Error Analysis of Sparkle Contrast by Image Subtraction Method

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ABSTRACT

Measurement error of sparkle contrast was investigated by using Image Subtraction Method. The statistical error was suppressed enough when the sampling points were around 100×100 pixels. The parameter as an indicator of both statistical error by insufficient sampling pixels and low- frequency luminance variation within the sampling field was proposed.

1. INTRODUCTION

Sparkle effect derived from anti-glare layer on the flat-panel displays are well known, and several measurement methods have been proposed to characterize this phenomenon [1], [2]. Regarding the measurement apparatus, imaging lens and 2D sensor array is generally used because the sparkle structure is observed as spatially modulated image on the retina, which is the result of imaging the color filter structure through the anti-glare layer (like random micro-lens array). As a parameter to characterize the sparkle level, sparkle contrast S_P is defined as follows;

$$S_P = \frac{\sigma}{\bar{I}} \tag{1}$$

where σ is a luminance standard deviation, $\bar{I}$ is an average of sparkle pattern.

Sparkle contrast is dependent on various parameters. It was investigated theoretically and experimentally so far to clarify the influence of each parameter, such as measurement geometries (measurement distance, viewing direction etc.), imaging conditions (focal length, F-number etc.) and the pitch of the sensor array [3], [4], [5]. At the same time, there are several sources of "possible error" regarding the sparkle contrast measurement, such as focusing, low frequency luminance variation, and the number of sampling points for the calculation of sparkle contrast. As for the sufficient sampling points for the sparkle contrast calculation, there has not been enough information from the experimental viewpoint, because multiple sources of error might be overlapped at once. In this report, "image subtraction method" was proposed to separate the error from insufficient sampling points and low frequency luminance variation.

2. Method

2.1. Image Subtraction Method

Assume that two different sparkle patterns with the same size (N×N) are extracted from the different location of a single sparkle pattern, as shown in Fig. 1.

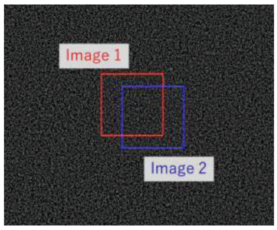


Fig.1. An example of images of sparkle pattern used for subtraction process.

The subtraction operations of luminance at all address (i = 0 to N, j= 0 to N)) are conducted as shown in Fig.2.

$$L_{sub}(x_i, y_j) = L_{image1}(x_i, y_j) - L_{image2}(x_i, y_j)$$

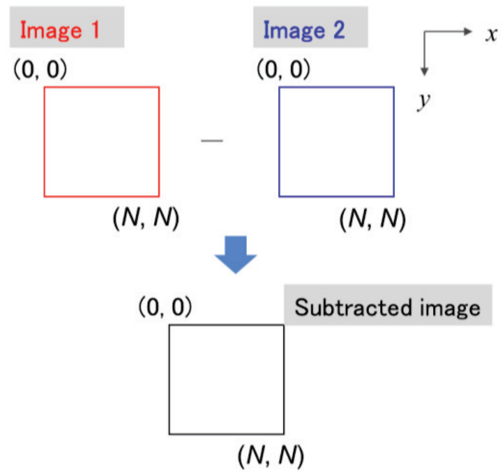


Fig.2. Image Subtraction Method

$L_{image1}(x_i, y_j)$ and $L_{image2}(x_i, y_j)$ are luminance at the address (i, j) of the image1 and the image 2. $L_{sub}(x_i, y_j)$ is subtracted value at the address (i, j). Subtracted image has standard deviation σ_{sub}. If both the image 1 and the image 2 does not have local luminance variation except for sparkle pattern, σ_{sub} can be expressed as formula (2),

$$\sigma_{sub} = \sqrt{\sigma_1^2 + \sigma_2^2} = \sqrt{2}\sigma_1 \tag{2}$$

This estimation is based on the conditions below;

1) Each sparkle pattern of both image 1 and image 2 are statistically random and independent,
2) In each local area of the image, the local average luminance is same,
3) The number of sampling points (i.e. the number of detector elements to calculate the sparkle contrast) is enough to reduce statistical error.

