Experimental study for the establishment of an evaluation criterion for the image sticking effect in OLED TV panels

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Abstract — The individual elements of organic light-emitting diode (OLED) displays degrade at different rates, because each element emits light independently; the resulting luminance differences between individual elements cause image sticking—a phenomenon where a displayed text or pattern remains on the screen even after changing the image contents—and are therefore an important issue in OLED displays. However, the introduction of OLED technology into large TV displays is still recent, and no criterion for image sticking evaluation has yet been established. The keystone of a criterion for image sticking evaluation is the definition of the difference level between the luminance of individual elements at which the viewer feels that image sticking is present. Therefore, in this study, an image sticking perception experiment is carried out in accordance with statistically sound procedures for experimental design, using a comprehensive set of human subjects to evaluate the presence of image sticking in moving images. The obtained results are analyzed, and two criteria for image sticking evaluation are proposed.

Keywords — *image sticking, luminance degradation, OLED, perception experiment.*

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1 Introduction

Organic light-emitting diodes (OLEDs) are attracting much attention and are widely considered to be a leading next-generation display and lighting technology. An OLED is a light-emitting diode whose emissive material is a carbon-based organic compound that emits light when an electric current is applied. The pixels of an OLED display are constituted by such emitting OLEDs, whose joint light emissions are used to display visible information.[1] Therefore, no backlight is required for an OLED display, and ultra-thin and ultra-light displays can be produced with this technology. These displays have the additional advantages of fast response and wide viewing angles.[2] Even though many studies on the application of OLED display panels to television (TV) sets and mobile devices have been published and are still actively being carried out, the lifespan limit of OLED displays is the most important problem still requiring improvements.[3]

The lifetime of displays—including OLED displays—is generally defined by the reduction in luminance; a commonly used measure is the L50 lifetime, which quantitatively expresses the time it takes for the display luminance to be reduced to 50% of its initial value. However, the luminance degradation rate of the individual elements of an OLED display varies, because each element emits light independently. A difference in the luminance degradation of the individual elements causes image sticking—a phenomenon where a displayed text or pattern remains on the screen even after changing the image contents. The original condition is not restored once degradation has progressed. Image sticking is more difficult to deal with than the general lifetime constraint.[4] Therefore, image sticking lifetime is an important issue in OLED displays.

The period of time until the occurrence of image sticking is defined as the image sticking lifetime. A criterion for evaluating whether or not image sticking exists should be established, so that consistent image sticking lifetimes can be determined. The keystone of a criterion for image sticking evaluation is the definition of the difference level between the luminance factors of individual elements at which the viewer feels that image sticking is present. To establish a criterion for image sticking evaluation, Choi and Cho[5] carried out an image sticking user perception experiment, by changing the luminance and color of a mobile OLED panel. Based on the results of the experiment, they obtained a threshold for image sticking presence at a luminance change in the 1 to 3% range. Laaperi[4] carried out a similar image sticking perception experiment and obtained a luminance change for each user perception level. Lee *et al.*[6] performed an evaluation on a small TV set display. However, all these studies were performed for small OLED displays. Johnson, O'Regan, and Trujillo[7] suggested a test pattern considered to be representative of the image sticking effect of general TV contents and the average watching customs of general TV users. However, all the mentioned studies were performed using test patterns, which cannot mimic real-TV environments. Lim *et al.*[8] carried out a perception test using videos, in an attempt to emulate

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the real TV environment; however, this study does not consider the influence of the number of participants on the perception of the screen defects. When an experiment is carried out through a survey, the number of specimens must be determined by the data characteristics and the desired confidence level and error upper bounds.[3]

Large OLED TV display panels are still in the initial stages of market penetration; objective studies and experiments are therefore required, so that verifiable information may be produced and users can reliably use the criterion for image sticking evaluation. In this study, an evaluation experiment for large OLED TV panels is planned and carried out using statistically sound procedures of experimental design, with the core objective of proposing a criterion for image sticking evaluation.

2 Experimental design and setup

The general experimental procedure is shown in Fig. 1. Of the five steps identified in this figure, the first four will be discussed in this section. The last step (experimental data analysis) will be covered in Section 3.

