PROCEEDINGS OF THE INTERNATIONAL DISPLAY WORKSHOPS, VOL.29, 2022

The Impact of Sensor Noise on the Reproducibility of Sparkle Values for Different Measurement Setups

Ingo Rotscholl, and Udo Krüger

ingo.rotscholl@technoteam.de
[1]TechnoTeam Bildverarbeitung GmbH, Werner-von-Siemens Str.5, 98693, Ilmenau, Germany
Keywords: sparkle, display metrology, uniformity, anti-glare layer, ILMD, sensor noise

ABSTRACT

This contribution examines the influence of ILMD noise on the reproducibility of different sparkle evaluation setups. Sparkle measurements at different sampling rates and aperture numbers are simulated for different ILMD sensors. Especially at low sparkle levels, the SNR can become very critical for some evaluation techniques such that the number of measurements needs to be increased significantly to ensure reproducibility among the different ILMD sensors.

1 Introduction

Anti-Glare Layers (AGLs) are essential components for many displays to ensure readability under changing illumination. The AGLs scatter the incoming light, enhancing the contrast perceived by the human eye. However, AGLs also affect the light emitted from the display, leading to an unwanted high spatial-frequency non-uniformity of the luminance. This effect is known as sparkle. An exemplary luminance distribution of a good and bad example is shown in Figure 1.

Reproducible evaluation of AGL-caused display sparkle is very challenging. Different evaluation techniques requiring different imaging conditions have been proposed and will also be discussed in the upcoming IEC 62977-3-9 standard. A previous study explored the impact of the ILMD (Imaging Luminance Measurement Device [2]) noise for one specific setup by comparing the sparkle result as a number of the averaged measurements [1].

The relation is shown in Figure 2. The y-axis shows the sparkle normalized to the value obtained with 10 averaged images. It can be seen that the impact of the ILMD noise depends on the magnitude of the sparkle. The lesser the sparkle signal, the stronger the impact of the ILMD noise. For low sparkling samples, the error due to the noise increases the sparkle value up to 25 %. For the highest sparkling sample, the sparkle values are barely affected.

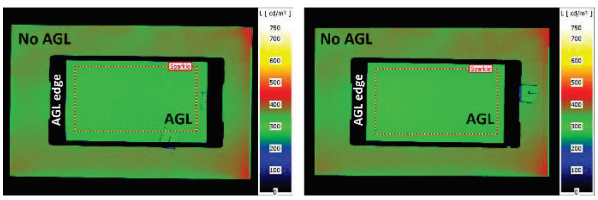

Figure 1: Visualization of the sparkle effect of the AGL on the luminance distribution for two samples: Left: High sparkle, Right: Barely visible sparkle

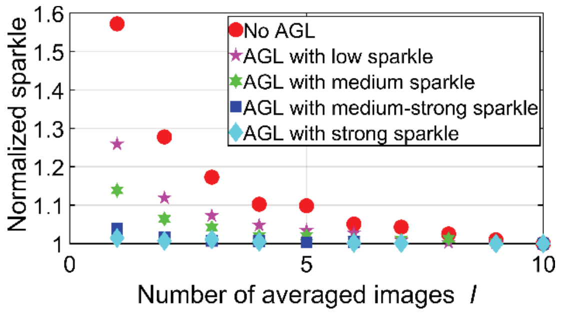

Figure 2: Impact of ILMD noise on the evaluated sparkle as a function of the number of images that were averaged before performing the sparkle evaluation (modified legend from [1])

However, this measurement series neither shows a general correlation nor can the influence on reproducibility be generalized. This contribution systematically analyzes the influence of sensor noise for different sparkle evaluation settings. We do this by simulating sparkle measurements similar to another study [3]. However, we extend the model to also include the ILMD noise and of different sensor types.

In the next section, we briefly review different sparkle evaluation techniques and the relevant capture parameters for sparkle. We then explain our ILMD noise simulation model as well as the sparkle measurement simulation model. In the last section, we show important results regarding the impact of the noise and draw a conclusion.

