レーザー走査方式ヘッドアップディスプレイ

Head-up Display with Laser Scanning Unit

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要　旨

車載向けのヘッドアップディスプレイ（HUD）が市場に普及してきている．HUDは車両センサからの情報をフロントガラス先の背景に重畳させて拡張現実（AR）を実現することで，安全な運転環境を提供しようとしている．レーザー走査方式HUDは広色域と高輝度コントラストを特徴として運転者に確実な注意喚起を促すことができ，また背景に対して違和感のない3D表示が可能になるため，ARを実現するHUDに最適な方式である．我々は新規の部品であるスクリーンと2軸MEMSミラーを開発し，レーザーHUDの画質劣化と低信頼性の課題を解決して高画質と高信頼性のプロジェクションユニットを実現した．

ABSTRACT

In-vehicle head-up displays (HUDs) are being marketed as augmented reality (AR) displays aimed at make driving safer by superimposing information from the vehicle sensor on the background behind the windsheild. A laser HUD is optimal for an AR display because it can effectively draw the driver’s attention to the information and display a seamless image with a wide color gamut and high brightness contrast. We developed a projection unit for an automotive laser HUD and attained high image quality and reliability. Laser projection units tend to cause image quality deterioration and low reliability. We addressed these issues by developing a new screen and a two-axis micro-electromechanical systems (MEMS) mirror.

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本稿は，SPIEに帰属の著作権の利用許諾を受け，*Proc. SPIE 11125*, ODS 2019: Industrial Optical Devices and Systems, 111250C (30 August 2019)に掲載した論文を基に作成した．

1. INTRODUCTION

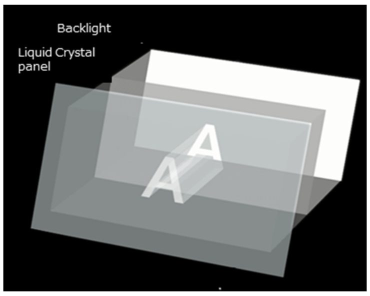
Automobiles are equipped with many functional devices for providing drivers with various types of information. Common devices that provide visual information to drivers include car navigation and meter displays. In recent years, head-up displays (HUDs) have been proposed as an alternative that may provide additional functionalities. HUDs display vehicle information, such as speed and GPS navigation data, on the windshield. Compared with conventional GPS systems, HUDs help to reduce the amount of driver eye movement, which in turn reduces driver fatigue and the risk of accidents caused by the driver's lack of attention to the road.

In addition to these benefits, HUDs are expected to play a role in helping drivers maintain their attention and through the use of augmented reality (AR) in combination with various sensors mounted on the vehicle.

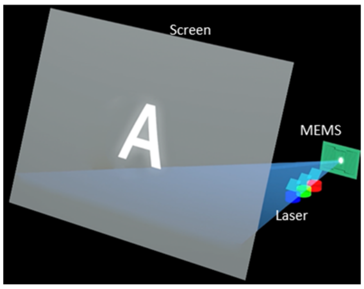
HUDs are generally divided into two types: liquid crystal display (LCD) and laser scanning. Unlike the laser scanning HUD, the brightness of the LCD type cannot be adjusted locally on the screen. It also has a narrow color gamut and suffers from the postcard effect, causing visibility problems in the AR display. On the other hand, laser scanning HUDs can eliminate the postcard effect; however, image quality deteriorates due to laser-oriented speckles and moiré1). Furthermore, its reliability needs to be improved so that it can be operated despite extreme temperatures, humidity, and dust inside of the vehicle. In this paper, we propose a laser HUD that is reliable, produces high-quality images, and can be installed on vehicles.

2. OVERVIEW OF HUD

The diagram in Figure 1 shows an overview of an HUD. LCD is the conventional type. LED is typically used as the backlight for LCD (Fig. 1 (a)). Other types include reflective liquid crystal on Si (LCOS) and the reflective digital micromirror device (DMD) made by Texas Instruments. LCD types modulate the intensity of the LED backlight by using liquid crystal. They use a color filter to express color. Laser scanning is a new method that creates an image by using red, green, blue (RGB) lasers that are scanned on the screen by a two-axis micro-electromechanical systems (MEMS) mirror (Fig. 1 (b)) 2,3).



(a) Liquid crystal panel with backlight



(b) Scanning with RGB lasers

Fig. 1 Overview of HUD.

