Development of an Automotive Head-Up Display using a Free-Form Mirror Based Optical System

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Abstract

In June 2013, the Optical Devices Division (Former Fujinon) and Electronic Imaging Division were integrated to establish the Optical Device & Electronic Imaging Products Development Center. This collaboration enabled us to develop a novel Head-Up Display (HUD) system for automotive devices. We adopted a newly designed free-form mirror system. By the mirror system, we were able to simultaneously realize following features in our HUD system: distortion-less large virtual images, high brightness/contrast, and small unit size. Herein, we report the development results related to this HUD system.

1. Introduction

Recent automobiles have come to have multiple functionalities. Due to them, they are equipped with systems to provide drivers with various information. Among these systems, the ones providing visual information to drivers, such as a car navigation system, as well as instrument panels in front of the driver seat, have been penetrated. Meanwhile, people have pointed out new problems for drivers who need to move their line of sight to obtain such information, causing an inattentive driving, which in turn results in an accident. Therefore, the head-up display (hereafter called HUD) technology has attracted much attention, as it supports information recognition without causing the movement of the driver's line of sight by overlapping driver support information on the background through the windshield in front of the driver. This market is expected to grow in the future.

Meanwhile, in June 2013, the Optical Devices Division (Former Fujinon) and Electronic Imaging Division were integrated to establish the Optical Device & Electronic Imaging Products Development Center. We started reviewing about the creation of new businesses by combining each division's competitiveness in optical device and electronic imaging technologies, and leveraging their synergy. As a result, we decided to focus on HUDs because of two reasons. One is expectation of market growth. The other is technical advantages in both optical design capability and optical material manufacturing technology based on long experience of projectors as well as movie theaters. Finally, we have commenced the development of the HUD system for automobile in September 2013.

2. Principle of HUD

We will explain about the principle of HUD using Fig. 1.

An image from the picture generating unit is projected on the surface of the diffuser as an intermediate image. This intermediate image is enlarged with the magnifier, and the lights are reflected with the windshield then led to an observer. At this point, a driver (observer) recognizes the intermediate image as a virtual one. Actual lights from the picture generating unit are transmitted through the light paths show in solid lines in Fig. 1, and entered into the driver's eyes. He/she feels that lights seem to come through the light paths in dotted lines (the right side of the windshield) in Fig. 1 before entering into his/her eyes. As a result, the driver recognizes as if the images displayed as intermediate ones (A, B, C) were placed on other points (A', B', C'), and feels that driving support information is floated on the road.

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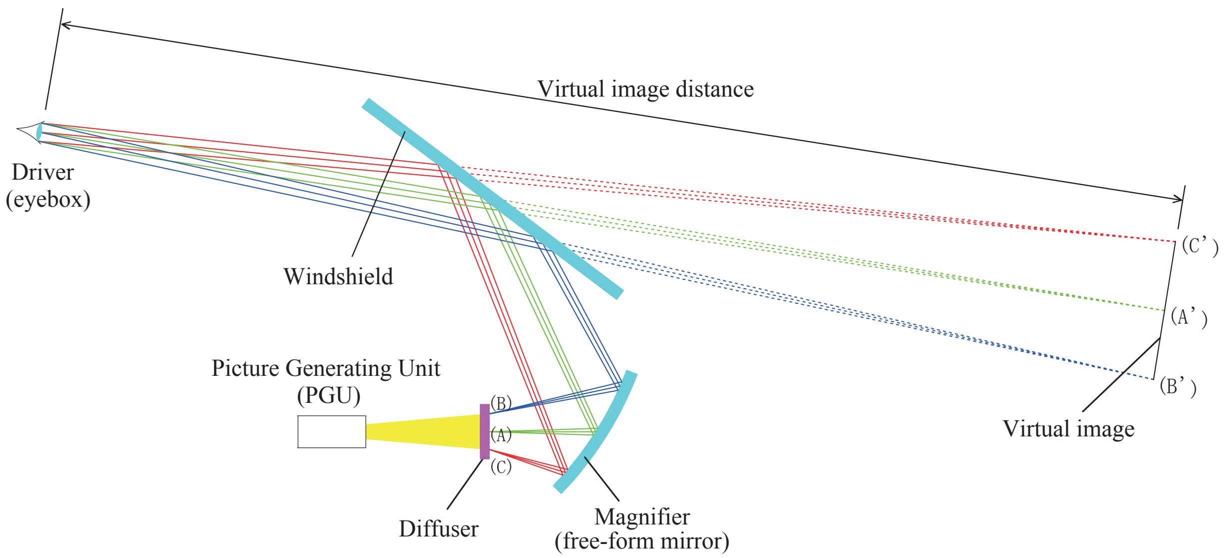


Solid line: Actual light path
Dotted line: Virtual light path the driver feels } → Both of the light paths the driver sees are the same. → The driver feels that the image displayed at Point (A) on the diffusing plate seems to be at Point (A').

