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Speckle Characterization in Laser Projector Display

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***Abstract*—**Speckle phenomena results from when coherent radiation is reflected from a rough surface. Characterizing the speckle strongly depends on the measurement condition and experimental setup. In this paper we report the experimental results produced with different parameters in the setup. We investigated the factors which affects the speckle contrast, such as, F-number, gamma value and exposure time of the camera, rather than geometric factors like the distance between the projector lens to the screen, the viewing distance, etc. The measurement results show that the speckle contrast decreases by decreasing F-number, by increasing gamma value, and slightly affects by exposure time of the camera and the gain value of the camera.

***Keywords*—**Characterization, laser projector, speckle

I. Introduction

MOST of today's projectors use short arc lamps (Mercury or Xenon) as light source. Laser sources have longer lifetimes than the lamps, which reduces costly lamp replacement. Laser beams are well collimated due to its smaller étendue, which improves the compactness, efficiency, and cost of optical engine.

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A laser projector can also reach a larger color gamut due to the line spectral width of the laser light source. However, the high cost of the laser source and speckle introduced by the coherence of the laser beam limit the commercialization of laser projection [1].

Considerable effort has been made to suppress speckle [2]-[5]. The investigations have based on the evaluation of speckle contrast. Many methods for speckle measurement were developed for an observer in the near field of an illuminated pixel [6]-[7]. However, the speckle contrast measured could be completely different with a different camera, which depends on the actual observation conditions, such as camera position, lens aperture size, CCD sensor resolution, the background illumination of the room, etc. Lee et. al. [8] measured the factors which affect the sensitivity of human perception on the speckle, such as, luminance, viewing distance and image content. The study mainly used the subjective evaluation for human perception on the speckle. Although the ICDM (International Committee for Display Metrology) Information Display Measurement Standard stressed how to measure and characterize laser display [9], there is no standard for how to characterize the speckle in laser display so far. In this paper, we will report how the experimental setup affects the speckle contrast measurement.

II. Experimental setup

The experimental setup for speckle characterization is illustrated in Fig.1. The solid-state laser (532nm) is used as light source. The polarizer (Edmund, 42×0.75mm MTD) is used to control the light intensity. The laser light via the beam expender propagates onto a diffuser which is used as the screen in the setup. The 50mm camera lens (Pentax, C5028-M) with variable F-number in the range from F/2.8 to F/22 was mounted on the camera. The illuminated surface on the screen is imaged onto the CCD chip of the digital camera (Texas Instruments DMK-21BU04). The CCD resolution is 640×480 pixels and

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allows acquisition response times up to 30s without vibrations, and each detector pixel has a dimension of $5.6\mu m \times 5.6\mu m$. A diffuser is used as a screen. For accurate measurements, the speckle image is obtained by subtracting the background image estimated with morphological opening from the original speckle image.

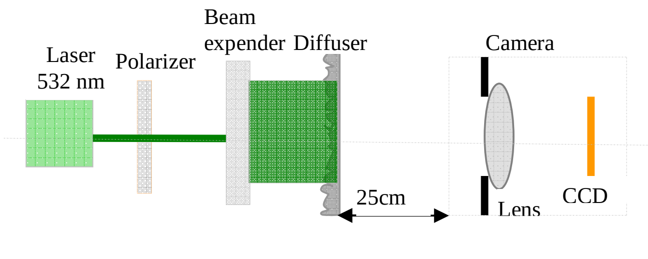

Fig. 1 Experimental setup

III. Basic Characteristics of Laser Speckle

Laser Projector Display quantifies the extent of a localized spatial blurring by calculating a quantity called local speckle contrast ratio that is defined as the ratio of the standard derivation σ_s to the mean intensity $\langle I \rangle$ of light in a small region of the speckle image [10].

$$C = \frac{\sigma_s}{\langle I \rangle} \quad (1)$$

In practice, to have statistical accuracy speckle contrast ratio in every 7×7 pixel sub-region of the image is firstly computed. The speckle contrast ratio of the image is then given as the following equation:

$$C = \frac{1}{MN}\sum_{i=1}^{M}\sum_{j=1}^{N}\frac{\sigma(i,j)}{I_{ave}(i,j)} \quad (2)$$

where i and j are integers, M = 128 and N = 96 for our experimental setup, $\sigma(i,j)$ and $I_{ave}(i,j)$ denote the standard deviation and average of intensity at the (i,j) sub-region of the speckle image.