2.1 Definition of objectives and experimental method selection

As previously mentioned, the luminance degradation rate of the individual elements of an OLED display varies, as each element emits light independently. As an example, two areas with different degradation rates are shown in Fig. 2: the luminance degradation of the logo elements in region 1 is high, because they are continuously operated in the same static conditions, whereas in region 2, the screen image is highly dynamic, leading to smaller degradation rates. As a result of the difference in luminance caused by the different degradation rates, the image sticking phenomenon appears: text or patterns displayed for a certain period of time remain visible even after changing the image contents. The concept of image sticking lifetime designates the time until the user perceives the phenomenon; that is, the time until the user perceives the difference between conditions 1 and 2. Accordingly, the objective of the experiment is to determine at what percentage of degradation difference the tester starts to perceive the existence of image sticking.

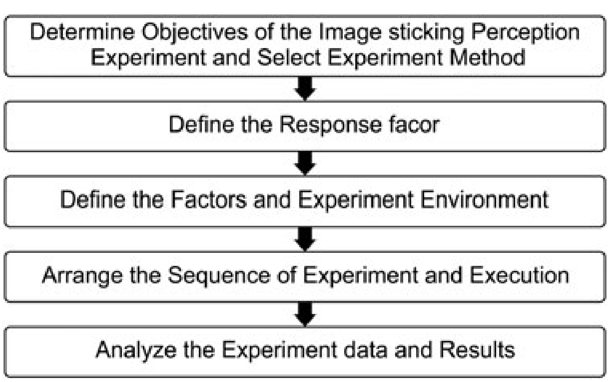

FIGURE 1 — Experimental procedure.

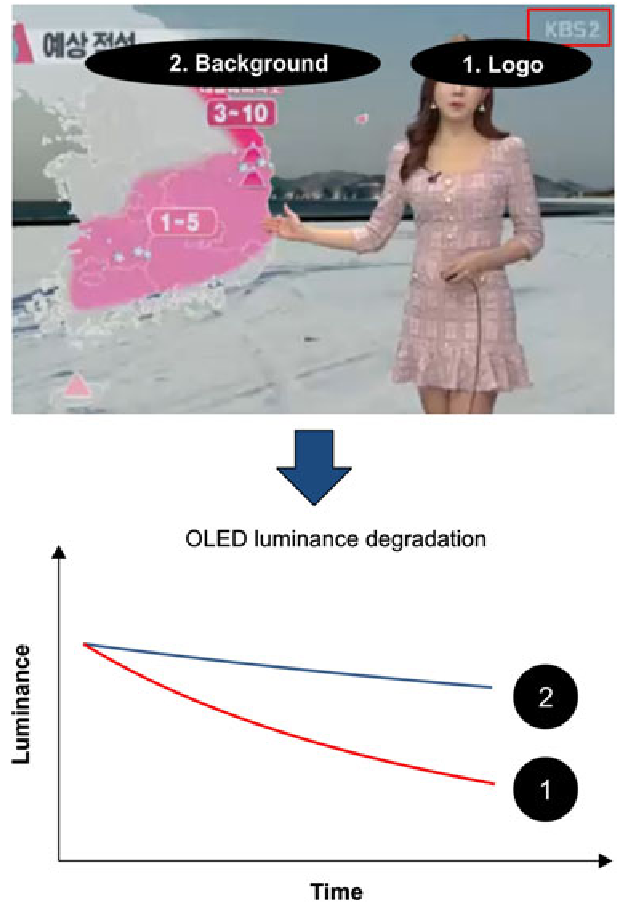

FIGURE 2 — An example of image sticking.

Two different types of approach can be adopted to evaluate the image sticking effect: obtain measured quantitative data using an automated system, or obtain a human evaluation of the phenomenon, using human subjects to evaluate screen quality.[9] The former approach of using a tester system to obtain quantitative data is faster and less costly, because defects in the panel are automatically processed; it has a disadvantage in that defects may not be accurately detected, as screen distortions may occur when the system records the screen, because of both light or distance conditions. The later approach—in which human subjects evaluate the screen—has the disadvantage of being susceptible to evaluation criteria that may differ from subject to subject; it is also more costly and requires more time. However, considering that the concept of image sticking lifetime is intrinsically human dependent (it is defined as the time until the user perceives the existence of image sticking, as discussed earlier) and no accurate criterion has yet been established, human evaluation is not only important but also unavoidable. Image sticking is therefore evaluated in this study by means of an evaluation experiment wherein human subjects evaluate the screen.

2.2 Response definition

Five image sticking levels are defined, using the criteria shown in Table 1.[4,9] They are established using evaluation questions.

The afterimage luminance corresponding to the detection time (the moment when a typical person starts to feel that image sticking is present) can also be obtained from the empirical distribution of the obtained responses. This is shown in Fig. 3, where the distribution of the responses is represented as a function of the afterimage luminance.

