Concepts in Image Sticking Measurements: Temporal Alignment, Uniformity Correction and Grey Level Dependency

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ABSTRACT

This study introduces two proposed image sticking evaluation methods from the automotive industry and identifies relevant differences. It further focusses on the importance of precise temporal alignment and outlines the differences between temporal and local non-uniformity corrections as well as grey level dependency. The complete study bases on measured 2D luminance data.

1 INTRODUCTION

Image sticking is an undesired display property, which requires time-consuming and expensive testing. The effect can either occur permanently or vanish after a period of time.

A general sticking image measurement procedure consists of three periods. In the first period, the display is warmed up while constantly changing the presented pattern. The aim is to reach steady-state condition and heal previous image sticking. After that warm-up period, the burn-in period starts. It usually applies a "worst-case" pattern that tries to induce as much image sticking as possible for an agreed period of time. After that, the induced image sticking is measured in the relaxation period, where usually a uniform pattern including image sticking is evaluated.

The automotive industry has proposed two different image sticking evaluation methods [1,2]. In this study, these two methods are analyzed with respect to their uniformity correction method. Further, the general grey level dependency will be discussed. Finally, the importance of precise temporal alignment between pattern switching from burn-in to relaxation will be presented. This includes an easy method to detect each possible grey-level of pattern switching to start the measurement at exactly the right point in time.

2 Analysis according to the 2-level approach [1]

The 2-level approach from Bauer et. al is a comparable classical image sticking measurement method. It starts with a period called pattern rolling. The device under test (DUT) shows different grey-level images and changes them for a predetermined period of time. By performing the pattern rolling, the display will reach steady-state condition and heal from any previous sticking image test.

After the pattern rolling a reference image with the uniform relaxation grey level is captured. This image is

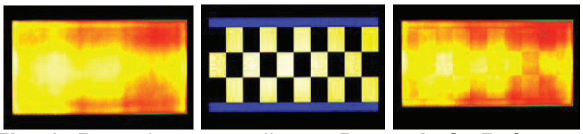

Fig. 1: Procedure according to Bauer: **Left:** Reference image; **Middle:** Burn-in; **Right:** Relaxation image

used to perform a non-uniformity correction on the sticking image measurement results. After that measurement, the burn-in pattern, which is a checkerboard with bright and dark fields is displayed for the burn-in time.

The first relaxation measurement shall start 100 ms after pattern switching to the relaxation grey-level image. Measurements are then carried out around continuously until a relaxation time has passed. The measurement procedure is outlined in Figure 1.

Each sticking image result is obtained by a comparison of a (former burn-in) checkerboard field and its four neighbors (also former burn-in) corrected by the luminance uniformity of the reference. The worst value is the value of that time frame.

The analyzed results are the maximum initial level of image sticking from the first relaxation image as well as the recovery time (time until the display has recovered).

3 Analysis according to the 3-level approach [2]

The 3-level approach from Lauer et. al does not necessarily require a warm-up period as long as it can be assumed that the display will reach steady-state condition during burn-in. Thus it can start directly with the burn-in period.

The first relaxation measurement starts within a short time after the pattern switching to the relaxation grey-level image. Measurements are then carried out around continuously, until a relaxation time has passed. The 3-level burn-in pattern (with black, white, and grey regions), the first relaxation pattern, and the measurement result are shown in Figure 2.

Each image sticking result is achieved by comparing a (former) white/black burn in the region with its grey (not burn-in) neighbors. The worst value from each column is the representative column value for that time frame.

The analyzed results are the initial level of image sticking for each column from the first relaxation image as well as the recovery time (time until the display has recovered).

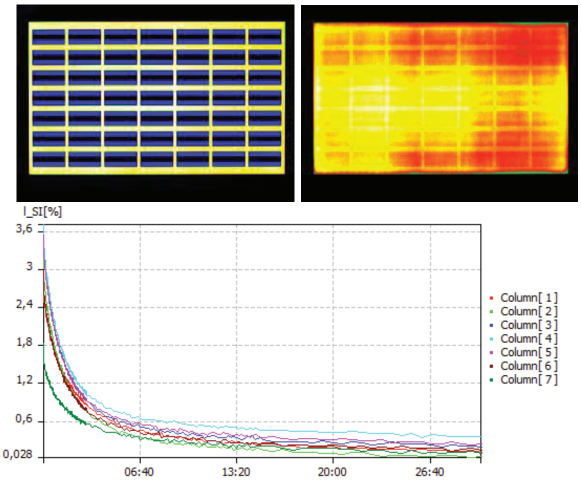

Fig. 2: Procedure according to Lauer et al.: **Left:** Burn-in; **Right:** Relaxation image; **Bottom**: Results with the original local reference

4 Non-uniformity analysis

Each sticking image evaluation requires the capability to differentiate between image sticking and spatial non-uniformity in the luminance distribution. The corrections are part of the evaluation methods. The 2-level approach and the 3-level approach each cover one correction type.