To minimize the error of the measured speckle contrasts, speckle grain needs to be mapped onto an area slightly larger than two pixels on the CCD which satisfies the Nyquist criterion. For image speckle, the minimum speckle size, which defines the limitation of the measurement setup, is given by [11]:

$$S_{speckle} = 1.22(M+1)\lambda F \quad (3)$$

where λ is the laser wavelength, F is the F-number of camera lens (the focal length f divided by the "effective" aperture diameter a), and M is the magnification of the camera.

Therefore, creating large speckles can be an issue by requiring a small aperture, which limits the amount of light reaching the detector.

IV. Experimental Results and Discussion

A. Effects of gamma value of camera on speckle characterization

For the fixed F# = 16 in the setup, different gamma values from 0.8 to 3 have been used to make the speckle measurements. In order to reduce the effect of ambient light, all the measurements were carried out in the dark room. The image was a fully developed speckle pattern on a perfect depolarized screen, which will produce the speckle contrast ratio of 70%. The results are presented in fig.2.

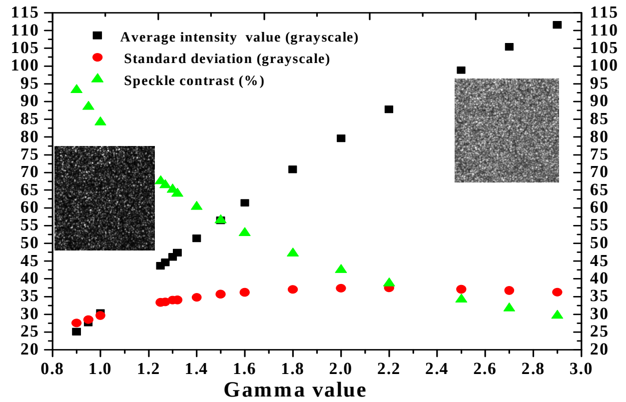

Fig. 2 Speckle contrasts for different Gamma values of camera

From the fig.2, we can see that the gamma value has strong effect on the mean value of the image intensity. Increased gamma value results in a larger mean value of the image intensity and brighter image as shown in the insert picture. The standard deviation of the image intensity is less affected by changing the gamma value. The measured speckle contrast ratio is rapidly reduced with increasing the gamma value. 70% speckle contrast has been measured as 27% to 95%.

B. Effects of gain value of camera on speckle characterization

In our experiment, the intensity of speckle patterns increase by increasing gain value of camera, and camera noise levels become more prominent when the gain level becomes higher. The maximum or minimum gain value should be consistent with the dynamic range of the camera. So choosing the appropriate gain becomes more important for speckle measurements. If gain is too small, the captured image would not take full advantage of the dynamic range (Fig.3(a); if gain is too large, the image would reach saturation (Fig.3(c)).

In both cases the calculation of average intensity would be distorted. Experimentally, we find that the optimal mean intensity is about 15% of the saturation level, corresponding to 38 counts for an 8-bit camera (Fig.3(b)). Lower mean count values yield an appreciably poorer signal-to-noise ratio, while higher values cause a significant fraction of the CCD pixels to saturate. Proper lens aperture and exposure time adjustments are required to reduce the gain level (i.e. opening lens aperture more and extending exposure time longer, etc.). The changing gain has little effect on the speckle contrast, as shown fig.4.