Regarding the condition 1), the theory to calculate the average sparkle grain size is useful to estimate the minimum requirement of the displacement of each image. The average sparkle size R is represented by the formula (3),

$$R = \frac{4}{\pi} F\#_{\text{image}} \lambda \quad (3)$$

where, $F\#_{\text{image}}$ is effective F-number of the imaging lens, λ is wavelength. R is defined as the FWHM of the auto-covariance function of the sparkle pattern. Therefore, almost 3R of the distance between each extracted image would be enough to regard both extracted images as independent. For the condition 2), the method to suppress the local luminance variation can be used [6]. Or, when such calibration is not applied, the deviation from the factor $\sqrt{2}$ in the formula (2) would occur. As for the condition 3), if the relative ratio of σ_2 to σ_1 is introduced as a statistical sampling factor α, the formula (2) would be changed as,

$$\sigma_{\text{sub}} = \sqrt{\sigma_1^2 + (\alpha\sigma_1)^2} = \sqrt{1+\alpha^2}\,\sigma_1 \quad (4)$$

α is non-linear function and it would vary according to the imaging conditions and sampling points. α falls to 1 when the number of the sampling points is sufficiently large. It is necessary to check experimentally how $\sqrt{1+\alpha^2}$, i.e. $\sigma_{\text{sub}} / \sigma_1$, actually varies with the number of sampling points.

2.2. Difference Image Method

When the anti-glare layer can be relatively shifted against the display matrix, “Difference Image Method” [7] can be also applied to investigate the factor α. Two different sparkle patterns which have similar standard deviation and mean luminance are obtained by displacing the anti-glare layer on the display between capturing image 1 and image 2. Thus, the analysis of the factor α can be done by the way in 2.1. The advantage of using Difference Image Method is to be able to extract the same image field from both image 1 and image 2, i.e. same area on the display, although the shooting timing is different between image 1 and image 2.

3. EXPERIMENTS

3.1. Measurement conditions

The measurement configuration of sparkle contrast is shown in Fig.3.

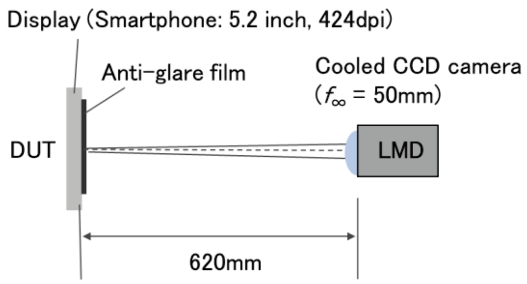


Fig.3. Setup for sparkle measurement.

As a Device Under Test (DUT), anti-glare film was attached on the smartphone (5.2-inch, 424dpi) with using optically clear adhesive film. Displayed pattern for the measurement was full-screen green (R, G, B = 0, 255, 0). As an LMD (Light Measuring Device), monochromatic cooled CCD imager of 5.5μm pixel pitch with the imaging lenses with the focal length f = 50mm at infinity was used. Image sampling ratio (pixel ratio) was 0.95. Effective F-number of the imaging lens was changed from 1.5 to 33.8. At the effective F-number of 33.8, additional pinhole aperture of 1.5mm was used and set in front of the imaging lens to explore the higher F-number than the default mechanical settings of the products.

3.2. Measurement procedure

The LMD was set in front of the DUT, with the measurement direction normal to the DUT surface. The lens focus was set on the display matrix. Image was captured by cooled CCD camera system.

From the captured whole image, the image 1 and the image 2 were extracted with the same image field size. The distance of each extracted image was 30 pixels i.e. 165 μm on the CCD, in both horizontal and vertical directions. This value was over 3 times of R of the effective F-number of 33.8. The size of the extracted images were changed from 10×10 LMD pixels to 200×200 LMD pixels. As increasing the extracted image size, each image was partially overlapped. Before analysis, the fluctuation of low frequency luminance variations in the measurement field was eliminated with the method described in the IEC 62906-5-4 [6].

After subtracting the luminance data of the image 1 from the image 2, standard deviation of the subtracted image σ_{sub} was obtained. Sparkle contrast of the image 1 and the image 2 were also calculated by using the formula (1) for the additional investigations.

For the comparison, Different Image Method was applied by shifting anti-glare layer 2mm away from the original position. Other experimental conditions were same as the image subtraction method.

3.3. Measurement results

3.3.1. Image Subtraction Method

Fig. 4 shows the sparkle contrast from each extracted image with various F-number. The factor $\sigma_{\text{sub}} / \sigma_1$ is also shown.

