TechnoTeam Bildverarbeitung GmbH

Reproducible quantification of display sparkle

Purpose of measurement

Anti-Glare-Layers (AGL), which scatter a large part of the incoming light (e.g., sunlight) to enhance the contrast, protect many displays that aim at outdoor applications. However, as shown in Figure 1, the AGL also affects the transmitted part of the light. This can lead to a high-frequency water-droplet-like luminance and chromaticity non-uniformity that base mostly on chaotic refraction of the transmitted light of an information display [1]. This phenomenon is called sparkle. Figure 1 shows a visualization of display sparkle.

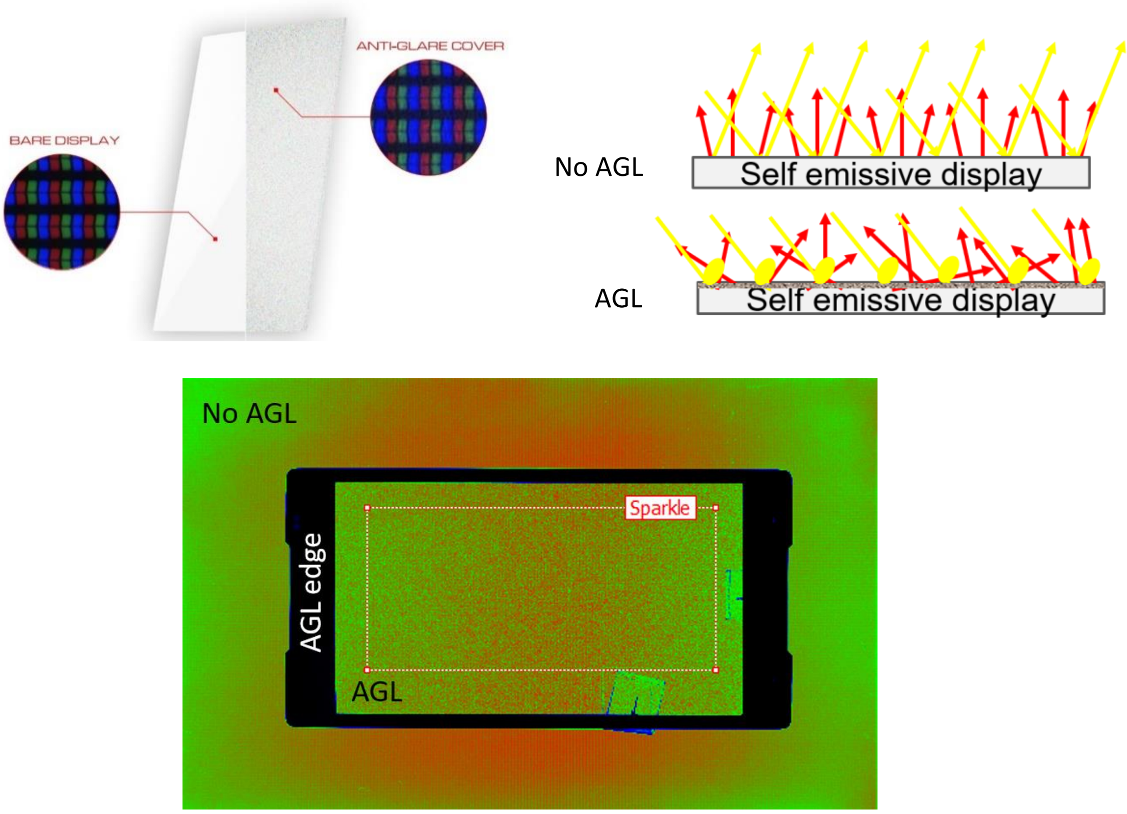


Figure 1: Anti-Glare-Layer caused display sparkle

The purpose of this document is to introduce a measurement solution for this unwanted phenomenon using the LMK camera systems such that the measurements

- show a high correlation to the sparkle perceived by humans.
- are absolute and reproducible for many different LMK camera systems.
- enable flexible setups, including BlackMURA-compliant setups.
- can be performed without removing the AGL.

Anti-Glare Layer caused display sparkle is a disturbing high frequency chromaticity and luminance variation that originate from the interaction of the transmitted light with the structure of the AGL.

General measurement procedure

The measurement procedure for sparkle consists of three steps. The first step is a general geometrical alignment of the camera relative to the display. The second step is the focus setup. After that, you can perform the sparkle measurements.