Fig. 1 Schematic of the optical system used to develop the HUD

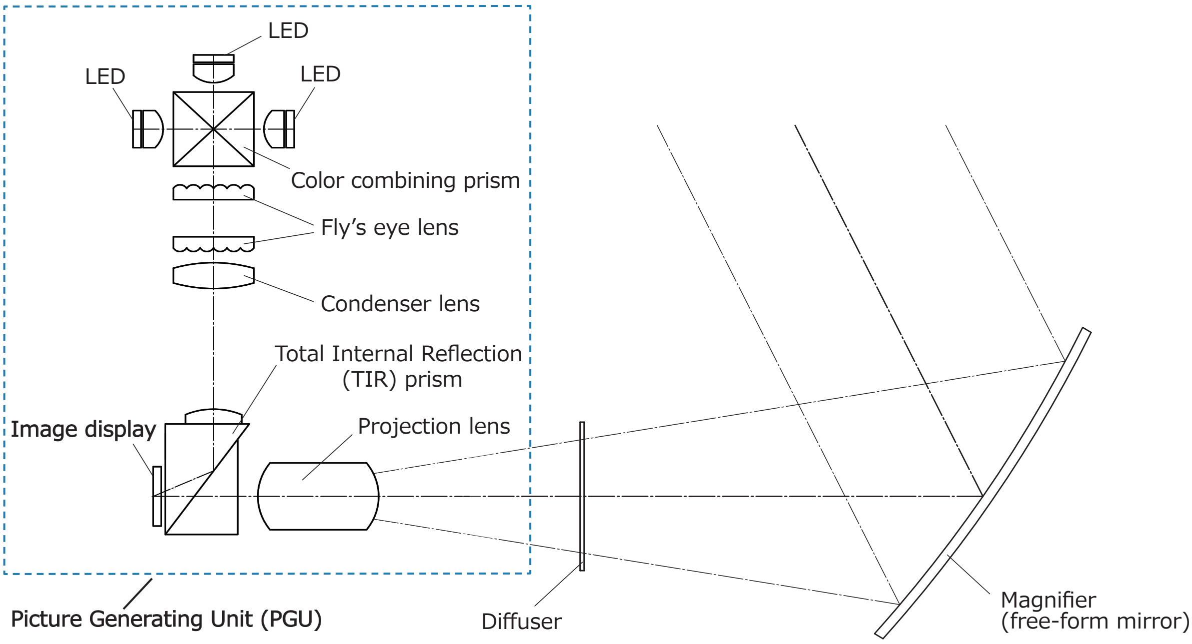


Fig. 2 Schematic of the internal structure of the projection system

3. Configuration of picture generating unit

The schematic configuration drawing for the picture generating unit is shown in Fig. 2. The light emitting diode (LED), laser beams, etc. are used as light sources. The vacuum fluorescent display (VFD), liquid crystal (monochrome/color), and micro electro mechanical systems (MEMS) elements are used as image display elements.

Optical parts constituting the light paths from the light source to image display elements, and lenses enlarging and projecting image display elements are also used. The picture generating unit is comprised of various other parts, but its element technologies are roughly divided into five fields: optical, mechanism, electric/electronic, software and materials.

4. Development of prototype HUD system

We had manufactured a picture generating unit, one component of the HUD system using our traditional projector technologies that had been accumulated, and started marketing activities in April 2014. During our marketing activities,