2 State-of the-art sparkle measurements

The main challenge in any sparkle evaluation is the separation of the periodic luminance evaluations of the display pixels from the random high-spatial frequency component known as sparkle. Several methods for this separation have been proposed:

- Spatial filtering of the captured image [4]
- Frequency filtering of the captured image [1]
- Defocusing the pixel matrix only within a low DoF configuration [5]
- Defocusing using diffraction blur in a high DoF configuration [6]
- Undersampling [7]

While the first two methods base on image post-processing, the latter three adjust the capturing conditions before the actual sampling process.

After separating the periodic luminance of the display matrix, the sparkle is defined as

$$S = \frac{stddev(L(x,y))}{\bar{L}}, \qquad \text{Eq. 1}$$

where $L(x,y)$ is the lateral luminance distribution and $\bar{L}$ its mean luminance.

The main setup differiences between the different methods are the image sampling ratio (ISR), which is the relation between the ILMD pixel pitch (d_{ILMD}) and the imaged display pixel pitch (d_{Display}) on the sensor, and the aperture setting given by the aperture number f# of the lens.

The image sampling ratio determines the maximum spatial frequency that can be measured. The measured sparkle increases with increasing sampling ratio [1]. It also affects aliasing artifacts such as Moiré. For an ISR range between 1.8 and 3.6, experiments showed that limiting the evaluated frequency range cancels out the sparkle value dependency from the ISR [1].

The f# affects several parameters of the image capturing process. An increasing f# increases the depth of focus and decreases the aperture angle. Further, a significant amount of diffraction blur can occur. All these parameters can impact the measured sparkle [1,6,8]. A simulation showed that a lower f# reduces or eliminates the aliasing of the sparkle itself [3].

3 Simulation of sparkle measurements

In order to simulate the effects of ILMD noise for different sparkle evaluation concepts, we change both the image sampling ratio and the f# used in the measurement. The general concept is illustrated in Figure 3 and Figure 4.

In the first step, an ideal regular spaced display matrix is defined by the vertical and horizontal fill factor as well as a pixel pitch. We assume that only green subpixels are turned on and that there is no pixel-to-pixel luminance variation in the bare display. Next, we add a high-frequency noise component to simulate the sparkle. The component can vary in its frequencies and amplitudes.

Next, the image is blurred according to the aperture setting by adding the diffraction blur. We assume that the lens has an ideal diffraction-limited MTF. The effect of the angular aperture is neglected in this simulation. The next step is sampling with the ILMD pixels to obtain the image in ILMD pixels.

Then the noise is added. Details about this step are provided in the following subsection. Finally, we repeat the last step to simulate the effect of a multi image capture, which averages a series of images into one.

Applying an image post-processing technique might be necessary before calculating the resulting sparkle according to Eq.1 if there are still contributions from the periodic pixel structure. This is the case if the condition derived in by Kurasdhige is not fulfilled [6]. We then use a frequency filter to eliminate the display pixel effects [1].

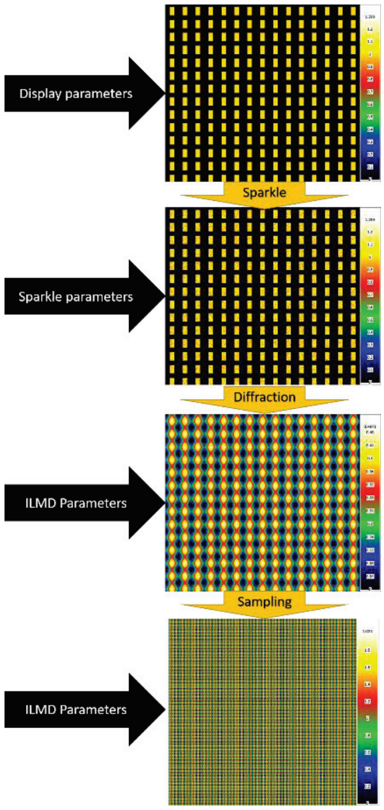

Figure 3: Visualization of sampling simulation for a measurement setup with a lower f#