Separation of the pixel matrix

The main challenge of each display sparkle evaluation procedure is visualized in Figure 2. It is the separation of the sparkle-caused luminance variations (left) from the luminance variations of the bare pixel matrix (right) based on the captured image (middle). If any influence from the pixel matrix remains, the sparkle value will be overestimated.

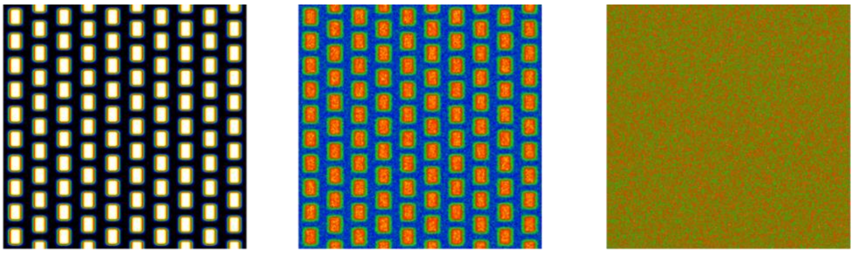


Figure 2: Pixel pattern (left), sparkle (right) and situation during the measurement (middle)

Approaches like defocusing are usually used to reduce the effects of the pixel pattern. However, the effect of defocusing on the sparkle highly depends on the system setup (lens, measurement distance, sensor pixel pitch), which limits both flexibility and reproducibility. Therefore, specific sparkle evaluation procedures have been developed [2]. They differ strongly regarding possible sampling ratios (camera pixels/display pixels) and the achieved sparkle values.

TechnoTeam's frequency filter approach

For maximized flexibility and measurement in BlackMURA-compliant setups, TechnoTeam has developed a frequency filter approach that analyzes the captured image and suppresses only the main frequency components from the periodic pixel pattern. The filter is individually tailored for each image [3].

Figure 3 shows a high, medium, and low sparkle luminance image before and after applying the frequency filter (same color scaling). It is clearly visible that the highest sparkle occurs in the sample at the top, but it cannot be quantized. In the frequency-filtered image, the effect is even more clearly visible and can be quantized easily via:

$$Sparkle = \frac{std(L)}{mean(L)}.$$

The main challenge of a display sparkle evaluation is the separation of the sparkle from the periodic display pixels.

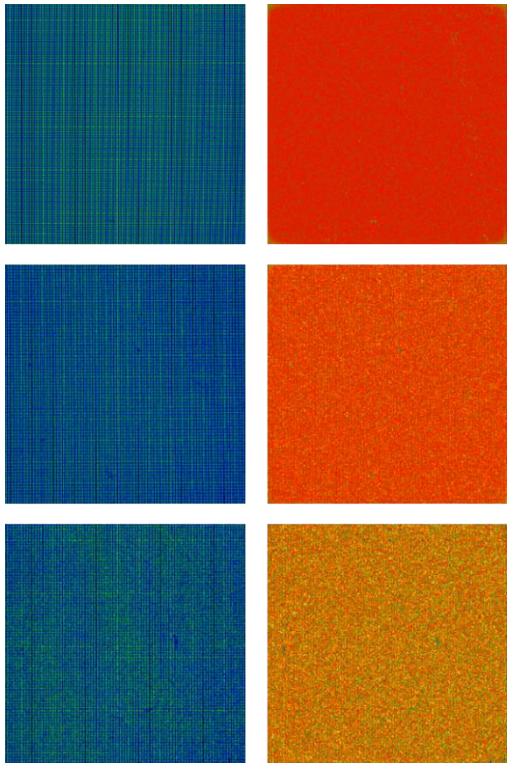


Figure 3: Samples with increasing sparkle from top to down: original images (left), frequency filtered images (right)

Focus sensitivity

The correct focus is one of the most important settings during a sparkle measurement because any slight defocus blurs the sparkle in an undefined way. This effect depends on the depth of focus (DOF) of the measurement setup and the focus setting and affects high sparkle values stronger. The reproducibility of the focus setting and the sparkle contrasts sharpness is affected by

- The AGL thickness and structure (affects maximum sparkle contrast location)
- The depth of focus (the pixel matrix is sharp within the lateral depth of focus)
- The human operator (manual focus only)