The 3-level approach relies on local references of neighboring fields, where no burn-in occurred. From these reference regions, the luminance of the burn-in field is interpolated and used to correct the non-uniformity.

The 2-level approach uses a reference image to ensure uniformity corrections. This means that the same region after burn-in is compared to the same region before burn-in to account luminance variations, which originate from the display non-uniformity. Both correction approaches have advantages and disadvantages:

Table 1: Comparison of the non-uniformity correction methods used by [1,2]

	Advantage	Disadvantage
Temporal reference according to [1]	• very good non-uniformity correction	• Prone to temporal variations (screen saver, environmental variations)
Local reference according to [2]	• not affected by temporal variations in the image • no warm-up necessary	• Uniformity correction slightly worse

Note that a temporal correction can be performed on the 3-level approach instead of the local correction. That way the 3-level approach can be used to detect temporal variations, but also with an improved non-uniformity correction. Both are important because according to [4] the burn-in is carried out at a temperature of 65° C.

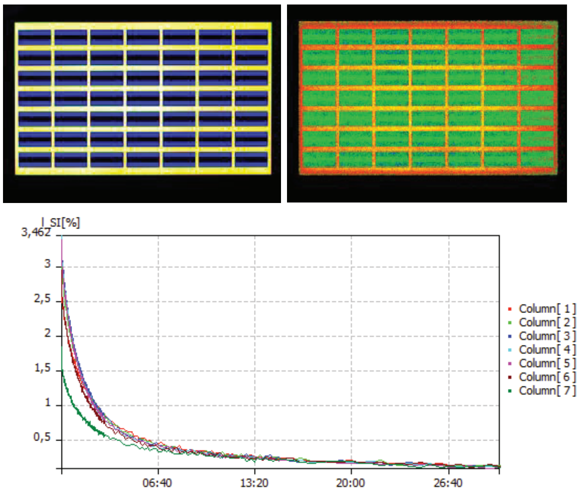

Fig. 3: Results from Fig.2 with a temporal reference: **Left:** Burn-in; **Right:** Relaxation image (with temporal based uniformity correction); **Bottom**: Results based on the temporal reference

Fig. 3 shows results from the same measurement series as Fig 2. but with a temporal reference instead of the original local reference. It shows that there are no temporal variations in the measurement because there is a smooth distribution in the original result. Further, the slightly better uniformity correction leads to a convergence towards zero.

Table 2: Comparison of measured sticking image values using the described methods (measured with the same LCD display and parameters)

Method/Time	1s	10s	100s	1000s	1800s
2-level	3.19%	2.83%	1.53%	0.39%	0.24%
3-level (local)	3.72%	3.12 %	1.56%	0.48%	0.38%
3-level (temporal)	3.46%	2.91 %	1.32%	0.23%	0.13%

Table 2 shows a direct comparison of measured image sticking values for different time frames of the same automotive LCD display using the 2-level, the 3-level (local), and the 3-level (temporal) method. All parameters such as warm-up and burn-in time were held constant.
The most interesting aspect about the results is the offset between the two correction methods of the 3-level-approach, which is approximately 0.24%±0.03%. This is the influence of the local correction only and in agreement to a measurement of the “Sticking image” using the 3-level (local) approach without burn-in.
The 2-level approach shows results that are in the same range. However, especially for the high values in the beginning, the results are smaller. The reason is a fundamental different evaluation: While in the 3-level approach SI values for bright and dark are compared to non-burn in regions, the 2-level approach compares burn-in regions directly with each other. Further, the comparison of the values at 1800s (which has no image sticking) shows that the least offset error is performed with the 3-level temporal approach.