2.3 Experimental environment and factors definition

2.3.1 Number of subjects

In the case of interval data and arbitrarily large populations, 119 specimens are required for a confidence level of 95% and an error upper bound of 5%.3 One hundred and twenty subjects were therefore selected, taking into account their characteristics, such as age, gender, and expertise in image quality evaluation. The subjects were divided into occupational groups: a group of people who professionally evaluate the screen quality of OLED TV panels, a group of office workers with activities not related to image quality evaluation, and a group of researchers—who are more sensitive to screen quality than general office workers. The subjects were selected disproportionately, because of the experimental conditions; their division by gender, age, and occupational group can be seen in Fig. 4.

2.3.2 Image choice

Considering that the objects of this study are OLED TV panels, whose main purpose is video watching, the evaluation was carried out using an experimental set of videos chosen to mimic common TV usage.[7,8] Images were selected from typical image type groups (news, movies, entertainment shows, sports, music, documentaries, animation, and home shopping), as shown in Fig. 5.

TABLE 1 — Image sticking level definition and quantification.

Image sticking level	Perception characteristics
0	Imperceptible image sticking
1	Perceptible, but not annoying
2	Slightly annoying
3	Annoying
4	Very annoying

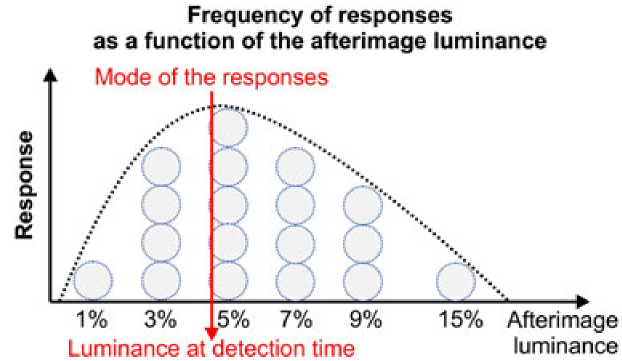

FIGURE 3 — Distribution of responses as a function of the afterimage luminance.

The values of brightness, chroma, and screen switching speed were defined as the control factors with impact on perception, and were $L_9(3^3)$-orthogonally arranged. The final images were arranged by matching the images with these control factors. The difference between the luminance values of the sticking image part and the background image part (afterimage luminance) was set to 1, 2, 3, 5, 7, 9, and 15%, thus including the 1, 3, 5, and 7% levels found in the literature. The final experimental design is shown in Table 2.

2.4 Image sequence arrangement

The experiment was carried out showing the total 63 images in random sequence.

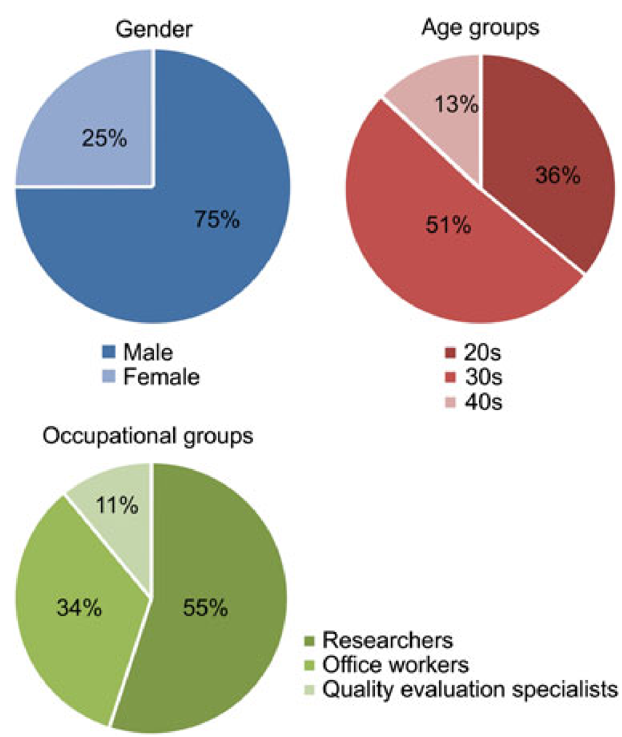

FIGURE 4 — Subjects by gender, age, and occupational group.

FIGURE 5 — Examples of images used in the experiment.