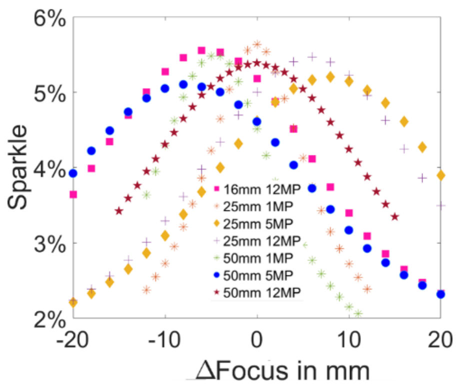


Figure 4: Focus reproducibility of same AGL in different setups (DOF and human error) [4]

The impact of these issues are shown in Figure 4 and Figure 5. All these effects can lead to a nearly "random" focus setting of the sparkle, which affects the reproducibility of the results and the correlation to human perception. Further, it should be noted that the human eye tends to focus on the plane with the highest contrast. In the case of an unstructured uniform image (but sparkling), this would be the sparkle contrast.

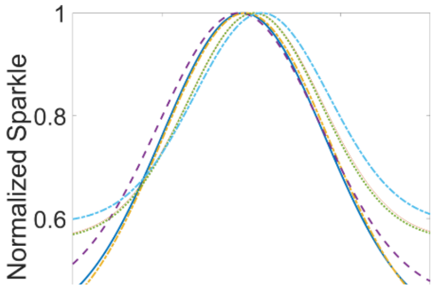


Figure 5: Normalized sparkle of different AGL measured within the same setup: the maximum shifts as a function of the AGL [4]

Reproducible focus setup: distance/focus scan

Figure 6: Setting for a distance/focus scan

To overcome all focus-dependent problems independent of the camera/lens setup and the current DOF, TechnoTeam has developed the distance focus scan. In this solution, the camera mechanical changes the distance to the display, and thus the relative focus position, to always capture a sparkle contrast at maximum sharpness. This simple and robust way enhances reproducibility. An easy measurement setup is shown in Figure 6.

TechnoTeam's distance focus scan:
Maximize the reproducibility by minimizing the depth of focus effect, AGL effects, and human error at the same time with any LMK lens system.

Influence factors and error sources in a sparkle measurement

As summarized in Table 1, there are even more things to consider during a sparkle measurement. The measured value depends, for instance, on the magnification (camera pixels per mm). At a higher magnification, the high-frequency nature of the sparkle increases the measured values [3, 5]. Sparkle also depends on viewing direction and thus from the measurement field angle. In addition, a dependency from the angle of aperture has been reported [6].

Further, imperfections such as defects, dust, and artifacts, which can often not be avoided completely, increase low sparkling values significantly. This phenomenon is also visible in the back-transformed image of the low sparkling samples in Figure 3. Thus, the key to reproducible sparkle measurements are well-protocolled setups and robust algorithms.

Table 1: Some influence factors of a sparkle measurement

Influence Factor	**Focus setting**	**Magnification (Reproduction scale)**	**Measurement field angle**	**Localized imperfections (Dust, defects**
Effect on sparkle	Defocused sparkle reduced sparkle value, especially for medium and high sparkle samples	Higher magnification increases sparkle value	Depends (usually, a larger field angle increases the sparkle value)	Increase sparkle value, especially for low-sparkling samples
Solution	Distance-Focus scan with plausibility check and protocol	Parameter adjustment with protocol	Parameter adjustment with protocol	Robust statistical evaluation by local median

Intuitive, established, and protocolled setup procedure

With the camera setup developed for BlackMURA [7] and the sparkle dialog, the user has complete control over all settings, including the magnification, measurement field angle, and evaluation region of the sparkle. Of course, all values are protocolled and reported automatically during an evaluation

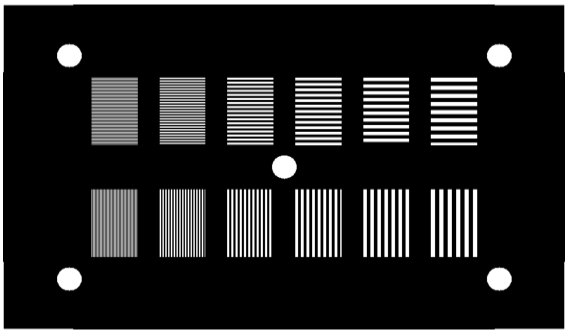
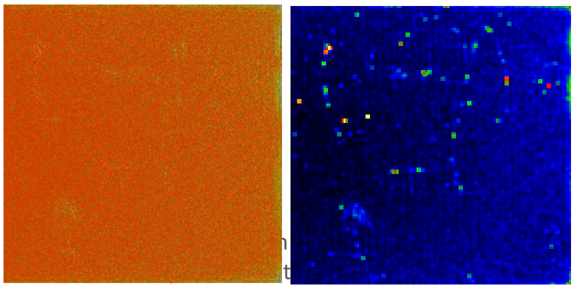