5 Grey level dependency

It has been shown [3] that the worst-case regarding the image sticking phenomenon not necessarily occurs for the burn-in grey levels black and white and a medium grey relaxation level as proposed by [1,2] and that grey wedge images can be used as burn-in and relaxation image to find the real worst case for an LCD display. An exemplary experiment is shown in Figure 4.

It starts with a pre-test, in which the burn-in pattern is a horizontal grey wedge and the relaxation pattern is a vertical grey wedge. Thus, the pre-test combines all possible grey level combinations regarding burn-in/relaxation. Based on the calculated image sticking matrix [3], it is possible to identify the worst case grey levels combinations (128/255 (burn-in) at 107 relaxation grey). A comparison of a 2-level type measurement (0/255 (burn-in) at 128 relaxation grey) and the detected worst case of the same display validates the result. The relative image sticking is nearly two times higher. However, this kind of wedge evaluation has noticeable shortcomings:

- Relaxation wedge images lead to insignificant integration times for black (see Figure 4, Middle)
- A second 2-level or 3-level measurement is required after finding the worst-case grey level combination with the pre-test
- The rather smooth gradients complicate the evaluation and plausibility checks [5]

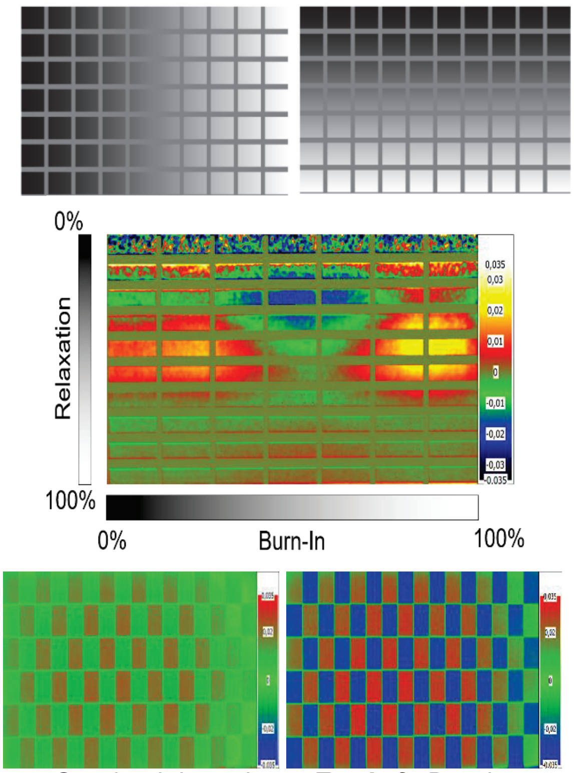

Fig. 4: Grey level dependency: **Top Left:** Burn-in pattern **Top Right:** Relaxation pattern; **Middle:** Sticking image matrix; **Bottom Left**: Results with default grey level values from [1,2]; **Bottom Right:** Results with worst case grey level values from the image sticking matrix [3].

Further spatial effects are not considered and may be mixed up with grey level dependency. The 3-level approach column-wise evaluation in Figure 2 and Figure 3 shows that there can be a significant spatial effect.

Therefore more advanced dynamic test procedures have been developed [5]. They are based on segmented measurements with dynamic grey relaxation image adjustment. An example is provided in Figure 5, which shows the burn-in pattern and a dynamic relaxation pattern, in which one region is evaluated (while maintaining burn-in in the other regions). The procedure is the following:

In the two upper left regions, a so-called “Manhattan Gamma” image is shown for burn-in (in the range 0 to 255). The relaxation grey images are Manhattan-Gamma images as well. The grey levels in the relaxation are divided into the darker values (left image) and brighter values (right) based on luminance to have a suitable integration time for each relaxation image. In the evaluation, several different burn-in and relaxation grey levels are compared to another similar to the grey wedge pre-test from [3].

The relaxation grey values, which produced the highest image sticking values in the first two regions, are then used as relaxation images for the following eight regions (all besides the two bottom right regions).

For the last two regions, the procedure is repeated based on an evaluation of the eight middle regions.

This procedure is more complicated. However, it overcomes most shortcomings of the simple pre-test from [3]. Only the influence of spatial effects remains. But it can be reduced if the number of dynamically adjusted grey levels is decreased and the same grey level is tested over a large part of the display area.