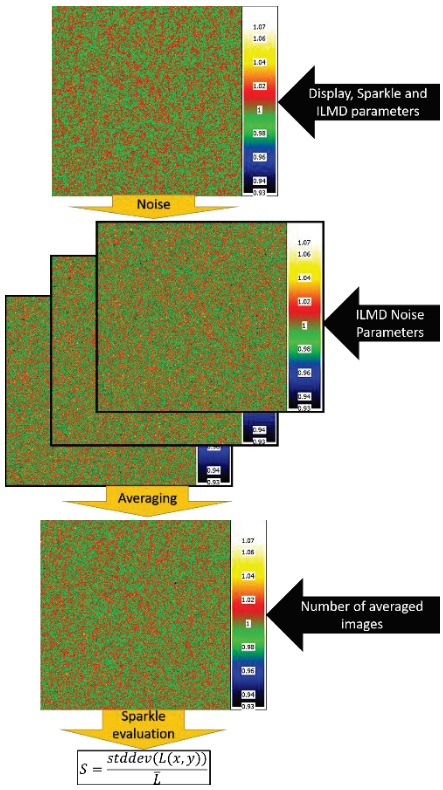

Figure 4: Visualization of noise addition for a measurement setup with a high f#

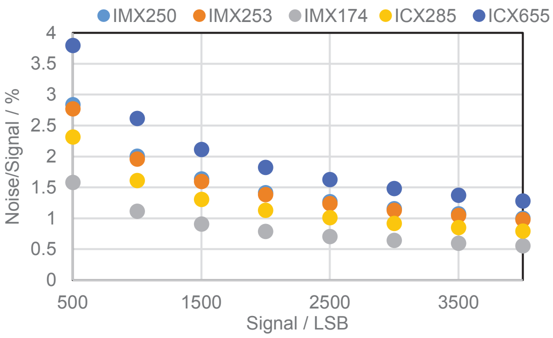

Figure 5: Noise parameters for the ILMDs

3.1 Simulation of ILMD noise level

We simulate sensor noise as a function of the saturation based on dark signal noise and the full well capacity of the sensors. We use published data [9] of five different commonly used ILMD sensors. The resulting Signal-to-Noise ratios in % as a function of the saturation (for 12 Bit A/D conversion) are provided in Figure 5. A maximal saturation of 80 % is assumed for the first image acquisition. The saturation is then determined for each pixel individually according to the sampling model (Figure 3). Noise is added to each pixel according to the standard normal distribution and its specific noise level [10].

4 Results

We simulated sparkle distributions ranging from 2 % to 12 % evaluated sparkle according to the measurement and evaluation procedure of our previus study [1]. First, we simulated repeatability, which is the deviation between measurement results of the same setup and sensor noise.

In this case, the measurement is simulated five times with the same ILMD. Figure 6 shows the simulated repeatability for an f# = 32 with an ILMD pixel pitch of 3.45 micrometer and an image sampling ratio of 3.3 as a boxplot. It can be seen that the repeatability of the measurement is unproblematic. This is true as long the region of interest used for the evaluation is large enough for similar reasons as described in another study [11].

Next, we simulate the impact on reproducibility, which is the deviation of results obtained with different ILMD sensors.

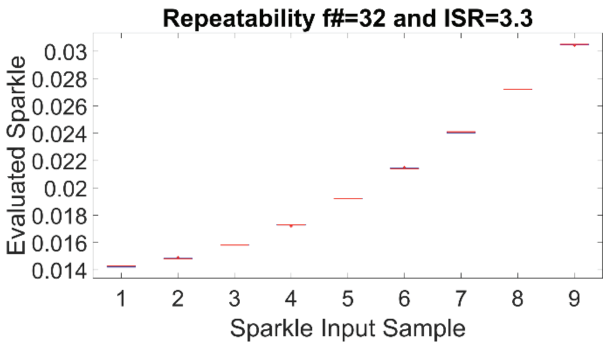

Figure 6: Repeatability of evaluated sparkle considering an ILMD with 1.4% noise and an f# = 32

