Development of Image Quality Simulation for Laser Scanning Projector using Microlens Screen

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ABSTRACT

Speckle can be reduced by using a scanning projector with microlens screen. However, the diffraction noises and the scanning-line-moire generated and degrades the image quality. To calculate these noises, the simulation was developed by integrating geometric and wave optics model. The simulation was validated by comparing with experimental result.

1 INTRODUCTION

Since laser display has many advantages of broader color gamut, compact device size, and low energy consumption, there are various applications for pico projector, head up display (HUD), head mount display (HMD). Especially, combining laser and scanning device can realize the high contrast with vivid color image. These features are suitable for HUD because it enables to call driver's attention more effectively comparing with TFT-HUD, because the images do not blend in to the background. Therefore, we develop laser scanning HUD as show in Fig.1. Due to the laser coherency and surface roughness in optical system, the image quality is degraded by speckle [1]. To solve this problem, a speckle suppression method using microlens as screen has been developed [2]. However, as shown in Fig. 2, there are some particular noise generated by scanning line, microstructure, and its diffraction pattern. Although the aspect of coherency and wave optics to image quality has been studied, there has been done little study to explore integrating the geometrical and wave optics for laser scanning display with microlens screen.

Therefore, we developed the simulation which capable to calculate the particular noises generated by scanning display with microlens. In this simulation, the intensity distribution on the retina of the observer is calculated by combining the geometric and wave optical model. The practical possibility of the simulation was validated by comparing with measurement result of virtual images observed by CCD camera.

2 SIMULATION METHOLOGY

To calculate the image noise, we characterized the intensity distribution on the retina: I_{Retina} as follows

$$I_{Retina} = I_{Geo}\, I_{Dif} \qquad (1)$$

where I_{Geo} is the intensity distribution of geometrical optical noise for the scanning line moire and

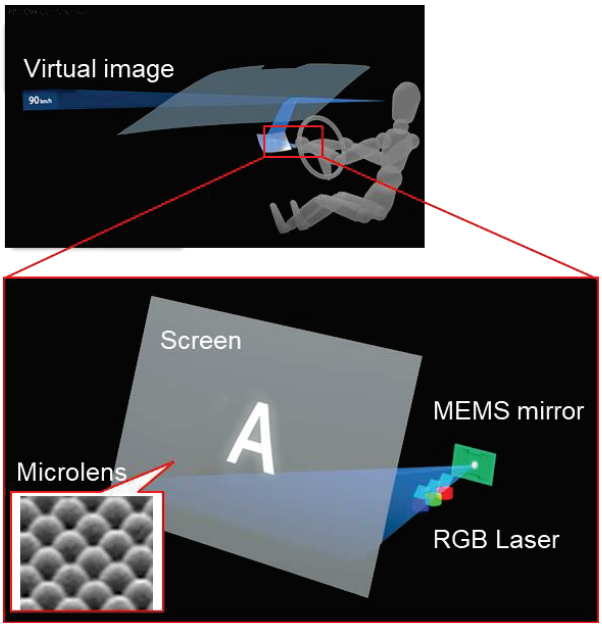

Fig. 1 Laser head up display system

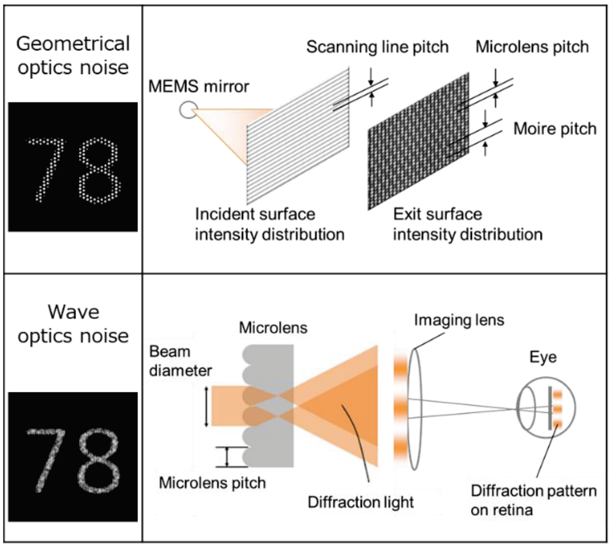

Fig. 2 Image quality of Laser HUD.

microstructure pattern, and I_{Dif} is the intensity distribution of wave optics noise for the diffraction pattern. To simplify the simulation, these two factors are normalized and multiplied. Fig.3 shows the simple example. In this figure, 0 means the point of dark area and 1 means the point of bright area. This figure shows when either one of points of I_{Geo} or I_{Dif} is 0, the points of light do not reach the retina. In other words, the intensity of final plane becomes 0. In the following, the geometrical optical noise and the wave optical noise will be explained separately.

