Estimation of Equivalent Conditions for Display Sparkle Measurement

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ABSTRACT

Various measurement conditions of sparkle contrast were analysed in terms of the equivalent area of the resolution spot of the imaging system on the display. The results show the possibility to achieve the equivalent measurement conditions among different measurement distance, F-number and focal length of imaging lens.

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 intensity of sparkle, sparkle contrast was defined as the ratio of the luminance standard deviation to the average of the sparkle pattern.

Sparkle contrast varies according to the measurement distance and other measurement variables [3]. If there is an equivalent measurement condition among the different measurement parameter sets, it will be able to increase the freedom of choice, e.g. measurement distance, F-number and focal length of the imaging lens. In this report, various measurement conditions were analysed in terms of the equivalent area of the amplitude point-spread function of the imaging system (resolution element) on the display, and the averaging effect of sparkle contrast by the sensor pixel size.

2. THEORETICAL BACKGROUND

2.1. Integration of sparkle pattern

As shown in our previous report, sparkle contrast Cs has similarity to the case of incoherent speckle, i.e. sparkle contrast is proportional to the F-number of imaging lens. This can be expressed as equation (1)

$$C_s \propto \sqrt{\frac{1}{K}} \propto \frac{1}{F\#_{\text{image}}} \tag{1}$$

where K is the factor of spatial diversity, $F\#_{\text{image}}$ is the F-number of the imaging lens (imager side). If the F-number becomes larger, the corresponding area on the display which affects the single pixel of LMD detector becomes larger, which results in the decrease of sparkle contrast because of the superimposition of the independent sparkle patterns on the sensor plane of LMD.

On the other hand, in the lower F-number region, the sparkle pattern is integrated over some finite area of detector elements, which results in decreasing the sparkle contrast. This phenomenon is opposite trend from the equation (1) at the same time. Theoretically in the speckle field, this was investigated as “integrated speckle” proposed by Goodman [4], and the mathematical formula is described as

$$C_s = \sqrt{\frac{1}{M}} \tag{2}$$

$$M = \left[\sqrt{\frac{A_c}{A_m}}\operatorname{erf}\left(\sqrt{\frac{\pi A_m}{A_c}}\right) - \left(\frac{A_c}{\pi A_m}\right)\left\{1-\exp\left(-\frac{\pi A_m}{A_c}\right)\right\}\right]^{-2} \tag{3}$$

where, C_s is speckle contrast (now only consider the effect of integrated speckle), M is integration parameter, Ac is the coherent area on the sensor, A_m is the size of square, uniform detector element, and erf (x) is a standard error function. A_c can also be described as average speckle grain size which is close to that of sparkle, and experimentally confirmed by Kurashige et al.

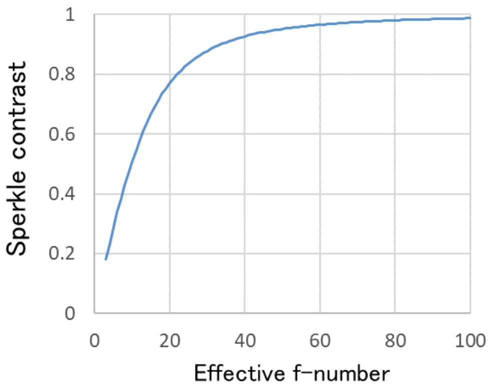

Fig.1. Speckle contrast of integrated speckle vs. effective F-number.

Fig.1 shows how integration of the speckle pattern affects the speckle contrast with the detector array element of 9μm by applying equation (2).

Kurashige also investigated the validity of the equation (3) under the incoherent speckle condition [5]. The theoretical expectation and the experimental results were well matched, therefore the equation (3) is expected also to be applied to the sparkle case, of which similarity with incoherent speckle was confirmed [3]. In the sparkle case, Ac is represented as average grain size of sparkle R, which can be written as

$$R = \frac{4}{\pi} F\#_{\text{image}}\,\lambda \tag{4}$$

where, $F\#_{image}$ is an effective F-number of the imaging lens, λ is wavelength. So, in this case, it is remarkable that only the variable in the equation (3) is the effective F-number within the series of measurement of sparkle contrast. This means that at least one of the requirement for the LMD setup is to select same effective F-number and detector element size of imaging LMD for the comparison of measurement results of sparkle contrast, especially from the different parties.