3. LASER HUD

3-1 Configuration of Laser HUD

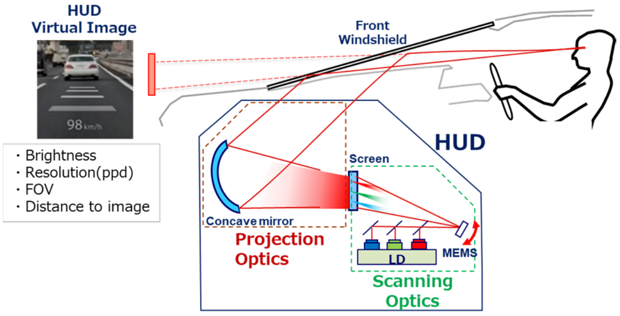
Figure 2 (a) shows the configuration of the laser HUD, which is roughly composed of two optical systems. The first is a scanning optical system, and the second is a projection optical system. In the scanning optical system, the RGB lasers are scanned on the screen by a two-axis MEMS mirror to create an image (Fig. 2 (b)). The relation between the movement of the MEMS mirror and the screen is expressed as

$$\tan\theta = X / 2L \qquad (1)$$

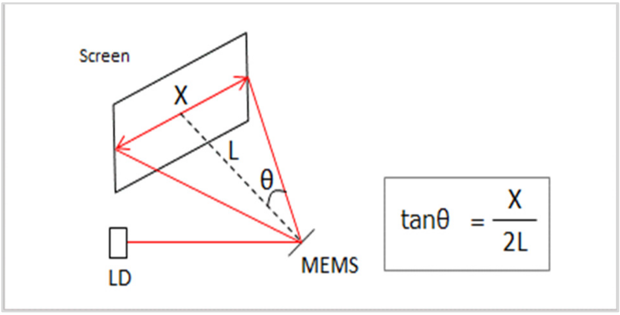
where θ is the half angle scanned by the MEMS mirror, L is the distance between the mirror and the screen, and X is the laser scanning width of the screen image. In the projection optical system, HUD projects a virtual image onto the front windshield of the vehicle by using a concave mirror (Fig. 2 (c)). Drivers looking at the screen through the front windshield see an image appear on the windshield. Assuming the front window is a flat plate, the expression connecting the screen to the virtual image is

$$H2 / H1 = (S'1 - S'2) / S \qquad (2)$$

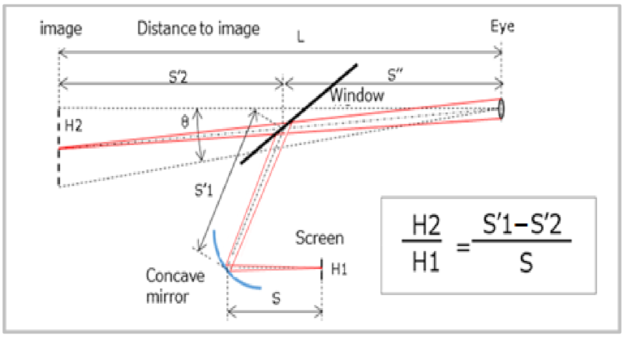
where H2 is the virtual image size as seen through the window, H1 is the image size of the screen, S is the distance between the screen and the concave mirror, S'1 is the distance between the concave mirror and the front windshield, and S'2 is the distance between the front windshield and the virtual image.



(a) Laser HUD configuration



(b) Laser HUD model (Scanning)



(c) Laser HUD model (Projection)

Fig. 2 Configuration and model of laser HUD.

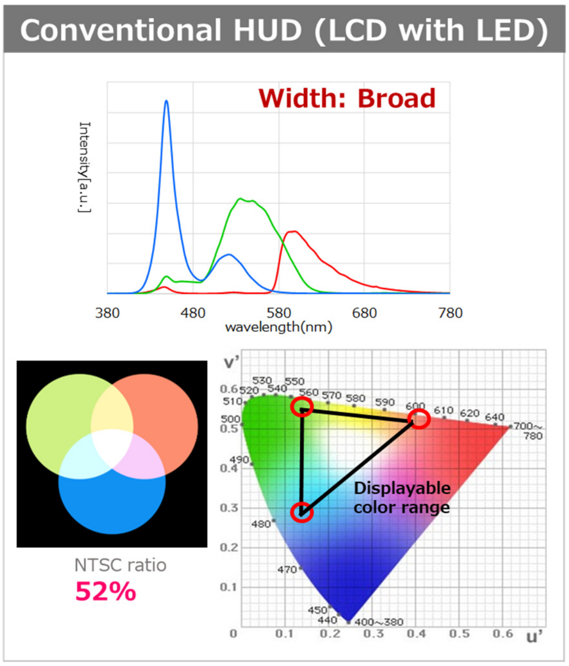
3-2 Features of Laser HUD

There are three advantages to using laser scanning over a conventional HUD such as the LCD type.

