Sparkle Measurements for an Automotive Specification: The Compromise between Reproducibility and Flexibility

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ABSTRACT

This contribution evaluates a frequency-filter-based sparkle evaluation and investigates the compromise between reproducible measurement results and flexible setup conditions. It bases on measurements with two displays and 9 AGLs. The findings serve as basis for the measurement conditions of an upcoming automotive display sparkle measurement specification.

1 Introduction

Anti-Glare-Layers (AGL) are an important component of many automotive displays, as they ensure the readability of the display even in direct sunlight. However, AGLs can also reduce image quality due to an additional cross-talk or due to an additional high-frequency luminance and color non-uniformity. Figure 1 shows a luminance distribution of a display with an AGL only in the center. Although a Moiré structure can be seen throughout the image, the random components in the center are much stronger than in the area without an AGL. This random high-frequency uniformity (not the Moiré structure) is called Anti-Glare-Layer (AGL) caused display sparkle, the measurement of which is to be standardized for an automotive specification.

A sparkle measurement method for the automotive industry must not only ensure reproducible measurement results but should also be applicable to the display at each development step. That's why a measurement methods that requires removing the AGL e.g. for a difference image method cannot be used. Furthermore, it is advantageous if existing procedures, setups, and equipment as known from the BlackMURA [1] specification can be used.

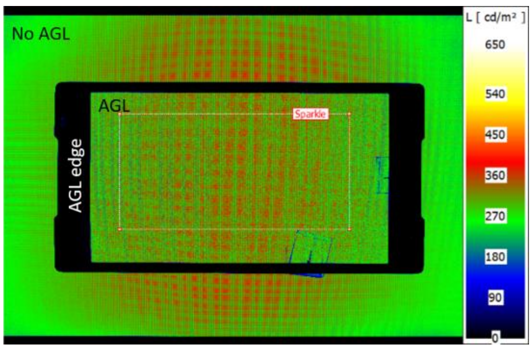

Figure 1: Luminance image with AGL in the center region

The measured sparkle S is usually defined as

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

where $L(x,y)$ is the lateral luminance distribution of the region of interest (ROI) and $\bar{L}$ its mean luminance. While Eq. 1 seems very simple, the setup and evaluations conditions for a sparkle measurement are very challenging.

2 State-of-the-art and Previous Work

The main challenge in a display sparkle measurement is the separation of the periodic luminance fluctuations caused by the pixelated display matrix and the random high-frequency components leading to the sparkle [2].

Several separation methods have been proposed. These include defocusing the pixel matrix within a low depth of focus (DOF) configuration [3], spatial filtering [4], frequency filtering [5,6], undersampling [7] and defocusing by diffraction blurring with a high DOF configuration [8].

While defocusing the pixel matrix within a low DOF configuration can lead to reproducibility problems, undersampling and spatial filtering require imaging conditions that are unusual for BlackMURA and thus less suitable for the automotive industry. The same is true for the small aperture required for the diffraction blur.

Therefore, the authors of this study proposed a Fourier filter based method. The basic idea is to transform the lateral luminance distribution $L(x,y)$ into the frequency domain and to eliminate the low frequencies luminance variations as well as luminance variations from the pixel structure [6].

This is done by image processing of the amplitude image in the frequency domain in order to identify frequencies corresponding to the periodic pixel frequency or low frequency components. From this, a binary filter is derived. This filter is multiplied with the image in Fourier space. Finally, an inverse Fourier transformation is used to obtain a filtered image in the spatial domain that can be analyzed for sparkle according to Eq. 1 or a local approach [6].

Figure 2 shows the luminance images before and after applying the frequency filter for three different sparkling glasses and the same display matrix.

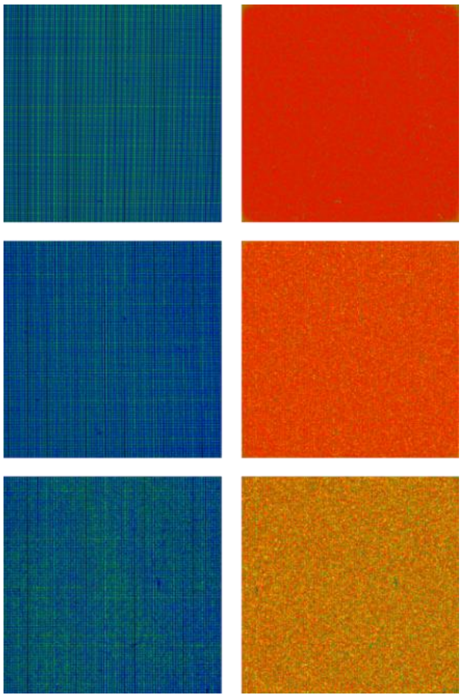

Figure 2: Samples with increasing sparkle from top to bottom: original images (left), frequency filtered images (right)