2.2. Equivalent conditions for display sparkle measurement

To find out the equivalent measurement condition, now we focus on the resolution element of imaging system on the display, which is interpreted as the average sparkle grain (close to the airy disc) projected on the display through the imaging system. Since the sparkle contrast depends on the incoherent scattering element within the resolution element of imaging system on the display, it is important to select each measurement parameters so as to keep the same resolution element size. The diameter of resolution element *S* can be expressed as (5), with using magnification of imaging system; m,

$$S = \frac{R}{m} \propto \frac{F\#_{\text{image}}}{m} = F\#_{\text{screen}} \tag{5}$$

where *R* is average sparkle grain size, $F\#_{screen}$ is the F-number of the imaging lens on the display side, i.e. it represents the aperture angle. The other expression of (5) is

$$S = \frac{R}{m} \propto \frac{F\#_{\text{image}}}{m} = F\#_{\text{image}}\frac{L}{f} \tag{6}$$

where *L* is measurement distance, and *f* is effective focal length of imaging lens. Fundamentally, to keep the same resolution element size on the display means to keep $F\#_{screen}$ (i.e. aperture angle) constant. The importance of $F\#_{screen}$ was already introduced by Isshiki [6] in the sparkle measurement field. However, from the reason in 2.1, $F\#_{image}$ should also be same for the comparison. Thus, to realize the equivalent measurement conditions of sparkle contrast, only the freedom is to adjust the measurement distance L and the effective focal length f so as to keep constant ratio of (*L*/*f*).

3. EXPERIMENTS

3.1. Measurement conditions

The measurement configuration of sparkle contrast is shown in Fig.2.

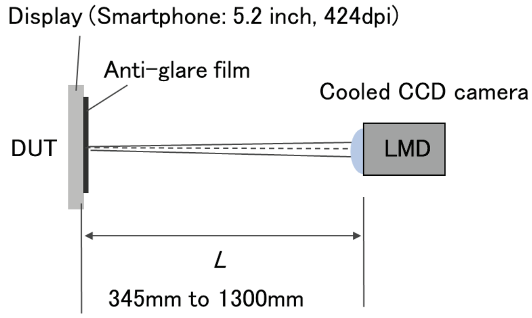

Fig.2. Setup for sparkle measurement.

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, cooled CCD imager of 9μm pixel pitch with the imaging lenses with different fixed focal length (f = 28mm, 35mm, 50mm, 60mm, 85mm, 105mm at infinity) were used. Table 1 shows the combination of the focal length of the imaging lens and the measurement distance under the same resolution diameter S. The sampling rate (pixel ratio) was 0.58 through the whole measurement. This is called "undersampling" condition, which the image of the display matrix element is smaller than the LMD detector size.

Table 1. Focal length of the imaging lenses and the measurement distance under the same resolution diameter *S*.

focal length of imaging lens (effective focal length)	measurement distance
28 (30.5)	345
35 (38.1)	435
50 (54.4)	620
60 (65.3)	745
85 (92.4)	1055
105 (114.2)	1300

Unit: mm

As for the F-number of the imaging lens, additional pinhole apertures of 0.8mm, 1.0mm,1.5mm were used and set in front of the imaging lens to explore the higher F-number than the default mechanical settings of each 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, following to the statistical calculations to get sparkle contrast. The fluctuation of average luminance in the measurement field was calibrated with the method described in the IEC 62906-5-4 [7]. After that, the sparkle contrast was calculated. Since the periodic structure derived from the display matrix could not be recognized through the measurement, the spatial filtering or filtering in frequency domain was not conducted.

3.3. Measurement results

Figure 3 shows the results of the sparkle contrast measurement according to the condition in the Table 1. As theoretically expected, sparkle contrast has same trend through the whole range of the effective F-number. Especially, in the lower F-number (<4) and the higher F-number (>20) region, the sparkle contrast was distributed in the very narrow range within the 0.5% at each F-number. However, there was small deviation in the middle range between above two regions. Since it was so difficult to identify the cause of this deviation from only the sparkle measurement results, additional experiments of incoherent speckle measurements were done with the same LMD conditions.