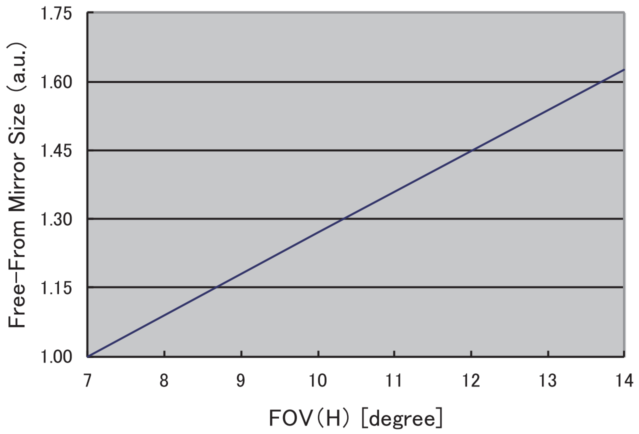


Fig. 3 Schematic of the relative horizontal FOV vs. mirror size

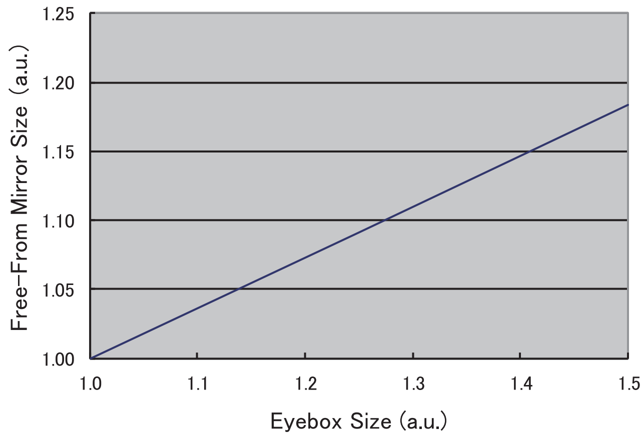


Fig. 4 Schematic of the relative eyebox size vs. mirror size

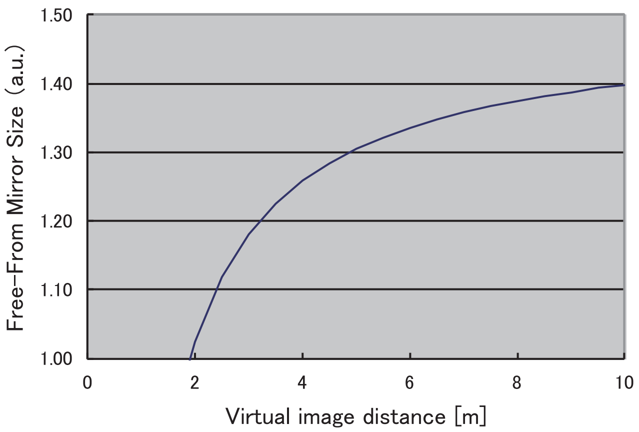


Fig. 5 Schematic of the virtual image distance vs. mirror size

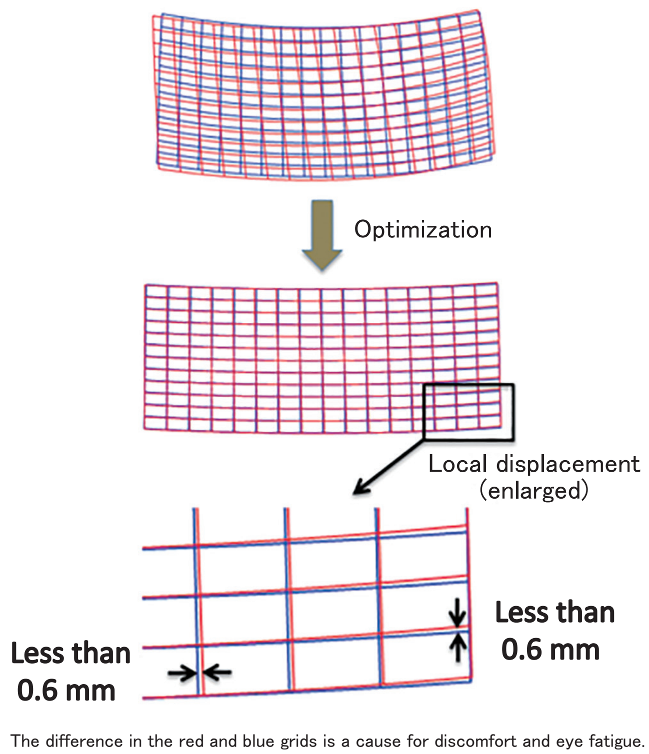


Fig. 6 Representation of the virtual image viewed by the right eye (red) as compared to that viewed by the left eye (blue)

we found that: (1) there are a lot of needs for providing an entire HUD system; (2) the keywords for their performance were "large screen", "high brightness", "high image quality", and "small HUD unit body size"; and (3) providing only one component would not create an added-value, which would soon make us facing a price competition.