3 Experiment

To have a large database for the setup dependency and reproducibility experiments, we evaluated a 224 ppi and 183 ppi automotive display with 6 different AGLs per display with low perceived sparkle (No AGL, L1 and L2), medium sparkle (M1, M2, M5 and M6), and high sparkle (H1, H3 and H4) according to the procedure described in [6]. We used four different ILMDs (Imaging Luminance Measuring Device) with two different camera pixel pitches (6.45 μm and 3.45 μm) and different standard lenses with focal lenses ranging from 16 mm to 50 mm. All lenses had an f number of f#=4.

4 Considerations During Sparkle Measurements

The measured sparkle depends on many setup parameters of the measurement [6,9-11]. We will briefly summarize important effects and optimization procedures.

4.1 Focus Position

We recently reported on the influence of a non-optimal focus position [6,11], which is especially critical for manually focusable lenses with a lower DOF. For this reason, a distance focus scan was proposed to ensure maximum sharpness of the sparkle. By using the focus scan, the reproducibility could be significantly increased.

Figure 3 (right) visualizes the negative effect. The x-axis shows the zero position, for different ILMDs and lenses, which were manually focused on the pixel layer by an operator. Without a focus scan, the reported sparkle value would be always the value at the zero position. With the focus scan, it is always the maximum. The left side shows that different AGLs may also shift the maximum sparkle focus position by a few mm.

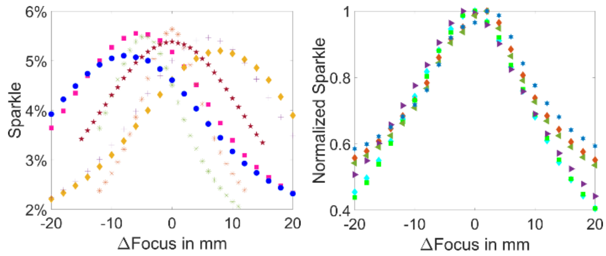

Figure 3: Sparkle/Focus sensitivity: Left: Sparkle of one AGL in different setups Right: Sparkle of different AGLs in one setup

4.2 ILMD Field Angle

Since the sparkle varies with the viewing angle, the field angle also has an influence on the measured sparkle. However, the field angle can be controlled by evaluating only a specific ROI [11]. It should only be ensured to that the ROI has a minimal size for evaluation [12].

4.3 ILMD Pixel Noise

The ILMD noise level has an influence on the measured sparkle. However, this influence can be reduced by averaging over N camera images, which reduces the noise by a factor of $\sqrt{N}$. The effect is only relevant for low sparkle values. We set *N=5* for all measurements.

4.4 Sampling Resolution and Downsampling

In [9,11], it was shown that the sampling resolution or the sampling ratio has an influence on the evaluated sparkle. We define the sampling resolution as the absolute sampling frequency in camera pixels per mm (cpx/mm). In contrast, the sampling ratio, also called reproduction scale, is defined as the sampled camera pixels per display pixels and thus depends on the ppi of the device under test (DUT)

Figure 4 (top) shows a quantitative example for the sampling resolution dependency of several AGL for the 224 ppi display. The x axis shows the sampling resolution and the y axis the sparkle value normalized to the mean value for 6 different AGL and no AGL.

For the evaluated sample resolutions the sparkle value decreases by 30% to 40%, which is a very strong dependency. We assume that the reason for that is the sampling theorem. By reducing the sampling resolution, we can reconstruct lesser frequency components of the sparkle. However, this would also mean that a measurement at a high sampling resolution can be downsampled to a measurement with a lower resolution by simply using only frequency components during the inverse Fourier transform, that are below the lower resolution measurement's Nyquist frequency.

Figure 4 (bottom) shows the same measured data as the top image. However, now this condition was fulfilled for the three higher sampling resolutions. The sparkle values become nearly independent of the sampling resolution and are now comparable with each other. Note that the relative sparkle ranking and human correlation of the samples are not affected by the downsampling.