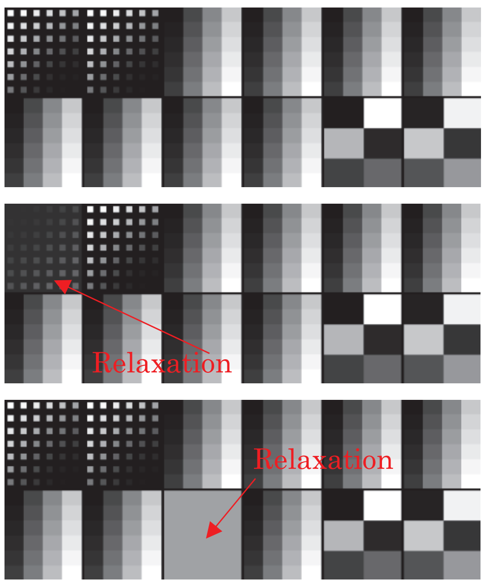

Fig. 5: Top: Burn-in pattern; **Middle**: Relaxation grey level pre-test; **Bottom**: Sticking image with dynamic relaxation grey level adjustment (based on pre-test) [5]

Note that these kinds of segmented evaluations can also be used to test several different burn-in times or burn-in times and grey level dependency or other parameters in just one burn-in period. That way more information regarding the image sticking behavior can be evaluated based on only one measurement series.

6 Temporal alignment

One important aspect of image sticking measurement is the temporal synchronization between the pattern switching from burn-in to relaxation and the relative start of the measurement of the first relaxation image.

If the measurement shall start within a short time delay (as required by [1], or the IDMS 10.4 [6]), two things need to be considered:

- An input lag might delay the pattern switching, which causes the measurement to be too early
- Delaying (to avoid the input lag) the measurement in case of fast relaxation reduces the measurement value and might reduce correlation to human perception of the phenomenon

The error that can occur if the measurement starts too early is comparably high. Table 3 shows an experiment, where the same display (without a burn-in period) has been measured using different computers and interfaces (including conversion adapters) to mimic different setup dependent input lags. As there was no burn-in, each measurement value should be very near to zero. However, the measured results are often much higher. While the high values have a chance of being recognized as erroneous, some of the smaller measurement errors are in the region of realistic image sticking data. This can easily cause false results.

With respect to an unknown input lag, there are two possible solutions: The first is to simply wait for a longer delay time. However, this can be problematic in case of short relaxation times and leads to systematic errors [3].

The other option is to combine an optical trigger, which can detect pattern switching with a much higher temporal resolution, with a (short) delay time. The optical trigger detects pattern switching and the camera starts the measurement after the delay time. Both, external as well as ILMD internal triggers, which react to image content, are possible. Examples for these realizations are shown in Figure 6. The important aspect is only the sensitivity towards pattern switching and the temporal resolution.

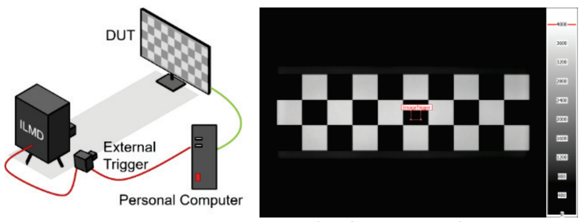

Fig. 6: Temporal alignment: **Left:** Scheme of an external optical trigger; **Right**: Example of an image contest based trigger (fast observation of one checkerboard field)

Table 3: Sticking image results caused by starting the measurement too early (without burn-in) [3]

Set-up		First measured Sticking Image value		
Computer	Interface	Median	Min	Max
PC 1	HDMI	5,8%	1,5%	41%
PC 1	VGA	2,7%	0,5%	9%
PC 1	USB	5%	3%	50,5%
PC 2	HDMI	3%	2%	6%
PC 2	VGA	35%	8%	61%

7 Conclusion

In this study, two important sticking image approaches from the automotive industry are compared. While the fundamental difference is the uniformity correction method, which leads to different advantages and disadvantages other concepts are similar.

Both procedures require temporal alignment between the pattern generator and the start of the relaxation measurements because the first measured sticking image value (especially in dynamic LCD systems) is an important result. In [1] the short delay of 100 ms can be ensured with an optical trigger technology. In [2] it depends on the agreed delay time. However, precision is also higher for short delay times as reported in [7].

The observed grey levels are identical in both methods. However, grey-level dependency has been reported and more advanced tests as proposed in this paper are under development. Thus, the grey levels in the test pattern of existing methods might change or become more dynamic in the future.

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