Considering these backgrounds, we started the development of a prototype HUD system. After a lot of trials and errors, we have finally realized a smaller unit body size, while maintaining distortion-less large virtual images with high brightness and high quality by incorporating a newly designed free-form mirror system. We will report our challenges we have done in the development process as follows.

4.1 HUD unit body size

Optical designs realize desired optical performance by optimizing various parameters specifying optical part shapes, while maintaining manufacturability. There are huge numbers of rays to be controlled and performance indicator functions describing the light-focusing status. Therefore, optical design software to be used in optimization is extremely important. The Optical Device & Electronic Imaging Products Development Center has developed in-house optical design software and utilized in the vast product portfolio of Fujifilm since the beginning of the company's history. The software has accumulated experiences and know-how of various types in several decades and still been making evolutions with optical designers.

As we proceeded the design of devices, we found that the unit body size depends specially on the "field of view (FOV)", "eyebox (the range where the virtual image can be seen)", and "virtual image distance (distance from eye to the virtual image)". Customers often request us to expand FOV and enlarge eyebox, but if we do so, the unit body size (near-

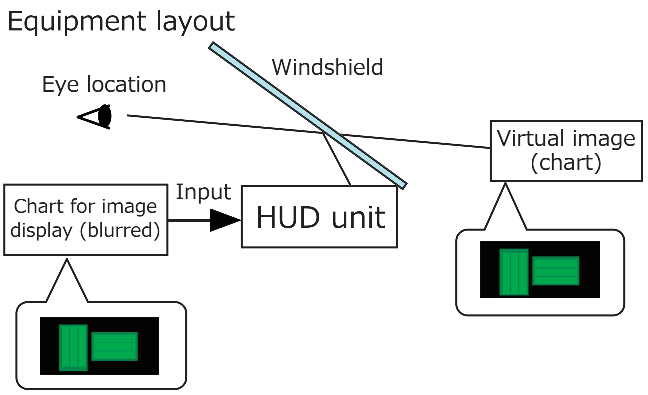


Fig. 7　Schematic of the quantification methods used for quantifying resolution

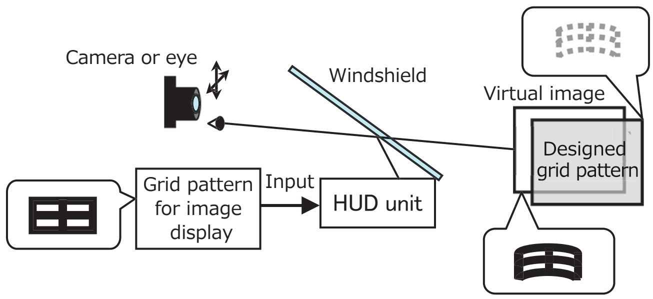


Fig. 8　Schematic of the quantification methods used for quantifying distortion

ly equal to the free-form mirror size) increases accordingly (Figs. 3 and 4). Customers also request us to push the virtual image further (i.e. 5m or so) than conventional 2 m. Such demands would also increase the unit body size, however it is saturated about 10 m (Fig. 5). Such trend is caused by the absence of optical power in the light path from the driver to the magnifier (free-form-mirror) via the windshield. This condition is mandatory to install the HUD system into automobiles, therefore competitiveness should arise from how we can reduce the unit size.

4.2　Quality of HUD virtual image

4.2.1　Suppression of position and shape displacements due to the eye position

If the image position or shape changes due to eye position variation in the eyebox (ex. right eye or left eye), it causes the driver's discomfort or his/her eye fatigue with, for example, doubled images and shaken images. To solve this issue, we optimized the mirror's position and shape optically. By this optimization, we realize to minimize image distortion within entire eyebox (Fig. 6).

4.2.2　Goals of reducing difference seen by the left and right eye

Here we discuss the situation when the driver focuses on the virtual image locally. Since the visual acuity of 1.0 means the ability to recognize the direction of a gap with the width of 1.5 mm in the ring with the diameter of 7.5 mm from the position 5 m away from the ring (angular resolution capability at 1 arc min). If the virtual image distance is 2 m, for example, the resolution capability for a person with the visual acuity of 1.0 is about 0.6 mm in calculation. The difference in grids at the lowermost drawing in Fig. 6 caused by parallax is about 0.6 mm at maximum.

4.2.3　Quantifying sense of resolution

When projecting information as a virtual image, the readability for drivers also plays an important role. We have tried quantification of a sense of resolution (sensory evaluation results) by establishing an evaluation environment in Fig. 7, aiming to optimize specifications and apply this as an inspection method in manufacturing lines. As a result, we have quantified necessary and sufficient resolutions and set design goals for optical devices.