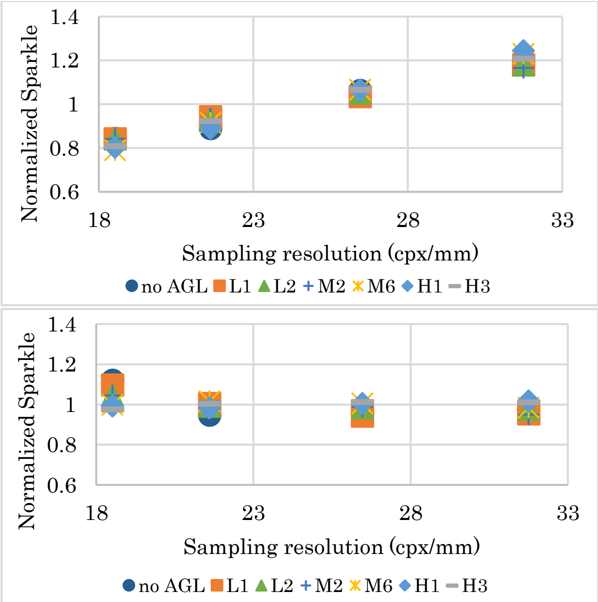

Figure 4: Normalized Sparkle as a function of the sampling resolution for different AGLs: Top: original data, Bottom: With downsampling

All evaluated measurements in Figure 4 have been carried out with the constant aperture number four and the same 3.45 µm camera pixel pitch. However, this means that besides the sampling resolution, also the angle of aperture changed between 0.9° and 1.4°. Note that this angle is estimated based on a simple lens equation only.

4.5 Angular Aperture

A simple experiment to measure the dependency of the sparkle on the angular aperture is to change only the ILMD aperture during measurement as done in [10].

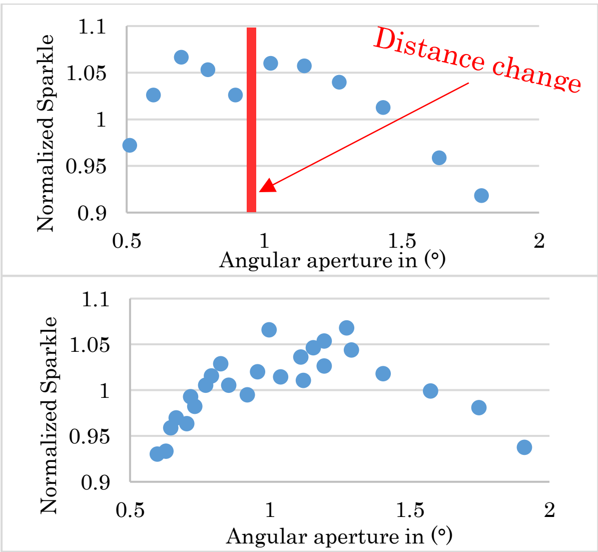

Figure 5: Angular aperture dependency of AGL H3: Top: With variable f# and one downsampling step, Bottom: From measurement series with downsampling and constant f#

Figure 5 (top) shows the results of such an experiment for the AGL H3. However, in order to ensure that we do not affect the experiment by introducing diffraction blur, we only used f# up to 5.6 in that particular experiment (f#=4 in all others). In order to realize smaller angle of apertures, we increased the measurement distance and limited the evaluated frequency components to those of the lower sampling resolution as described above. The inconsistency at 0.9° marks the position, where the distance was changed. Besides this small outlier, this shape of the curve is similar to those shown in [10]

For comparison, we evaluated our complete measured and downsampled data for H3. The result is shown in Figure 5 bottom. It can be seen that the curves look very similar although they were all measured at different distances with different focal length lenses and two ILMDs pixel pitches.

5 Flexible Sparkle Measurement Setups

The concept of frequency downsampling can be used to correct and reduce the sampling resolution influence on the measured sparkle value. Thus, the measurement distance would not be fixed anymore for a specific camera-lens combination. However, setup boundary conditions for the sampling resolutions and aperture angles need to be selected to ensure correlation to human perception and a certain level of reproducibility.

By assuming that the resolution limit of the human eye is approximately one arcminute and that the distance to an automotive display will always be above 450 mm, the maximal object size would be 0.13 mm. This corresponds to a resolution of 7.7 cpx/mm which requires a sampling resolution of approximately 15 cpx/mm as lower boundary and for the downsampling. This also ensures a BlackMURA compliant setup. As the highest tested sampling ratio was around 30 cpx/mm, we select this as the upper boundary.