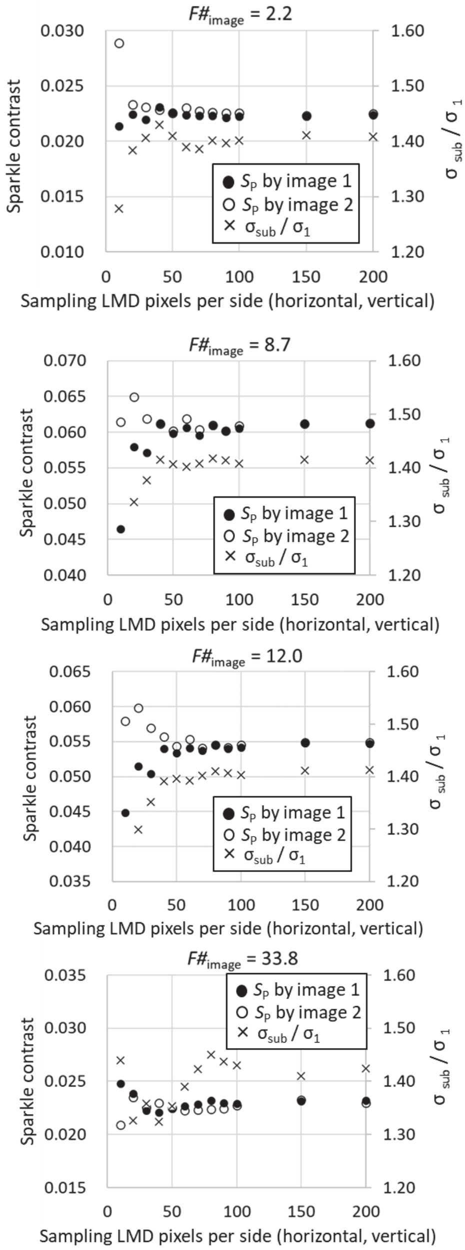


Fig.4. Sparkle contrast and the factor σ_{sub} / σ_1 by Image Subtraction Method under different sampling LMD pixels and F-numbers.

In all the cases, sparkle contrast converged to the certain value around 100×100 LMD pixels and almost corresponding to each other at 200×200 LMD pixels. At the same time, the factor σ_{sub} / σ_1 was also getting close to $\sqrt{2}$ in all f-numbers around 200×200 LMD pixels, i.e. α was close to 1. However, in terms of sparkle contrast, the variation was different in each condition. To investigate this point in more detail, the relative deviation percentage to the converged value of sparkle contrast was investigated by using the formula (5),

$$D_P = \frac{S_{P\text{-}E} - S_{P\text{-}C}}{S_{P\text{-}C}} \times 100(\%) \qquad (5)$$

where, $S_{P\text{-}E}$ was sparkle contrast under evaluation from the image 1 and the image 2, $S_{P\text{-}C}$ was converged value of sparkle contrast, D_P was relative deviation percentage of S_P to $S_{P\text{-}C}$. As a value of $S_{P\text{-}C}$, average of the sparkle contrast of both image 1 and image 2 at 200×200 LMD pixels were used. Fig. 5 shows the results.

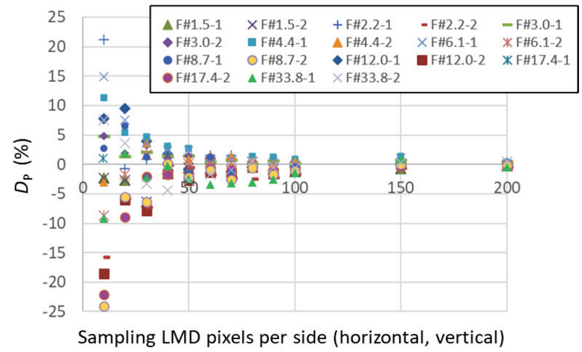
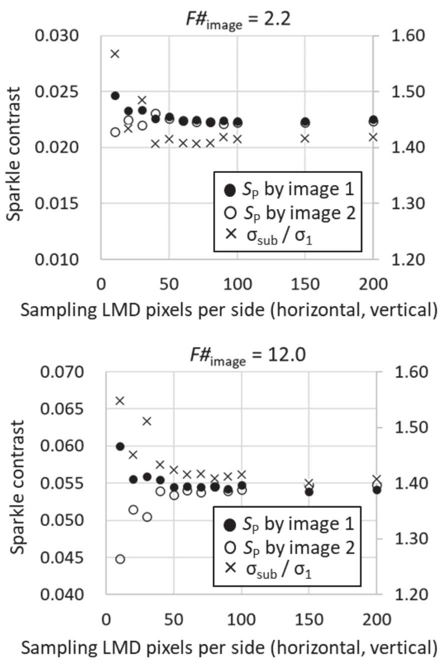


Fig.5. Relative deviation percentage of sparkle contrast against its value at 200 LMD pixels per side.