4.2.4　Distortion evaluation

The HUD optical system tends to generate asymmetrical distortion as it does not use rotational symmetry. As described in 4.2.1 and 4.2.2 above, we need to strictly control the difference between the distortion in the virtual images seen by the right and left eyes, as it would cause the driver's eye fatigue. We therefore verified the validity of optical design simulation results and actual distortion of prototypes (Fig. 8).

As a result, we confirmed that the simulation results and actual distortion almost coincided in the eyebox center. Meanwhile, distortion seen from the left and right sides in the eyebox were different from the simulation results. We will analyze the cause to brush up the evaluation accuracy. We have achieved quantification of distortion measurement values, and are establishing a strict control method for asymmetric distortion. In the future, we plan to define necessary and sufficient distortion specifications, and to further develop a distortion correction method utilizing image processing.

4.2.5　Environment robust design (measures against stray light)

The in-vehicle HUD system is required to secure visibility in various outdoor environments. To establish a design policy for inhibiting stray light caused by sunlight, one of causes interfering with the visibility, we compared the optical design

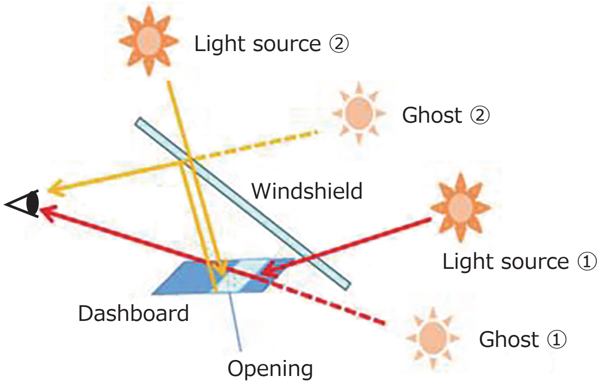


Fig. 9 Schematic of the paths of stray light that hit the HUD

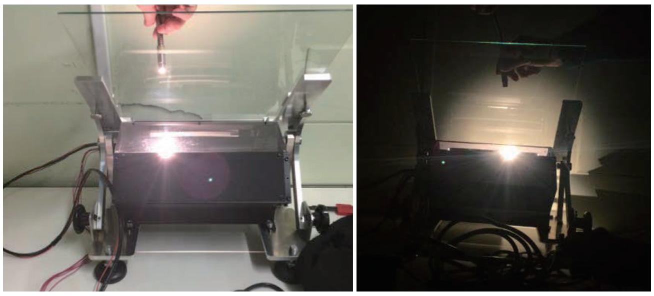


Fig. 10 Illustration of the optical simulation of the stray light path ①

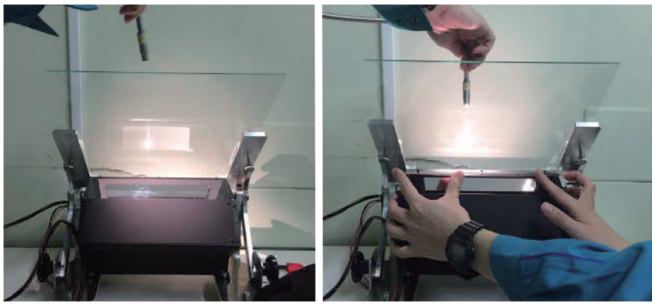


Fig. 11 Illustration of the optical simulation of the stray light path ②

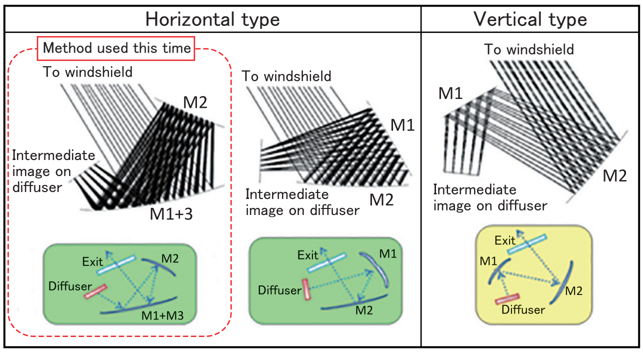


Fig. 12 Schematic of the variation of the free-form mirror

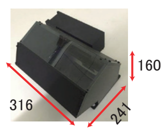
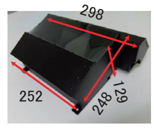
	Prototype name	
	Past prototype	Latest prototype
Unit dimension (mm³) (volume in litter)	316x241x160 (Real volume: 6.1L) 	298x248x129 (Real volume: 5.1L) 
Viewing angle	Horizontal 7 degrees × Vertical 2 degrees	
Virtual image size	Diagonal 10 inches (Horizontal 245 mm × Vertical 70 mm)	
Vertical image distance	2 m forward from eye	
Eyebox	Horizontal 180 mm × Vertical 40 mm	