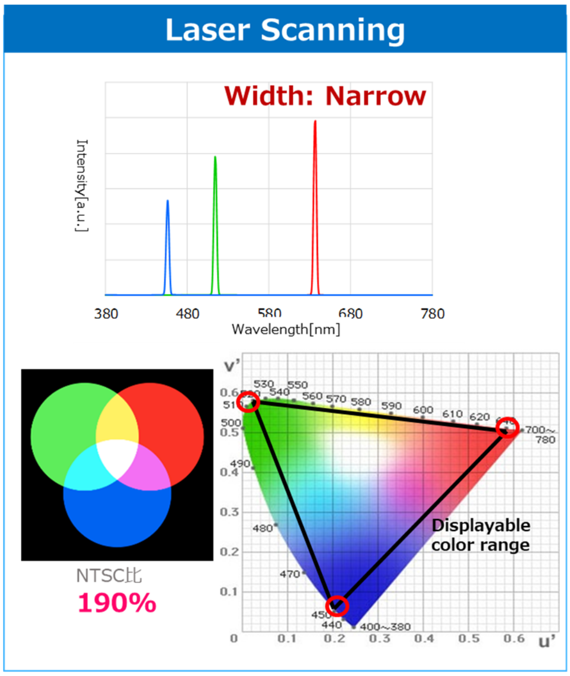
First, the brightness of the screen can be adjusted at will; that is, the laser enables the brightness distribution on the screen to be adjustable. Although the LCD type enables the brightness of the whole screen to be changed, it cannot be changed locally because the whole screen is illuminated by the LED and the brightness of screen is adjusted by the liquid crystal. Laser scanning enables brightness to be adjusted as needed for the driving circumstances, this has the merit of information selectivity such that the information required by driving, for example, a warning is strongly illuminated to make it easier to recognize.

The second advantage of laser scanning is its seamless display. With the LCD type, the backlight is always on so the whole screen is illuminated, and the brightness is adjusted with the liquid crystal. This means unnecessary light appears as background noise, also known as the postcard effect. On the other hand, in the laser scanning type, the laser light is turned off in the areas of the screen that do not show an image. This means that it does not produce background noise, and its brightness contrast, which is the ratio of black and white light, is higher than that of the LCD type. The seamless display provides a sense of depth when expressed in AR.

The third advantage is wide color range. Figure 3 shows the difference between the color gamut of the LCD (Fig. 3 (a)) and the laser scanning HUDs (Fig. 3 (b)). In general, the wavelength of a laser is narrower than that of an LED, so the laser HUD can display a wider range of vivid colors$^{4)}$. A wide color gamut provides good visibility not buried in the background, for example, using a pure red color can draw the driver's attention.



(a) LCD with LED



(b) Laser scanning

Fig. 3 Difference between color gamut of LCD with LED and laser scanning.

4. PROJECTION UNIT FOR LASER HUD

4-1 Issues and key technologies of Laser HUD

Figure 4 shows an automotive HUD projection unit that uses laser scanning technology for an automotive human machine interface (HMI). The HMI enables information to be exchanged between people and machines. The hardware and software required for this are based on developments in advanced driver assistance systems (ADAS) centering on sensing technology and in-vehicle electronics.

While developing the unit, we encountered two issues: image quality deterioration and low reliability for automotive application. To solve these issues, we developed a screen using a micro lens structure and the 2-axis MEMS mirror as the key devices for the projection unit. The laser control technology includes scanning control, and the beam focusing technology for the projection unit is based on an optical system developed for our company's multi-functional printers. The image-forming technology of the projection unit are based on optical systems used in our company's cameras and projectors.

The screen and 2-axis MEMS mirror for attaining high image quality and reliability are described in detail below.

Fig. 4 Projection unit for laser HUD.

