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Laser speckle reduction via rotating diffuser in LCOS projection display

Hong Liu [1, a], Weisheng Wang [1,b], Bailin Na [1,c], Weidong Liu [2,d]

[1]School of Information Science & Technology, East China Normal University, Shanghai, 200062, China

[2]Module, Hisense R & D Center, Qingdao, 266071, China

[a]Liuhong0520163@163.com, [b]wangweisheng@hotmail.com, [c]52091202024@ecnu.cn

[d]liuweidong@ac.hisense.com

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Abstract. Through theoretical analysis the reasons of generating laser speckle, we use an optical scheme for reducing composite speckle in the three LCOS laser projection system. The project of rotating diffuser has a simple optical structure and can be easily implemented. Finally, experimental verification of rotating diffuser plate can effectively suppress laser speckle contrast.

Introduction

Nowadays, display technology develops quickly and the development of a portable projector is currently one of the main goals in projection display. And Liquid-crystal-on-silicon (LCOS or LCoS) belongs to a new type of reflective LCD projection technology. LCOS as a "micro-projection" or "micro-display" technology typically is applied in projection display. The Laser-LCOS projector can work well and has many advantages such as large field of view, uniform irradiance, long working distance and so on. In comparison to standard projection lamps, LCOS projection displays utilizing laser light sources are expected for becoming next-generation displays.

In the previous work, we have accomplished the optical configuration design of Laser-LCOS display with three-LCOS panels and three-primary-color lasers as illuminant, respectively, as shown in Fig. 1. In order to obtain an excellent image quality we have used the best way to optimize the optical engine and strictly control color, distortion and heat influence. Although we can obtain the image, the observer has been disturbed by some spots, which cause significant image quality degradation. Through testing the first LCOS- laser projection specimen, we find the spots are speckle noise. The high coherency of laser light (a near-Gaussian pattern) and the auxiliary surfaces, produce speckle noise, which is an intrinsic problem and the most significant problem of laser display system. Thus, there is a strong demand for effective and practical speckle reduction methods. Analysis of speckle reduction is an inevitable part of optimal design. In recent years, reduction speckle effect of semiconductor laser diode has stimulated great interest in laser display systems. Several appropriate solutions to decrease the speckle contrast have been proposed [3-8]. The different methods of reducing speckle averaging: destroying time coherence (wideband sources) or destroying spatial coherence by using angle diversity with relation beams coming from different angles (or by vibrating screen) or polarization diversity. Among the moving screen method is considered to be an effective speckle reduction technique. In the moving screen method they use a moving screen, which consists of two diffusers, one of them is moving diffuser, and the other is fixed diffuser. In a short period of time it can generate various speckle patterns for the moving diffuser. Applying temporal effect of the human eye, the observers cannot recognize rapidly changing patterns, and perceive the image as if there were no speckles. However, although the moving screen method can effectively reduce speckle noise, it is difficult to incorporate into universal spread, because moving diffuser as large as the projection screen is too difficult to produce and remove [4]. In this paper, we will describe the results of an analysis of composite speckle, and its effect on speckle reduction in LCOS-laser projection system. Finally, we use an optical scheme for reducing composite speckle in the three LCOS laser projection system.

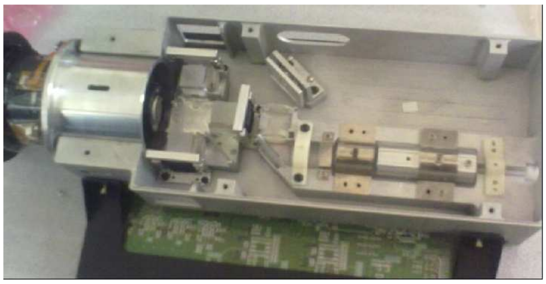

Fig. 1 The first optical specimen of the laser LCOS projector

Speckle patterns of the LCOS projection system

In laser projector displays, we used speckle contrast ratio (CR) [1-2], which has been widely used in this field. The speckle contrast represents the range of speckle intensities in a measured area compared to the average intensity of the area. The speckle contrast ratio is defined as follows:

$$C = \frac{\sigma_1}{\langle I \rangle} = \frac{\sqrt{\langle I^2 \rangle - \langle I \rangle^2}}{\langle I \rangle} \quad (1)$$

where $\langle I \rangle$ and σ_1, respectively, are the mean value and standard deviation of the light intensity in the speckle pattern and $\langle I^2 \rangle$ is the mean value of the squared light intensity. The speckle contrast must be kept as small as possible. A smaller speckle contrast means that the illumination over the measured area is more uniform and that speckle noise is more effectively reduced.