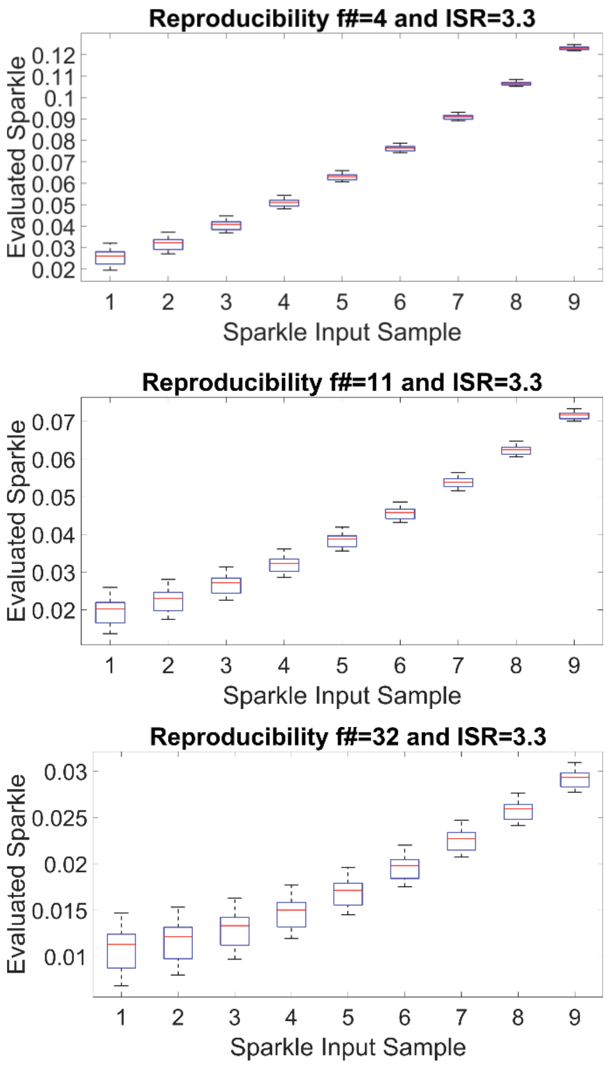

Figure 7: Reproducibility of evaluated sparkle for different f# and an ISR of 3.3 with different ILMD noise levels according to Figure 5

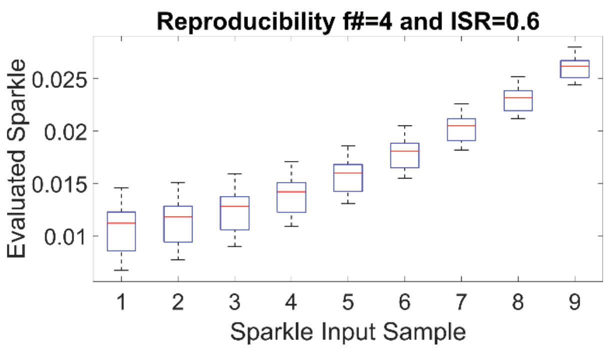

Figure 8: Reproducibility of evaluated sparkle for an ISR of ~0.6 considering sensor noise according to Figure 5

The results for different f# but constant sample conditions are shown in Figure 7. Each box of the boxplot shows the reproducibility of the evaluated sparkle for one sparkle input sample. It can be seen that the reproducibility depends on two main factors, the aperture setting, and the sparkle input sample.

Increasing the aperture number results in a more blurred sparkle distribution and a decreasing sparkle signal. The same is true with a low ISR shown in Figure 8, which can be compared to Figure 7 top. When the original sparkle is low (low sparkle input sample), the remaining signal and ILMD noise reach the same order of magnitude. If the ILMD noise then deviates between the sensors, reproducibility between them becomes problematic.

One way to improve the SNR would be to capture the images multiple times. While the sparkle signal remains constant, the ILMD noise distribution differs and could be averaged out. Figure 8 shows simulation results where five images were used for the averaging process. It can be seen that the reproducibility improves significantly compared to Figure 7. Further, it shows that the evaluated sparkle decreases, consistent with the experimental data shown in Figure 2. This effect determines the number of images required to eliminate the ILMD noise effect as it will converge to the actual sparkle signal.