4-2 Screen

Image quality deterioration in laser HUDs is caused by speckle and moiré. Speckle is a phenomenon in which scattered light interferes when laser light illuminates the screen. The application of micro lens arrays to head-up displays has been previously reported in[5,6]. Moiré is a phenomenon in which a periodic pattern occurs due to the deviation of cycles when multiple regular patterns are superimposed. The image quality degradation was resolved with micro lens technologies used for integrated simulation of speckle and moiré and for precise fabrication. Figure 5 shows our proposed screen which is based on a micro lens structure. A diffuser is a commonly used type of screen; its surface has a random structure, which causes random interference and speckle. The micro lens structure suppresses speckle. The laser beam spot is focused on each pixel of the micro lens to prevent diffused light from interfering on the screen. Moiré occurs in the array of laser scanning lines and micro lenses. We suppressed moiré by making a random array of micro lenses. In order to develop these fundamental technologies for the screen, we needed to design the optimal shape and arrangement of the micro lenses, develop the process for manufacturing the screen, and devise a means of quantitatively evaluating image quality.

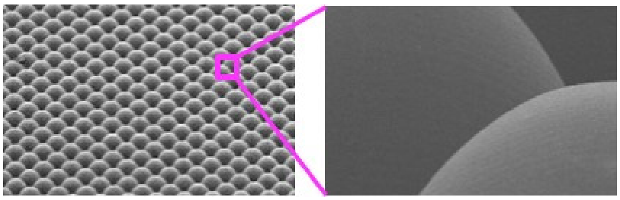
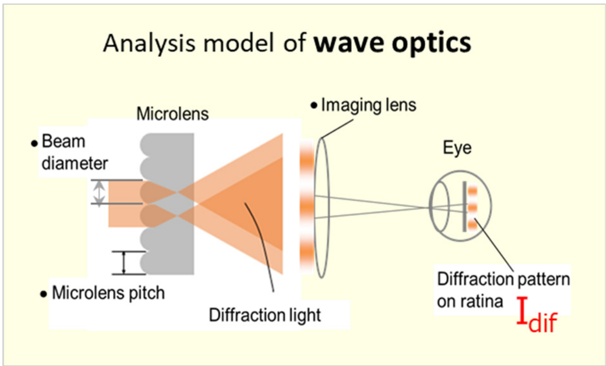


Fig. 5 Screen based on micro lens structure.

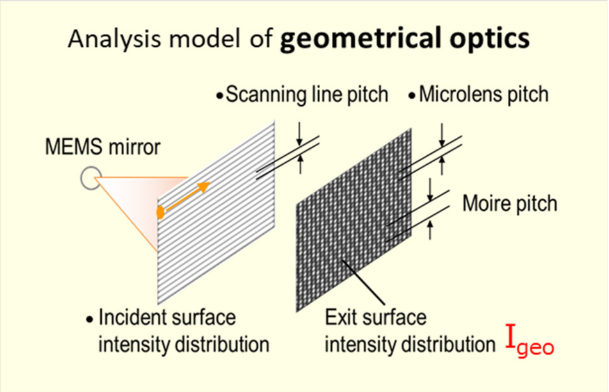
Here, let us briefly describe our methods for designing the screen. To deal with speckle and moiré, we devised a light-intensity analysis model that combines wave optics and geometrical optics. Figure 6 shows the different parts of this model. The screen has a micro lens structure, and the wave optics simulate the light intensity distribution (Idif) projected on the retina of the eye (Fig. 6 (a)). The control factors are the laser light intensity distribution, micro lens pitch and height, and characteristics of the imaging lens. The geometrical optics model simulates the light intensity distribution (Igeo) generated on the screen (Fig. 6 (b)). The control factors in this case are the laser light intensity distribution, pitch of the laser scanning lines, and the micro lens. Itotal is image noise that can be visually recognized and can be expressed as

$$\mathrm{Itotal} = \mathrm{Idif} * \mathrm{Igeo} \tag{3}$$

We optimized the structure and array of micro lenses by using a simulation tool based on this model, and the resulting laser HUD produced a high quality image$^{7)}$.



(a) Speckle; analysis model of wave optics



(b) Moiré; analysis model of geometrical optics

Fig. 6 Model for analyzing image quality on screen.

4-3 Two-axis MEMS mirror

MEMS mirrors for automotive applications need to be able to operate even in extreme conditions such as high temperatures, humidity, vibration, and dust. Figure 7 shows the two-axis MEMS mirror with several features aimed at ensuring its reliability.

The first feature is a lid to protect the mirror from particles. The lid is made of glass with an anti-reflection coating and is designed to separate the reflections from the lid and the mirror.

The second feature is a hermetic shield to protect the mirror from humidity. The package is ceramic and is sealed by seam welding. Nitrogen gas fills the inside of the package.

The third feature is a piezoelectric drive system with high drive power and high temperature resistance. Compared with other electromagnetic and electrostatic MEMS drive systems, the piezoelectric system can maintain drive power at temperatures as high as 100°C inside the vehicle. Furthermore, it has a low drive voltage as the piezoelectric material is PZT.