For the aperture angle, a similar argumentation leads to small values, around 0.2°-0.6° for an eye entrance pupil diameter of 2-5 mm at a viewing distance of 400-600 mm. However, we decided against these low aperture angles for three reasons.

Table 1 :Evaluated sparkle $\pm 3\sigma$ for flexible, angular aperture limited and fixed setup for different AGLs (AGL column: 224 ppi/183 ppi display)

224 ppi display

AGL	Flexible All	Flexible Limited	Fixed
No	1.1±0.3	1.1±0.3	1.0±0.1
L1	1.2±0.3	1.2±0.2	1.3±0.1
L2	1.2±0.2	1.2±0.2	1.2±0.1
M2/M1	2.1±0.8	2.2±0.3	2.3±0.0
M6/M5	3.7±0.7	3.8±0.3	3.8±0.3
H1/H3	6.6±0.8	6.8±0.4	6.6±0.4
H3/H4	7.9±1.2	8.1±0.7	7.9±0.6

183 ppi display

Flexible All	Flexible Limited	Fixed
1.7±0.3	1.7±0.1	1.7±0.1
1.7±0.2	1.7±0.2	1.7±0.1
1.7±0.3	1.7±0.2	1.8±0.1
2.6±0.5	2.7±0.1	2.7±0.0
3.4±0.4	3.5±0.1	3.5±0.1
8.0±1.0	8.1±0.6	7.9±0.4
11.3±1.9	11.6±0.8	11.5±0.8

First, if the sampling resolution of 15 cpx/mm shall be fulfilled with the most common state-of-the-art ILMD pixel pitch of 3.45 μm, the resulting f# for the lower aperture angles would be in the range of 11 to 5.6. However, these f# leads to a significant contribution of diffraction blur, which would affect the measurements. In order to avoid a significant influence, an aperture of at least four is required. This leads to aperture angles above 0.7°.

The second reason is that the dependency of sparkle on angular aperture tends to be stronger in the range of <0.7° for all measured samples but weaker in the range 0.7° to 1.2°. This can be seen in [10] and Figure 5. Note that physiological experiments in [10] showed no fundamental different correlation to human perception.

The last reason is the applicability of ILMDs with larger pixel pitches. A 6.45 μm ILMD with at least f#=4 (see first reason) cannot reach low aperture angles. In fact, this leads to approximately 1.3°.

5.1 Flexible Measurement Experiments

We evaluated all measured data from [6] and compared the reproducibility from the different setups. Table 1 shows the evaluated mean sparkle ± 3 times the standard deviation σ.

The column “All” shows the complete measurement series downsampled to 15 cpx/mm. The standard deviation is large compared to the mean sparkle for the low and mid sparkling AGLs. We assume that the main reason for these outliers is the different aperture angles realized by the different measurement distances and especially by the different ILMD pixel pitches.

The column “Limited” only considered measurements, from “All” in which the aperture angle was between 0.9° and 1.3°. While the mean values of all sparkle values remain or increase slightly, the 3σ region, representing the reproducibility is significantly reduced compared to “All”.

The results of a fixed setup without downsampling and constant angular aperture but realized with different ILMDs of the same type and different lenses are shown in the column “Fixed”. As expected, reproducibility is best. However, here only one valid measurement distance exists, which is very unflexible in practice regarding different labs, lens, and ILMD availability.

Table 2 shows the theoretical measurement distance according to the ideal lens equation for a state-of-the-art ILMD system. The case “Limited” offers much more flexibility. Note that theoretically, a more optimal condition would be the range 0.7° to 1.0°. However, these conditions would exclude ILMDs with larger pixel pitches.

Table 2: Flexible setups with aperture number (f#=4)

	Resulting measurement distance (mm)		
Focal length / Angular aperture	f=16 mm	f=25 mm	f=50 mm
0.9°/ Fixed	256	400	800
0.9°-1.3°/ Limited	176-256	275-400	550-800

6 Summary

By limiting the frequencies during an inverse Fourier transform, the influence of the sampling resolution can be reduced without affecting the correlation of evaluated to perceived sparkle. However, the measurement reproducibility is still limited by the angular aperture. The angular aperture conditions define a compromise between measurement reproducibility and flexibility. This allows for flexible measurement setups with reproducible results in different labs and with different equipment. The procedure was validated for automotive displays with a ppi between 183 and 224 and ILMDs with 16-50 mm focal length and a pixel pitch between 3.45 and 6.45 μm. It will be used in an upcoming automotive specification.

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