Color speckle measurement in laser display

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Abstract. In recent years, with the continuous development of laser projection display technology, people's choice of electronic display equipment has become more diversified. However, due to the high coherence of the laser used for imaging in the laser projection display device, the speckle phenomenon is more obvious than other display devices, which will greatly affect the user's actual perception. A color speckle measurement device based on XYZ filter is designed. The computer software is used to control the camera to take speckle pictures under different filters, and calculate the speckle contrast of red, green, blue and white fields.

1. Introduction

The related work of color speckle measurement in laser display is less at China and abroad. At present, a small number of groups doing laser display are doing speckle measurement and research in China. They used an CCD camera to capture laser speckle, then processed the image, and finally calculated the speckle contrast. There is no automatic and systematic measurement method. The more perfect device for measuring laser speckle known abroad is a machine named Doctor-Speckle from Japan Oxide company. It can measure monochromatic speckle of RGB three colors and get the value of speckle contrast by software.

In recent years, the laser display industry has developed rapidly. For example, the laser TV, which has caught fire in recent years, is a new product in the laser display industry. For laser display equipment speckle measurement, different equipment, different display screen, various parameters will affect the speckle measurement, which brings a lot of difficulties to people who want to accurately measure speckle. Therefore, it is necessary to design a scientific and accurate speckle measurement method [1].

This paper introduces the principle of speckle produced by correlated light source. Speckle is an inherent phenomenon of laser source. At present, there is no effective method to eliminate and reduce speckle in the related technology at home and abroad. In this paper, the phenomenon of laser speckle is studied. The laser speckle is measured with rigorous and scientific methods [2], and the key parameters affecting the degree of speckle are explored.

Laser display equipment will produce speckle phenomenon that cannot be eliminated [3]. Due to the high coherence and monochromaticity of the laser light source, when the laser projection equipment emits the light source, the superposition of multiple light sources will produce interference phenomenon. According to Huygens principle, when the laser projection display equipment irradiates the screen surface, because the surface microstructure of the screen is rough, when the relevant light
source irradiates these rough surfaces, the rough surfaces can be regarded as irregular reflecting surfaces, and these points will reflect and transmit the light source. The reflected light will interfere with each other due to different phases. These large amount of interference light forms the irregular distribution of composite speckle. The speckle distribution of the laser projection equipment is shown in Figure 1.

![Figure 1. Speckle phenomenon of industrial camera](image)

When a smooth Fresnel screen is placed in front of the laser projector, the speckle on the screen can be observed by turning on the laser projector. The manifestation of speckle is related to the physical structure of the screen surface and the coherence of laser equipment.

The speckle phenomenon associated with laser display will reduce the image quality and resolution, easily cause visual fatigue and discomfort for a long time. For many years, people mistakenly believe that speckle is a phenomenon formed on the display screen. But in fact, this idea is wrong. The correct speckle is actually interfered by the laser beam reflected from the screen. The roughness of the screen also has a great influence on the speckle. The speckle pattern seen by human eyes is a laser interference pattern suspended on the screen surface. In principle, the speckle pattern can be obtained directly with a 2D image sensor.

2. Measuring device and steps

2.1. Brief introduction of measuring device and measuring principle

The speckle measurement device of laser projection equipment is mainly divided into hardware and software. The software part can control the shooting of the industrial camera and the rotation of the steering gear, so that the photos taken by the camera can be processed, and the speckle contrast of the color speckle can be calculated. The hardware part includes the industrial camera and the steering gear which controls the rotation of the filter disk. The speckle measurement device of laser display projection equipment is shown in Figure 2.

![Figure 2. Hardware external diagram of measuring device](image)

In the international standard laser display devices Part - 5-4: optical measuring methods of colour speckles, two methods for speckle measurement are mentioned. One is the speckle measurement method of laser display equipment with XYZ filter, the other is the speckle measurement method with RGB trichromatic filter. This device adopts the method of measuring more accurate XYZ filter. The basic schematic diagram is shown in Figure 3.
The measurement of laser speckle with XYZ filter is more accurate than that with RGB trichromatic filter and spectral equipment. The two peaks of X-ray filter are difficult to ensure the accuracy of spectral transmission, so XB and XR filters are used.

2.2. Measurement steps and required conditions of the device

The measurement step of the device is that the camera in the device sets the exposure time and focuses, and takes four kinds of speckle photos under the filter, then the computer software intercepts some pixels of these photos for screening and calculation, and finally obtains the speckle contrast of the laser projection equipment. The measurement flow chart is shown in Figure 4.

![Figure 4. Measurement flow chart](image)

In order to capture the speckle pattern with the camera, the pixels of the industrial camera must be larger than the pixels of the speckle pattern. This is because the size of the speckle is always smaller than the size of the pixels displayed on the screen. In order to ensure the accuracy of speckle measurement, more than ten times of the pixel magnification is necessary. This is a 20 megapixel industrial camera model MV-CE200-10UC, which can clearly capture the speckle on the screen. The steering gear used in the device is a magnetic encoding RS485 brushless high life intelligent servo motor controlled by PLC and Modbus RTU protocol. The steering gear is controlled by a urt-1 control board connected with USB cable to the computer. In order to ensure the accuracy of speckle measurement, in addition to turning off the relevant light source at night, a simple darkroom is also built. The illumination produced by the background light in the dark room is less than 0.1 LX. It belongs to a more qualified darkroom environment.