Fig. 13 Comaprison of the specification

simulation and actual device evaluation, thereby verifying the effectiveness of optical design simulation and reviewing countermeasures (Figs. 9, 10, 11).

For the light path ①, we have already found a countermeasure of mechanically covering the HUD opening. For the light path ②, we will continue to study countermeasures as we have confirmed the actual light path by optical simulation.

4.3 Design of prototype (further downsizing)

We have explained about the verification results for the basic performance with the quality of virtual images of the HUD system in 4.2. We have further downsized the unit body size by adopting a newly designed free-form mirror system, while keeping its performance (latest prototype). The new optical design (leftmost in Fig. 12) realizes further body size reduction as well as distortion suppression by two surfaces – three reflection magnifier. These two free-form mirrors are placed afterward of intermediated image resulting longer light path and freedom to correct aberrations.

Depending on automobiles, there are variations of acceptable volumes and shapes for HUD unit, so we have variations of configuration of free-form mirror systems to achieve the best optical characteristics. The examples are shown in the center and right of Fig. 12.

Simplified specifications for the past and the latest prototypes for the HUD systems are shown in Fig. 13 above,

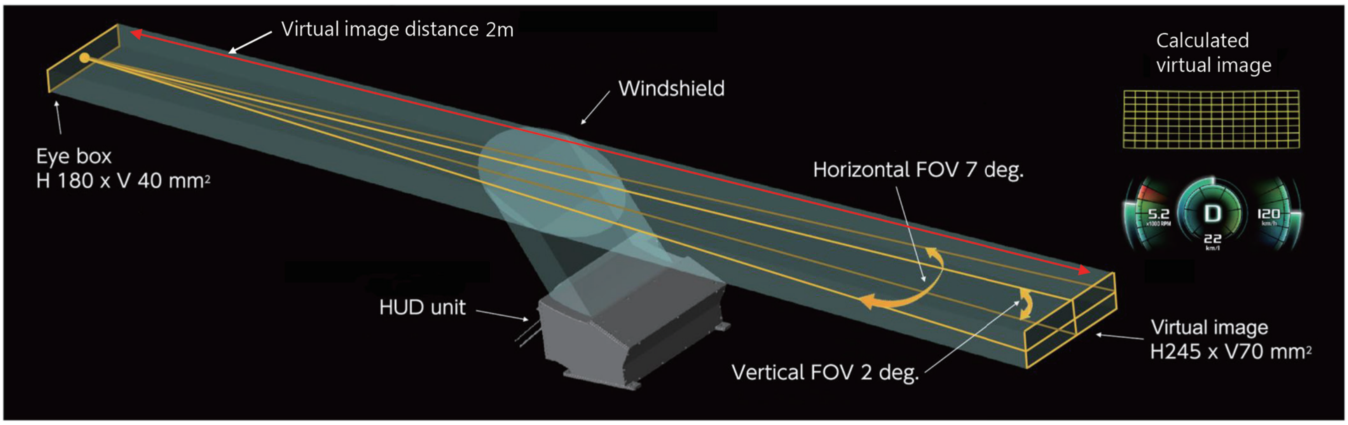


Fig. 14 Schematic of the configuration of the proposed prototype

and the schematic diagram is in Fig. 14. The latest prototype achieves a smaller (thinner especially) unit body while maintaining optical characteristics. We have demonstrated the latest prototype to several potential customers, and received a high evaluation with its wide field of view and distortion-less virtual images. We have also confirmed that the unit body size is at a level of installable to actual vehicles.

5. Conclusion

In this paper we reported our development of prototype achieving "distortion-less large virtual images", "high image quality", and "small unit body size". Currently we are addressing with various challenges, such as electronic distortion correction, internal production of free-form mirror systems, review of their materials (change from glass to plastic), and realizing further higher brightness with our material technologies. In the future, we will aim to enter into the market by fully utilizing FUJIFILM's technical strengths to generate customer value.

References

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