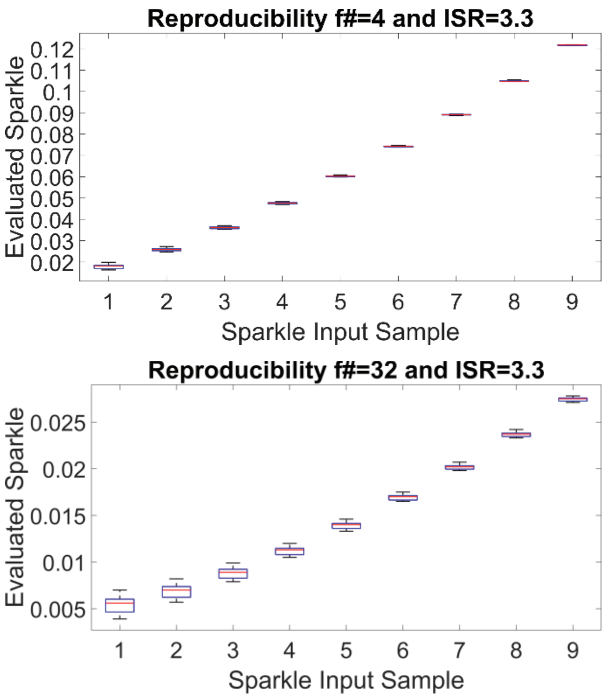

Figure 9: Reproducibility of evaluated sparkle for different f# considering sensor noise according to Figure 5 and image averaging.

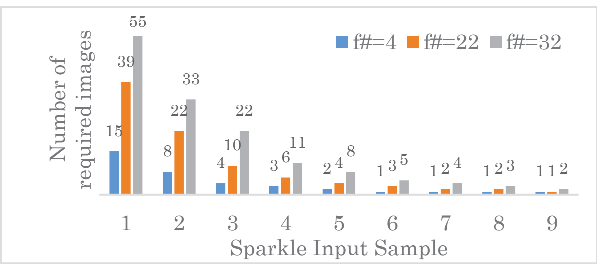

Figure 10: Images required until the ILMD noise contributes less than 5 % relative to the evaluated sparkle signal (for an ILMD with 1.0 % noise at full saturation) and ISR = 3.3.

5 Conclusion

The influence of ILMD noise on the evaluated sparkle depends on the magnitude of the sparkle and the sampling conditions. While unproblematic for the repeatability within one setup, it is problematic for reproducibility if there is a difference in the ILMD noise level. The only way to ensure reproducibility is to average over a large number of measurements until the evaluated sparkle converges. The results of this study are of interest for every sparkle measurement regardless of the actual evaluation method and thus important for consideration in international standardization such as the IEC to improve reproducibility.

References

[1] Rotscholl I., Schlipf A., Rickers C., and Krüger U.: “Sparkle Measurements for an Automotive Specification: Evaluation Method for Flexible Setup Conditions” J. SID accepted Manuscript to be published at J. SID, 2022

[2] CIE 244:2021. Characterization of imaging luminance measurement devices, CIE 2021

[3] 30-4: Isshiki M. and Endo, Y “Requirements for Reliable Display Sparkle Contrast Measurement: Analysis in Spatial Frequency Domain presented at SID 2022,

[4] Becker M. E., Sparkle measurement revisited: A closer look at the details, J. SID, 23 (10), (2015)

[5] Ferreras Paz V., Kohlenbecker S. and Persidis E., 8-2: Sparkle Characterization of Anti glare layers on Displays with Grey Value Histogram Analysis, SID Digest, 49,1(2018)

[6] Kurashige M., Furui G., Ishida K., Nishio, S., Kuzuhara M., Suzuki H.,Tsujimoto J., Tsunekawa M., Iwata Y., and Nakamura, N., "VHF6-4L Novel Approach on Sparkle Contrast Measurement by utilizing Diffraction Blur", Proc. IDW (2020)

[7] Hayashi M., I Simplified Method to Quantify Sparkling of Antiglare. Display without Image Processing and Its. Application, Proc. IDW (2017)

[8] Isshiki M., Inouye A., Tamada M., Kobayashi Y, 78-3: The Optimized Condition for Display Sparkle Contrast Measurement of Anti-Glare Cover Glass based on the Solid Understandings, SID Digest, 50, 1, (2019)

[9] Teledyne FLIR, SENSOR REVIEW: MONO CAMERAS 2022 edition, https://www.flir.com, 2022

[10] Krüger U., Schmidt F., “The impact of cooling on CCD-based camera systems in the field of image luminance measuring devices”, Metrologia 46 S252, 2009

[11] Kurashige M., Furui G., Ishida K., Nishio, S., Kuzuhara M., Suzuki H.,Tsujimoto J., Tsunekawa M., Iwata Y., and Nakamura, N, VHF6-1 Error Analysis of Sparkle Contrast by Image Subtraction Method, Proc. IDW (2020)