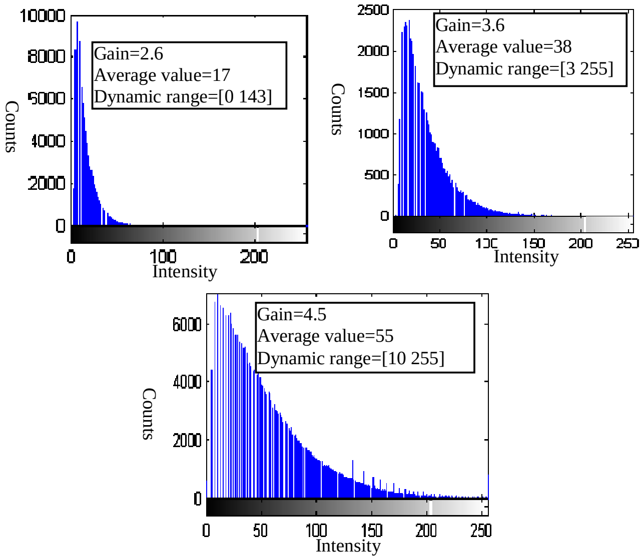

Fig. 3 The intensity distribution over the camera pixels for low (a), optimal (b), and saturated (c) signals

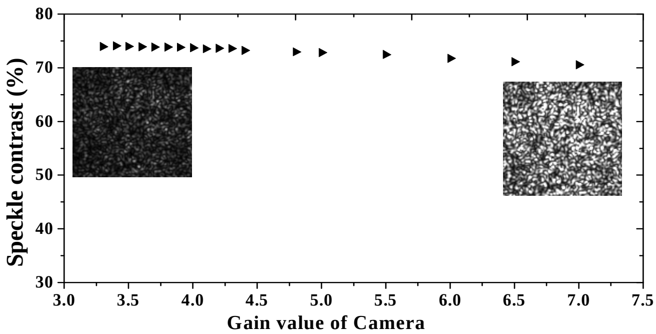

Fig. 4 Speckle contrasts for different gain values of camera

C. Effects of F-number of camera lens on the speckle characterization

Under the same setup condition, speckles were measured with different F# of Camera lens. Since the change of the F#, the speckle size on the CCD screen will be changed, which leads to the change of the ratio of the speckle size to the pixel size of CCD screen.

Setting magnification of camera lens as 0.25, gamma value as 1.35, exposure time as 1/30s, measured speckle patterns are shown in Fig.5. The speckle size calculated by the equation 3 can be determined as given in fig.6, which varies from 2/5 of a pixel for F#=2.8 to 4 pixels for F#=22. Fig.7 shows the measured speckle contrast ratio. When the measurement setup is with camera lens of smaller F#, the speckle size on the CCD will be smaller than the pixel size of CCD, shown in fig.5 (a), reduced speckle contrast ratio is due to the intensity average of the speckle grains on the single pixel. As the F# of the camera lens increases, the speckle size becomes larger than the pixel size, there thus is no spatial integration of the speckle grains over a pixel area, the measured speckle contrast ratio saturates at about 70% which is the speckle contrast ratio for a fully developed speckle on a perfect depolarized screen. These results in the behavior show fair agreement with those measured by Peter Janssens [12].

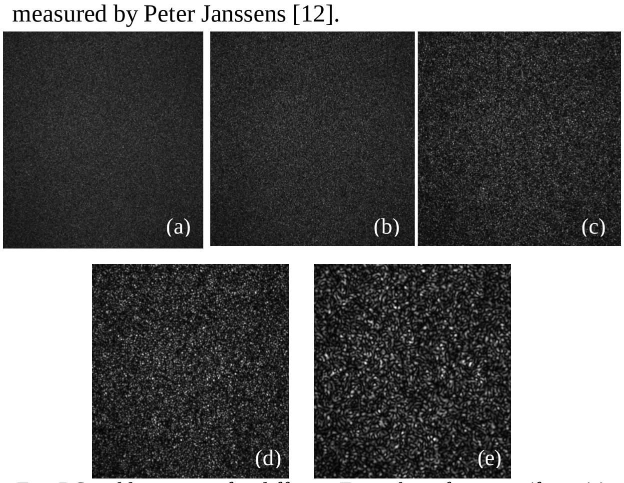

Fig. 5 Speckle patterns for different F-number of camera (from (a) to (e): F/2.8, F/4, F/8, F/16, F/22)

