The binocular disparity is the main cue applied to create stereo contents in 3D HUD for this work. The binocular disparity cue becomes less effective as the distance increases, and then does not work around several hundred meters in Fig. 7. The observation range of this experiment – 3D virtual objects are perceived in similar error range up to 50 m – needs to be extended to at least 100 m. Then, the working distance by the binocular disparity cue applied for 3D HUD will be able to be compared with the previous study result shown in Fig. 7.

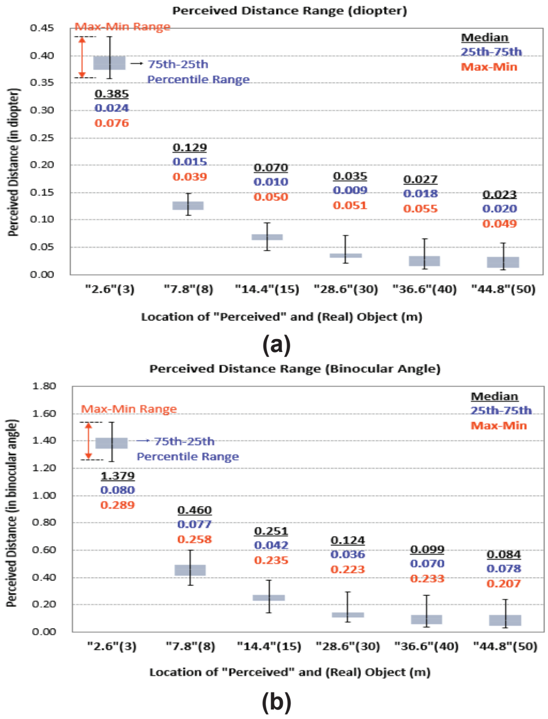


Fig. 6 The perceived distance results (a) in the diopter, and (b) in the binocular angle

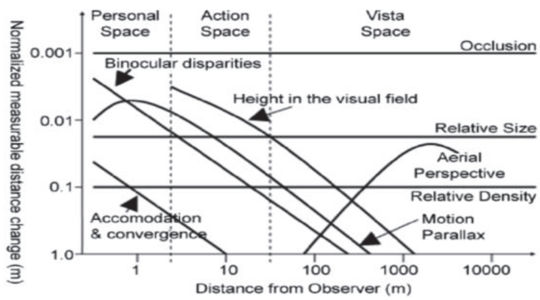


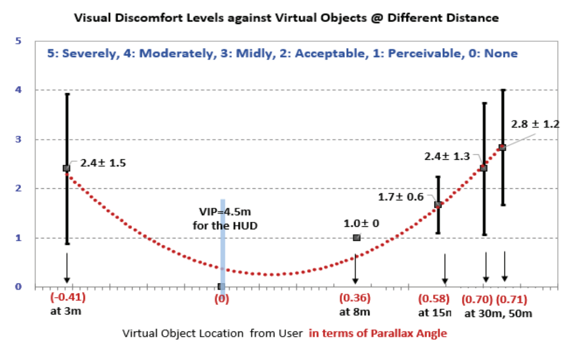
Fig. 7 Depth cues operating in different distance and just-discriminable depth thresholds [2].