2.1 Geometrical Optical Noise

There are two factors in the geometric optical noise in laser scanning display with microlens, one is image pixel size and the another is scanning-line-moire. Image pixel is equal to microlens size. In the aspect of geometrical optical noise, smaller microlens is better for reducing its noise because the angle of view per image pixel becomes small.

On the other hand, the scanning-line-moire is depended on some factors such as the beam spot diameter, microlens size, and scanning line pitch. As shown in Fig. 4, the scanning-line-moire become the periodic pattern caused by the pitch difference between the microlens structure and the scanning line.

In addition, the optical system of HUD and eye degrade the MTF characteristics and is visible as a blurred image on the retina. MTF is divided into geometric optical MTF and wave optical MTF. To simplify calculations, this simulation is performed by adding MTF characteristics that match the actual optical system.

2.2 Wave Optical Noise

The wave optical noise is mainly due to multi-beam diffraction when coherent beam area is larger than the microlens, as shown in Fig. 5.

The coherent time of the laser characteristics is extremely short compared to the time to scan at each lens. This means that the diffraction patterns generated by adjacent lenses can be regarded as independent. Therefore, the simulation model is divided two parts. The model first calculates each diffraction pattern generated by the adjacent lens. Then the wave optical noise is calculated by accumulating all the calculated diffraction patterns on the retina surface.

3 VALIDATION METHOD

We compared the simulation and experimental result to validate the simulation model using 2 types of screen formed by random diffusion sheet and microlens. The screens were mounted in a prototype of laser scanning HUD.

Fig.6 shows the optical measurement system. The CCD camera is mounted on eye position and observed the virtual image with 2 degrees angle. The pixel size is 3.45×3.45um and focal length of imaging lens is 50mm. The aperture is selected with D=1.2mm.

To evaluate the validation of simulation model, we calculate the speckle contrast as numerical output. The definition of speckle contrast: *S.C.* is as follows.

$$S.C. = \sigma / Ave. \quad (2)$$

σ is standard deviation of the image area and *Ave.* is average intensity of the image area.

$$\underset{I_{Geo}}{\begin{pmatrix}1&0&1&0\\0&1&0&1\\1&0&1&0\\0&1&0&1\end{pmatrix}} \times \underset{I_{Dif}}{\begin{pmatrix}0&0&1&1\\0&0&1&1\\1&1&0&0\\1&1&0&0\end{pmatrix}} = \underset{I_{Geo}\,I_{Dif}}{\begin{pmatrix}0&0&1&0\\0&0&0&1\\1&0&0&0\\0&1&0&0\end{pmatrix}}$$

Fig. 3 Concept of proposed simulation model.