Figure 7: Established alignment pattern for geometrical setup [7]

Advanced analysis using the "sparkle matrix"

TechnoTeam has developed a simple algorithm to minimize the effect of tiny imperfections. The "sparkle matrix" is a locally calculated sparkle contrast for the complete back transformed image, including the measurement field angle setting from the camera calibration. To reduce the impact of outliers, the robust median value is used on the sparkle matrix [3]



The key to sparkle evaluation are robust algorithms and robust protocolled setups

Validation Experiment: Sparkle of an automotive display

In order to verify the proposed sparkle measurement values and their reproducibility, TechnoTeam tested it on two automotive displays with a PPI of 224 and 183 with several different AGL and different camera/lens setups (see Figure 9 for details).

Table 2 shows the achieved reproducibility for the 224 PPI display as coefficient of variation (CV), which is a measure for the relative deviation between the different setups. The first line shows the results from a direct measurement (without focus scan). The CV values are poor and range from 6% to 25%. The second line shows how the results improved by applying the distance focus scan. It significantly improves the CV for higher sparkle values because blur affects these sparkle samples more. The third line shows the results achieved via a distance focus scan combined with a local median-based sparkle matrix evaluation. This time, especially the low sparkling samples improve because tiny imperfections such as dust affect especially these samples. Altogether, the reproducibility between the different setups improved to a CV in the range of 3% to 5%.

Table 2: Reproducibility as CV from different setups with and without optimized procedures [3]

	Direct Measurement	**Focus Scan**	**Focus scan+ Sparkle Matrix**
No Glass	25.3%	18.9%	4.1%
Low 1	8.7%	10.1%	4.1%
Low 2	5.8%	8.6%	4.0%
Medium 1	8.4%	3.3%	4.6%
Medium 2	8.7%	4.4%	2.8%
High 1	9.7%	5.3%	5.2%
High 2	8.4%	4.3%	4.2%

Figure 9 shows the measured sparkle results. The x-axis of the graph shows the perceived sparkle by humans, which was rated by OEM and Tier 1 experts. The y-axis shows the measured sparkle in the specific camera lens setup.

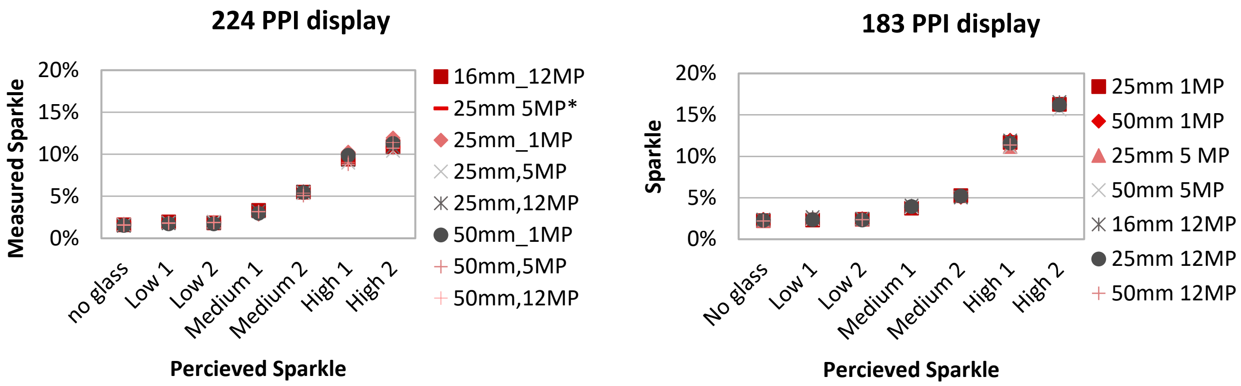


Figure 9: Sparkle results for two displays and seven different AGL in several different measurement setups

TechnoTeam's sparkle measurements are reproducible with all original LMK camera systems in flexible setups, produce values that correlate well with human perception, and can be performed without removing the AGL.

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