2.3. Calculation of speckle contrast

For an image with obvious speckle, the formula of monochromatic speckle contrast $C_s$ can be as follows:

$$C_s = \frac{\sigma}{I}$$  \hspace{1cm} (1)

Among $\sigma$ is the standard deviation of speckle pattern intensity, and $I$ is the average intensity of speckle pattern. In the measurement and calculation of laser display speckle, the monochromatic speckle contrast of RGB three colors can be calculated by this formula, but when measuring the speckle contrast of white field, the calculation formula of color speckle contrast $C_{cs}$ should be used:
\[ C_{cs} = \frac{\sigma}{\langle Y \rangle} \]  

Where \( \langle Y \rangle \) is the average value of the photometric distribution.

### 3. Experimental results and analysis

#### 3.1. Effect of Different Focusing Schemes on Speckle Measurement

After a large number of measurements and consulting relevant papers and standards, it is found that the calculated speckle contrast will also change without changing the device and laser projection display equipment.

In the speckle measurement, we also find that there are two focusing schemes in the focusing process of the camera. One is to focus the outline of the font projected on the screen clearly, and the font on the screen can be seen clearly through the camera. Another method is not to focus the font in camera shooting, but to focus the speckle pattern in the captured image. At this time, the image captured by the camera shows a clear speckle pattern. Although the difference between the two focusing amplitudes cannot be distinguished by naked eyes, it will have a greater impact on the measurement results of speckle contrast.

Two different focusing modes have a great influence on the calculation of speckle contrast. For the two different focusing schemes, the following steps are made. First, the display equipment of incoherent light source is used to focus to display clear font, and then the uncorrelated light source is replaced with the relevant light source display device of laser. At this time, the measurement is aimed at the speckle contrast of the screen focusing. When focusing measurement is made for speckle, the relevant light source is used to focus directly until the screen has clear pattern of speckle.

The speckle contrast of the two focusing states is measured in the respective color field, and the results are recorded in Table 1. It can be seen that the speckle contrast obtained by focusing the speckle is larger than the speckle contrast measured by focusing the screen, which is because the speckle focusing camera can capture clear speckle patterns, which results in the calculated speckle contrast value being too large.

| Table 1. Speckle contrast in two focusing modes |
|-----------------|-----|-----|-----|-----|
|                 | R   | G   | B   | W   |
| Screen          | 19.07% | 14.89% | 12.96% | 10.95% |
| Speckle         | 23.12% | 16.54% | 14.11% | 11.84% |

#### 3.2. Influence of different focusing schemes on speckle measurement

For measuring the color speckle at different positions of the measuring screen, the center of the screen is selected, and the speckle contrast of the four fields, red, green, blue and white, is measured at the lower left and right positions. The data in Table 2 are obtained. The measurement uses a pure laser light source display device, which maintains the distance and exposure time of each color field during the measurement process, and makes several sets of measurements. The measurements show that the speckle contrast varies between different color fields and different positions of the screen. As can be seen from the table, due to the projection characteristics of the laser display device, the brightness of the center of the screen is the highest, followed by the brightness of the left and right sides, and the decrease in brightness results in a decrease in speckle contrast. It can be inferred that the color speckle contrast is related to the brightness of the laser projection device. The bright area at the center of the screen has a greater speckle contrast than the left and right areas of the screen. This also corresponds to the uneven projection brightness of the laser display device. That is, the center is bright and the surroundings are dark.
Table 2. Speckle contrast at different screen positions

| Speckle contrast | Central position | Lower left position | Lower right position |
|------------------|------------------|--------------------|---------------------|
| R                | 19.38%           | 16.77%             | 15.46%              |
| G                | 13.65%           | 8.51%              | 7.56%               |
| B                | 15.60%           | 10.42%             | 9.60%               |
| W                | 9.54%            | 6.85%              | 5.72%               |

Next, different measuring distances are selected for multiple groups of measurements, and the measuring distances of 1m, 1.2m, 1.5m, 2m and 2.5m are selected. Each time, the measuring device is always aligned with the center of the screen, and other conditions remain unchanged. Multiple measurements are carried out and the line chart is drawn, as shown in Figure 5.

![Figure 5. Speckle contrast at different measurement distances](image)

As can be seen from the data comparison in Figure 5, with the further development of the measuring device, the speckle contrast becomes smaller. This is because with the increase of the distance, the clarity of the speckle pattern captured by the camera will become smaller in a certain proportion, which directly leads to the decrease of the color speckle contrast. It is concluded that the contrast of color speckle is inversely proportional to the measurement distance. When the measurement distance is set at 1.2m, the industrial camera can capture the clear speckle pattern, and the stray light of the projection equipment does not interfere with the measurement device.

There are many factors that affect the speckle measurement. In this measurement, several key conditions are repeatedly measured, and other external conditions are in the same state in each measurement. In order to simulate the speckle observed by human eyes, the exposure time of the industrial camera used to photograph speckle is related to human eyes. This setting method based on human vision makes the speckle contrast consistent with the subjective speckle perception observed by human eyes. Through the above measurement data, standardized measurement of speckle contrast.

### 4. Conclusion

Speckle suppression is an insurmountable mountain for the laser display industry. Compared with measuring speckle, the laser display industry at home and abroad wants more technology to eliminate or weaken speckle. For the domestic laser display industry, we can also explore the speckle reduction effect of different kinds of screens from the display screen.

In this paper, a laser display measuring device is used to measure the speckle contrast of the speckle image. The key factors affecting speckle contrast are studied by changing the measurement conditions [4]. Although the speckle contrast has a certain dependence on many measurement parameters, and it is difficult to ensure the consistency of the speckle contrast measured under different conditions, through a large number of repeated measurements, the uncertain factors are minimized. Using this method to measure speckle will make the measured data more comparative and meaningful [5].
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