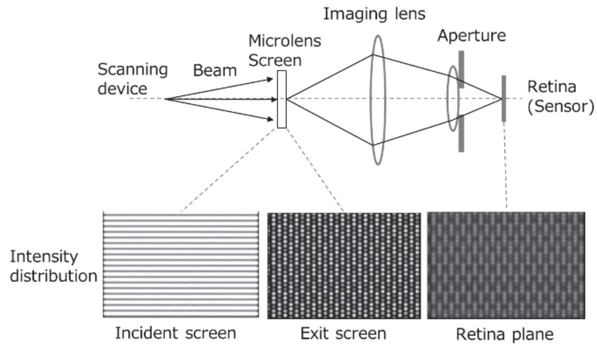

Fig. 4 Schematic diagram of geometric optics noise

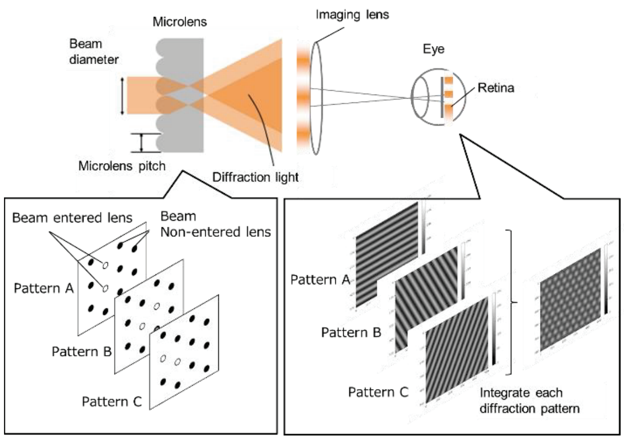

Fig. 5 Schematic diagram of wave optics noise

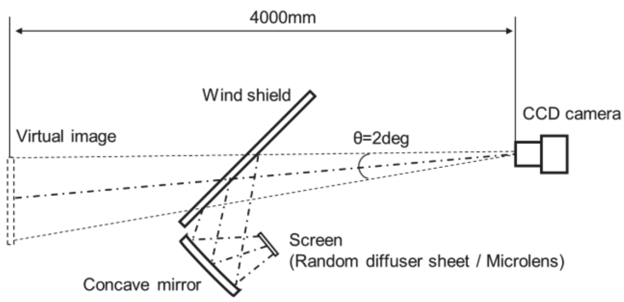

Fig. 6 Experimental schematic

4 VALIDATION RESULT

Fig. 7 shows images comparing with simulation and measurement results. The random diffuser screen caused random patterns by randomizing diffraction patterns and scan line moire. There are many elements within the beam spot size on random diffusion screen. This means that there is a large number of elements in the coherence region, and random interference lights are generated, which becomes speckle noise with high contrast.

On the other hand, the microlens screen generated the periodic patterns by integrating the periodic diffraction and scan line moire. There are only several elements within the beam spot size comparing to random diffuser screen. This means that there are small number of elements in the coherence region, and generated periodic interference lights are generated, which becomes periodic diffraction noise with low contrast.

Fig.8 shows the comparison of speckle contrast of simulation and measurement result. There is a deviation in the absolute value, however, the linearity is maintained relatively. It is possible to use the proposed simulation to identify the relationship between the screen structure and image quality in laser scanning HUD.

Fig.9 shows the relationship between design parameters and image quality type. In this study, we investigated the two type of screen. Random diffuser screen caused the random image with high contrast because the surface structure is random and there is large number of elements in coherent area. Microlens screen caused the periodic pattern with low contrast because the screen structure is the periodic structure with small number of elements in same coherent area. Since evaluation was performed under extreme condition, it will be necessary to investigate the intermediate characteristic in the future. Future works is to examine the improvement of image quality by changing parameters related to the random and periodic structure.

5 CONCLUSIONS

We developed a novel simulation method to calculate the image quality of laser scanning HUD using microlens screen. The proposed simulation calculates the intensity distribution of retina by combining the geometrical optical noise and wave optical noise. The simulation was validated by comparing with the measured virtual images observed with a CCD camera using two types of screen formed by random diffusion screen and microlens screen. This simulation can help identify the relationship between the screen structure and image quality in laser scanning projector systems.

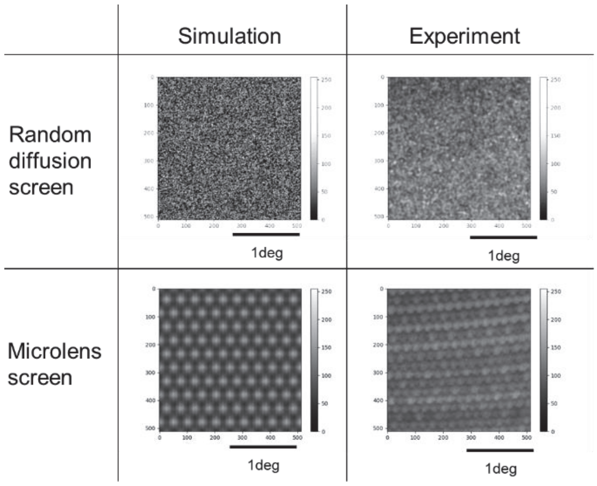

Fig. 7 Intensity distribution on retina surface with simulation and measurement image.

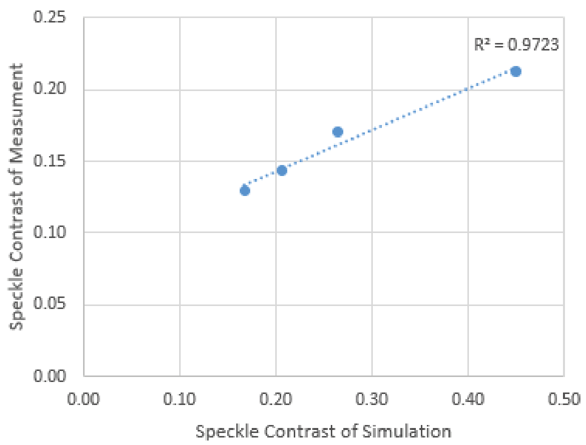

Fig. 8 Speckle contrast of simulation and measurement result.

		Random / Periodic structure		
		Random	Intermediate	Periodic
Number of elements	N>>1	✓	▲	▲
	N~1	▲	▲	✓
	N<1	–	–	–

✓ : Investigated, ▲: Not investigated, – : No diffraction

Fig. 9 Relationship between design parameters and image quality type.

6 REFERRENCES

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