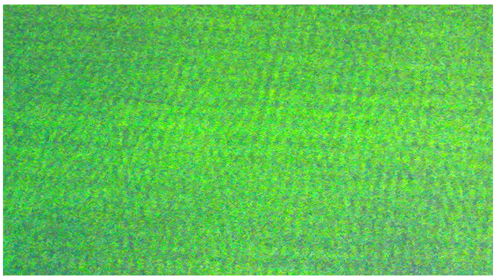

Fig. 2.Speckle pattern of the laser LCOS projector

It is known that a speckle pattern depends on the interference conditions of the laser light. By considering speckle patterns, as show in Fig. 2, we analyze the optical configuration of the LCOS-laser projection system, which will affect the formation of speckles and enable us to identify important factors for speckle reduction. Speckles are interference patterns resulting from laser light scattering on diffusive media. When the screen is very smooth, the very big speckle spots disappeared and the small speckle spots remained. This indicates that the big speckle spots are caused by interference at the screen and the small speckle spots are generated in the laser projection optical system. These two kinds of speckles consist of composite speckle.

An optical scheme for reducing composite speckle

In order to obtain a high-quality with low speckle CR as if speckles were not recognized on the screen, we focused on studying the composite speckle. We know that the small speckles are generated by the system, while big and coarse speckles are generated at the screen itself. So the optical configuration is one of an important factor in speckle occurrence. This means that seeking a fine speckle reduction method inside the projection system is a key. To solve this problem, an optical scheme for reducing speckles in laser display system by using a specific small-size rotating diffuser, as shown in Fig.3, has been proposed. In such a system, laser light is diffused by the small angle ($0.5^0 \sim 1^0$) and small size moving diffuser plate before passing through beam expand. Because the laser light reaching the screen has already been diffused by the small rotating diffuser, which is driven by piezoelectric motor, the results are expected to be the same as in the moving screen method. The project has a simple optical structure and can be easily implemented.

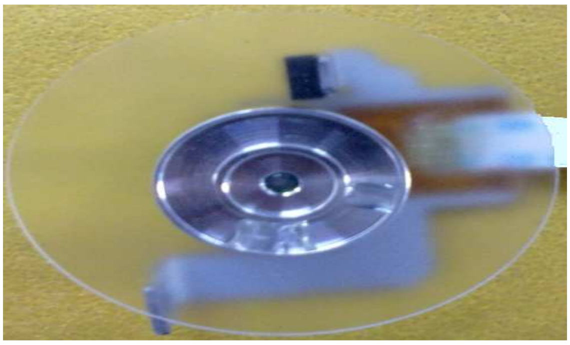

Fig. 3 The rotating diffuse plate

Conclusions

To study the speckle reduction effect on the projection system, we set up the experimental platform, as show in fig. 4. And in the experiments we will investigate and verify of speckle reduction in order to successfully obtain a high-quality image with low speckle CR. A CCD with a pixel size was used as a camera. The distance between the camera and the screen was 3~5 m, the speckle can be reduced by the moving small diffuser and allowed speckle contrasts to be evaluated under equal conditions. A lot of images were saved in the computer are the speckle patterns obtained when the CCD camera was defocused from the screen. We measured speckle noise in terms of diffusion rotating speed of the small diffuser. Under the measurement conditions, the speckle contrast is obtained by the program written by Matlab. From the computer output date, we find the CR is become smaller with the moving diffuser increasing speed, but CR has saturation at a speed of rotating diffuser. From these experimental results, we conclude the moving diffuser can improve of image quality. Namely, speckle reduction by this method is effective.

We can say that the universal spread of laser displays depends on the speckle reduction. Now, the LCOS-laser projection can work well with more beautiful and reasonable appearance for we success in applying the moving diffuser. It can perform a good performance for light efficiency and uniform irradiance.

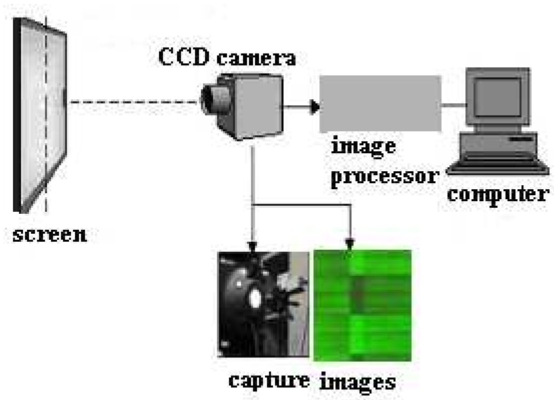

Fig. 4 Schematic setup for speckle measurement

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