In all the cases, relative deviation percentage D_P was converged within 1% around 200 pixels, like the factor σ_{sub} / σ_1. These results showed that the statistical error of sparkle contrast regarding the number of sampling pixels has a similar trend in all sparkle contrast level, and the factor σ_{sub} / σ_1 can be used as an indicator of statistical error from the insufficient sampling pixels.

3.3.2. Difference Image Method

Fig. 6 shows the sparkle contrast from each extracted image with various F-number. The factor σ_{sub} / σ_1 is also shown.



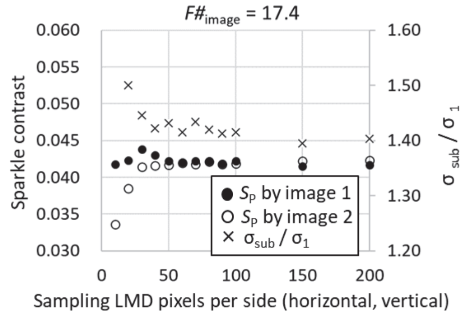


Fig.6. Sparkle contrast and the factor σ_{sub} / σ_1 by Difference Image Method under different sampling LMD pixels and F-numbers.

Like the case of 3.3.1, sparkle contrast converged to the certain value around 200 pixels. At the same time, the factor σ_{sub} / σ_1 was also getting close to $\sqrt{2}$ in all f-numbers around 100×100 LMD pixels.

3.3.3. Image Subtraction Method without correcting low-frequency luminance variation

In this case, the condition 2) in the section 2.1 was not satisfied, even if the statistical error in condition 3) could be reduced enough. Fig. 7 shows the sparkle contrast from each extracted image without correcting low-frequency luminance variation at effective F-number of 33.8. The factor σ_{sub} / σ_1 is also shown.

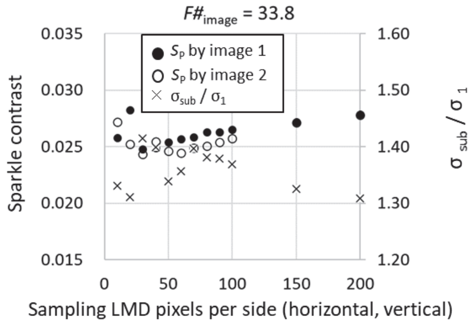


Fig.7. Sparkle contrast and the factor σ_{sub} / σ_1 by Image Subtraction Method under different sampling LMD pixels and F-numbers without correcting low-frequency luminance variation.

In this case, both sparkle contrast and the factor σ_{sub} / σ_1 kept changed with increasing the sampling points. This is because the gradual luminance variation was counted in the standard deviation σ_1, although it was almost cancelled in σ_{sub} by the subtraction operation when the each extracted image was close enough. In this case, the factor σ_{sub} / σ_1 can be used as an indicator of low frequency luminance variation within the sampling field when the number of sampling point is enough large.

D_P was also investigated with the effective F-number from 1.5 to 33.8 like 3.3.1. Fig. 8 shows the results. Unlike the case of 3.1.1, envelope of the data was not symmetrical against 0%. Furthermore, convergence rate of D_P against sampling LMD pixels was slow compared to Fig.5. These were caused because the low-frequency luminance variation strongly biased σ_1, σ_2, and mean luminance.

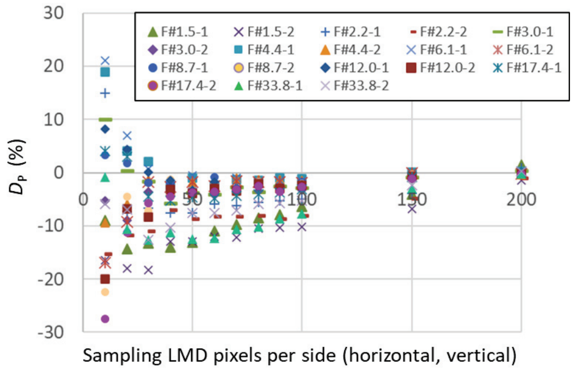


Fig.8. Relative deviation percentage of sparkle contrast against its value at 200 LMD pixels per side without correcting low-frequency luminance variation.

4. CONCLUSIONS

The statistical error and the error by the low-frequency luminance variation in sparkle contrast measurement were investigated by using both Image Subtraction Method and Difference Image Method. The statistical error was suppressed enough when the sampling points were over 100 LMD pixels square. The factor σ_{sub} / σ_1 could be effectively used as an indicator of both statistical error by insufficient sampling points and low frequency luminance variation within the sampling field.

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