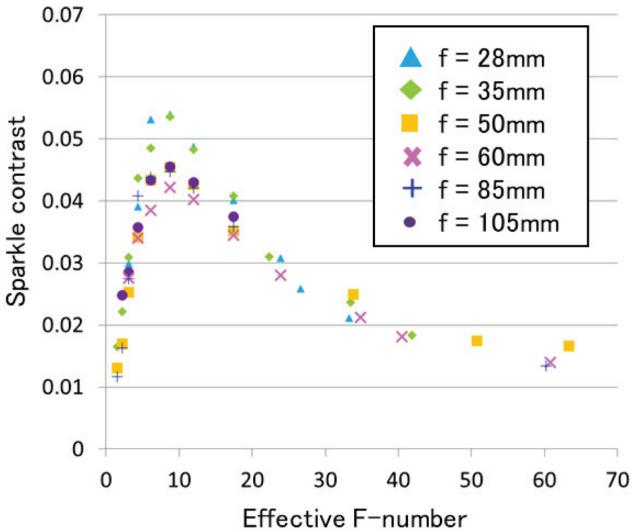

Fig.3. Sparkle contrast under the conditions of same resolution spot of the LMD on the display.

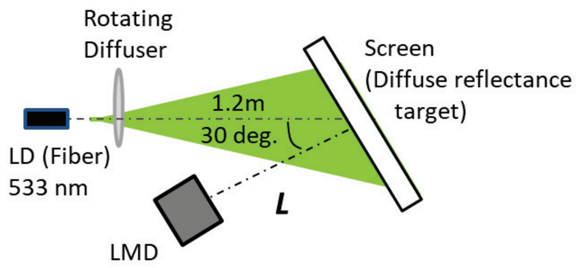

Fig.4. Measurement configurations for the incoherent speckle contrast conditions.

Setup for incoherent speckle contrast measurement is shown in Fig.4. SHG laser (wavelength 533 nm) illuminated the rotating diffuser, making a spot about 1 cm diameter at 1.2m away from the diffuse reflectance target. The same cooled CCD was used as in 3.1 with the focal length of the imaging lenses of 35mm, 50mm, and 85mm respectively. Measurement distances for each imaging lens were also same values in the Table 1.

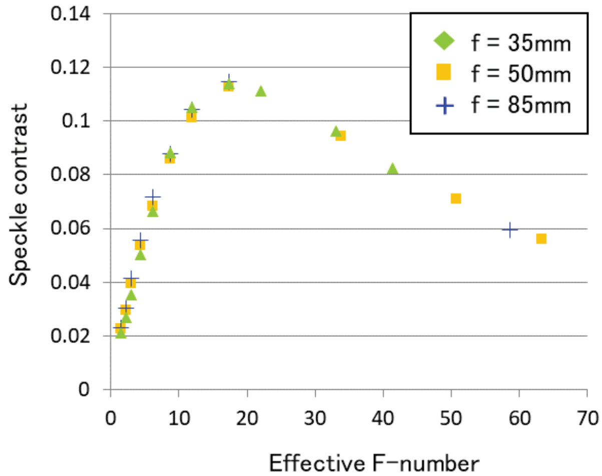

Fig.5. Incoherent speckle contrast under the conditions of same resolution spot of the LMD on the display.

The results were shown in Fig. 5. Each speckle contrast curve was almost same through the whole range of the effective F-number. These results indicated the validity of the equivalent measurement conditions based on the equation (2) and (3). At the same time, it was implied that the deviation in the Figure 3 was not just an error caused by the measurement conditions, e.g. distances, focusing, accuracy or repeatability of the cooled CCD imager and so on. The huge difference between these two experiments was the existence of the periodic matrix on the measurement surface (display or screen). Isshiki [6] pointed out the possibility of measurement error of sparkle contrast caused by aliasing in case of undersampling condition. He proposed to adopt higher F-number so as to tune the cut-off frequency of the MTF of the imaging lens of the LMD lower than the Nyquist frequency of the LMD detector array to avoid the generation of aliasing. It seems reasonable to explain the slight deviation and the trend of sparkle contrast in the Fig.3.

4. CONCLUSIONS

The equivalent, exchangeable measurement conditions of sparkle contrast were investigated with considering the size of the resolution element of the imaging lens on the display. Although the measurement results showed the applicability of the concept by the setting of different focal length lenses and distances, small deviation of sparkle contrast was occurred in the specific range of the effective F-number. One of the possibility was that “undersampling condition” affected the results, however, it needs more investigation for the details of the origin of the deviation of sparkle contrast in the middle range of the effective F-number.

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