5 MEASURING VISUAL COMFORT

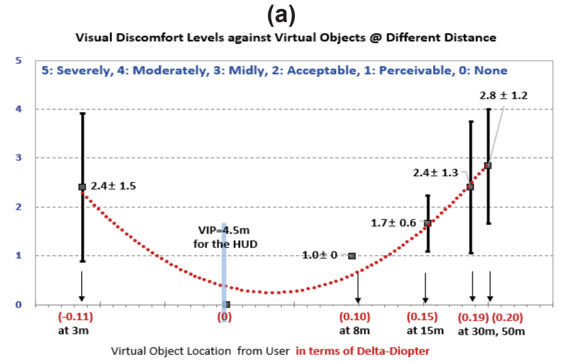
The visual comfortable 3D content is an important issue particularly for safe driving in automotive applications. It is known in the field of conventional stereoscopic 3D displays that viewing the 3D contents with excessive parallaxes can evoke visual discomfort because of the difficulty in fusion and an increased disagreement of accommodation and convergence [3]. The viewing condition however differs between 3D TV and see-through 3D HUD. The investigation of visual comfort range is required for 3D HUD in the front/rear distance from the virtual image plane on which there is no parallax (zero disparity) i.e., the reference 2D screen. The assessment methodology and its results are introduced to find out the parallax range in which users view comfortable 3D virtual contents. Following are the evaluation procedures but a) to c) sub-procedures are the same as in Section **4.2**:

a) selection of the target distances to be assessed;
b) siting the real square panels at the target distances;
c) preparation of the respective virtual-object image; and
d) the observer is asked to stare at the virtual object (at least for one second) and then to rate his/her symptom on a **6-point Likert scale**: **0** for comfort, **1** for perceivable discomfort (just recognizable), **2** for acceptable discomfort (a little bit uncomfortable but tolerable), **3** for mildly discomfort (slightly uncomfortable), **4** for moderately discomfort, **5** for severely discomfort

The observed rating values are compared in the parallax angle and delta-diopter dimensions in Fig. 8 (a) and (b) respectively. The observers tend to recognize more discomfort as the delta-dioptre or parallax angle value becomes deviated from zero at the virtual image plane in both negative (the front) and positive (the rear) directions.



(a)



(b)

Fig. 8 The visual discomfort results (a) in the parallax angle, and (b) in the delta-diopter

It is limited to derive the visual comfort zone from this observation result alone due to lack of prior research. Considering more severe experimental condition (at least staring at virtual object for one second) compared to the real situation, it can be said that users are perceived to be comfortable 3D virtual-objects up to 30 m (scale **3**, 'slightly uncomfortable'). It is unlikely to appeal discomfort up to 30 m. To find out the visual comfort zone, more experiments including dynamic situation is required. The visual comfort is also compared between 2D HUD viewing (**V**irtual **O**bjects on the virtual image plane at 4.5 m vs. its corresponding **R**eal **O**bjects at 8, 15 m) and 3D HUD viewing (both 3D **V**irtual and its corresponding **R**eal **O**bjects at 8, 15 m) cases. The statistical analysis (Mann-Whitney) shows in Fig. 9 that the observers perceive more comfortable viewing for 3D HUD than for 2D HUD in the 90 and 95 % confidence levels at 8 and 15 m. This finding supports the 3D HUD can provide a safer viewing experience to drivers than 2D HUD.

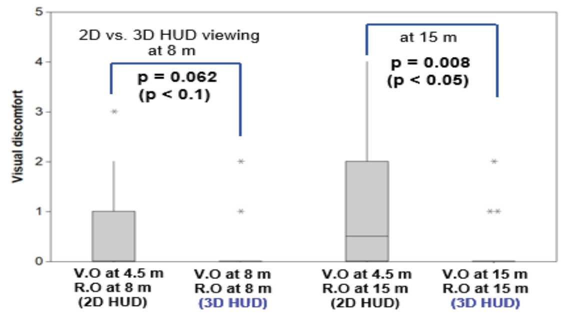


Fig. 9 The Mann-Whitney statistical test result

6 CONCLUSIONS

This paper introduces the 3D HUD optical-performance items underway with the IEC 62629-62-11 standard development and the key subjective evaluation items handled for the ISO TS 21957. The proposed measuring items can be applied to both automotive and non-automobile HUD where visual information based on application purpose is displayed on the road or in the museum, showroom etc. The subjective experimental results show that observers well perceive 3D virtual objects up to 50 m (the farthest viewing distance in this work) for 3D HUD to which binocular-disparity depth cue is applied. In addition, statistically significant evidence is shown that 3D HUD provides a safer viewing experience than conventional 2D HUD.

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