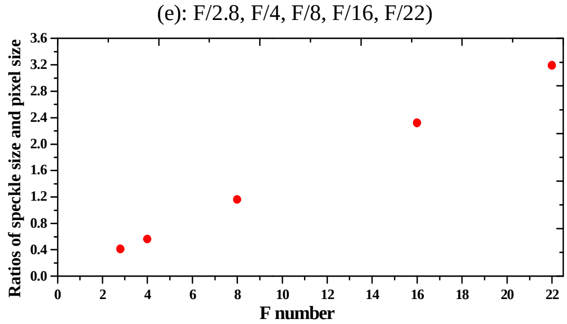

Fig. 6 Ratios of speckle size and pixel size versus F/# of camera

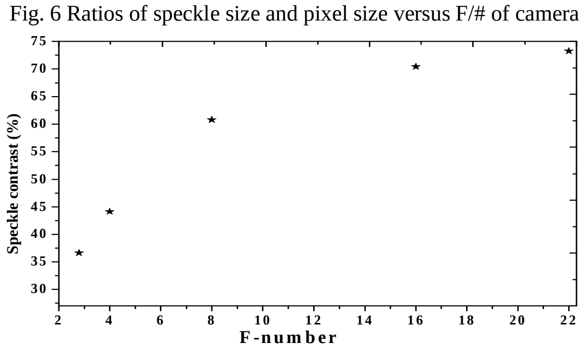

Fig. 7 Speckle contrast for different F/# of camera

D. Effects of the exposure time of camera on the speckle characterization

When use a CCD camera, the speckle is always measured using an exposure time. In our measurements, F# =16, gamma value = 1.35. We have made two measurement procedures. First we keep the intensity of the image on the screen as a constant; speckle image was recorded using different exposure time. The results are presented in fig.8 (a). Second, we adjusted the intensity of the image on the screen to keep the mean intensity of measured speckle image as a constant under all exposure times. Fig.8 (b) shows the results when exposure times T from 1/108 to 1/18s were used.

Those two measured results indicate that the speckle contrast values for the shorter exposure times are slightly greater that those of longer exposure time. When changing exposure time T from 1/108s to 1/18s, the former average intensity value increases and the speckle structures are more apparent as shown in the inset of fig.8 (a). Those phenomena in the latter do not appear.

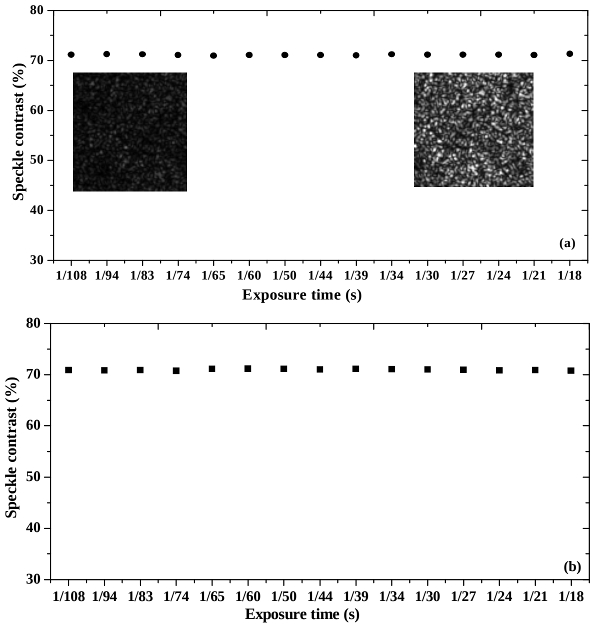

Fig. 8 Speckle contrast and mean intensity versus different timed exposure

(a) To keep the intensity of the image on the screen as a constant.

(b) To keep the mean intensity of measured speckle image as a constant by adjusting the intensity of the image on the screen.

V. Conclusions

In this paper, we mainly analyze the effect of the parameters of the camera (F-number, gamma value, gain, and exposure time) on the measured speckle contrast ratio. The measured speckle contrast is strongly affected by the first two parameters compared with other parameters.

It is clear that all these properties have to be fixed in order to properly characterize the speckle in laser display.

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