The fourth advantage is in the structure and drive control of the MEMS mirror. Our MEMS mirror was originally designed with a meander structure to attain high angle scanning with a low drive power. When such a mirror can be moved at a low voltage, unexpected oscillation is likely to occur. Therefore, we designed the resonance mode of the MEMS mirror and control the drive input signal automatically by a feedback signal so as not to generate unexpected vibrations.

We have developed the means to optimally design, manufacture, and evaluate MEMS structures to incorporate the aforementioned features of the two-axis MEMS mirror. Let us briefly describe the MEMS design. The main characteristics of MEMS mirrors can be broadly divided into three, i.e., mirror surface deformation, deflection angle, and resonant frequency. We developed a simulation tool based on the MEMS mirror model that uses finite-element-method calculations. The tool enables us to precisely predict mirror surface deformation, deflection angle, and resonance frequency in a MEMS simulation. The simulation results are incorporated into the parameters and tolerance design of the MEMS mirror on the basis of quality engineering, resulting in a robust MEMS mirror.

To evaluate the reliability of the two-axis MEMS mirror, we conducted a reliability test under conditions equivalent to the AEC-Q101 electronic component automotive standard. The mirror passed the test.

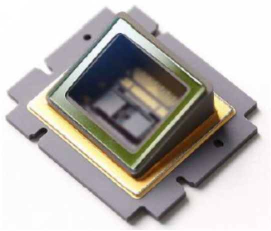


Fig. 7 Two-axis MEMS mirror.

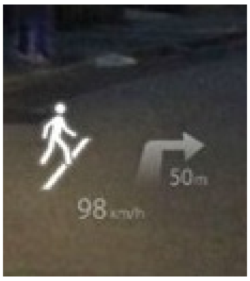
5. VALUE OF LASER HUD

We intend to use the laser HUD for an AR display linked with vehicle sensors. Figure 8 shows examples of AR displays that integrate information collected by vehicle sensors.

Automotive sensors, such as cameras, radars, and lidars, detect the vehicle's surroundings and its distance from objects. The HUD can display information processed from this data, such as (a) the distance to the vehicle in front. It can also display (b) proximity warnings of vehicles or (c) pedestrians in front of the vehicle.

(a) Distance to the vehicle in front

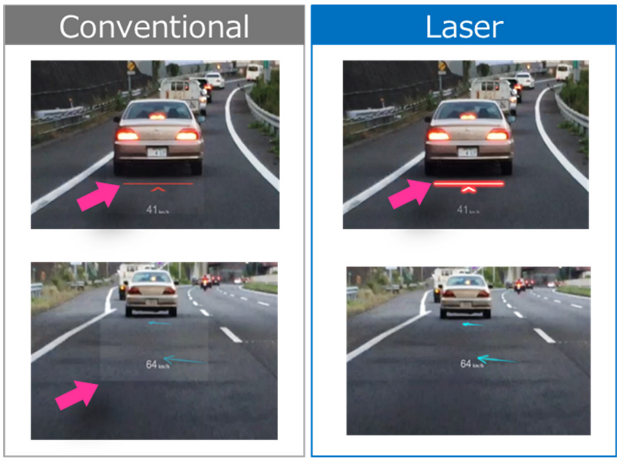
(b) Warning of vehicle in proximity



(c) Warning of pedestrian in proximity

Fig. 8 Example of AR display in vehicle.

Figure 9 shows the difference between the AR LCD with LED (a) and the laser scanning display (b). The laser scanning HUD uses bright red to draw the driver's attention and displays a seamless image with 3D expression. The postcard effect, which is caused by unnecessary light, can prevent the driver from clearly viewing the HUD display as 3D information. Thus, we have determined that the laser scanning HUD is the optimal method for AR linked with vehicle sensors.



(a) LCD with LED (b) Laser scanning

Fig. 9 Difference between AR LCD with LED and AR laser scanning.

6. CONCLUSION

Despite its advantages, laser HUDs typically suffer from image quality deterioration and low reliability. To address these issues, we developed a projection unit for an automotive HUD that is reliable and maintains high image quality. Our projection unit includes a proprietary screen and MEMS mirror technology which are key devices for laser HUDs. Laser HUDs effectively catch the driver's attention by using bright red and displaying a seamless image with 3D expression.

We intend to use laser HUD in an AR display linked with vehicle sensors to help drivers operate their vehicles more safely.

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