3 Experimental data analysis

3.1 Integrated image sticking perception results and threshold determination

Table 3 shows the relative frequency of the integrated response to images 1 to 9, at each perception level, for the different afterimage luminance conditions. The image sticking perception increases for increased afterimage luminance, except for level 0 (imperceptible image sticking). In the following statistical analysis of results, only the levels where sticking was present will be considered (levels 1 to 4).

The goodness-of-fit values obtained for each image sticking perception level with three different analytic distributions (normal, lognormal, and Weibull) can be seen in Table 4. As shown, the best fit was obtained for a Weibull distribution, for which the Anderson–Darling values are generally the lowest and the correlation coefficient values are generally the highest.

The Weibull distribution is very widely used as a reliability model, mainly because of the flexibility conferred to it by its shape parameter β. The Weibull probability density function is given by[10]

$$\mathrm{f(t)} = \frac{\beta}{\eta}\left(\frac{t}{\eta}\right)^{\beta-1} e^{-\left(\frac{t}{\eta}\right)^{\beta}} \qquad \beta > 0,\ \eta > 0 \tag{1}$$

where β is the shape parameter determining the distribution shape, and η is the scale parameter, which determines its time scale. Figure 6 shows the probability density function of the responses for each perception level.

The mode (Mo) of the Weibull Distribution can be calculated by

$$\mathrm{Mo} = \eta\left(1 - \frac{1}{\beta}\right)^{\frac{1}{\beta}}. \tag{2}$$

Table 5 shows the mode obtained for each perception level using 2.

TABLE 2 — Experimental design.

Test No.	Brightness	Chroma	Screen switching speed ➜	Image	Afterimage luminance (%)	Notes
1	Low	Low	Low	Movie	7 levels (1–15)	
2	Low	Medium	Medium	Music	7 levels (1–15)	
3	Low	High	High	Animation	7 levels (1–15)	
4	Medium	Low	Medium	Home shopping	7 levels (1–15)	
5	Medium	Medium	High	Entertainment shows	7 levels (1–15)	
6	Medium	High	Low	News	7 levels (1–5)	
7	High	Low	High	Sports	7 levels (1–5)	
8	High	Medium	Low	Documentary	7 levels (1–15)	
9	High	High	Medium	Documentary	7 levels (1–15)	A total of 63 images were evaluated.

TABLE 3 — Relative frequency of responses (%) for various afterimage luminance values.

Image sticking perception level	Afterimage luminance (%)						
	1%	2%	3%	5%	7%	9%	15%
Level 0	88.69	86.13	81.80	77.58	74.13	66.37	53.19
Level 1	9.046	11.40	14.84	17.99	19.96	23.59	24.48
Level 2	1.671	1.769	2.654	3.638	4.621	6.883	12.97
Level 3	0.590	0.590	0.590	0.786	1.081	2.654	6.981
Level 4	0.000	0.098	0.098	0.000	0.196	0.491	2.359

TABLE 4 — Goodness-of-fit values.

Image sticking perception level	Anderson–Darling			Correlation coefficient		
	Weibull	Lognormal	Normal	Weibull	Lognormal	Normal
Level 1	27.61	35.47	47.28	0.961	0.952	0.941
Level 2	17.96	19.40	19.77	0.960	0.912	0.925
Level 3	13.68	13.89	12.60	0.932	0.851	0.888
Level 4	7.200	6.145	6.30	0.850	0.740	0.785

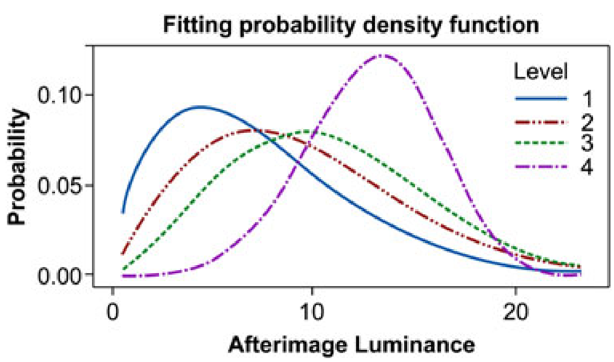

FIGURE 6 — Probability density function of each response.

TABLE 5 — Mode of each image sticking perception level.

Image sticking perception level	Shape parameter (β)	Scale parameter (η)	Afterimage luminance mode (%)
1	1.61017	0.081507	4.461
2	1.93572	0.105118	7.220
3	2.32878	0.121034	9.512
4	4.52342	0.140518	13.29

Two criteria may be defined from the results in Table 5, depending on the desired quality stringency requirements. For high-quality precision screens, a level 1 severity criterion (4.46% of afterimage luminance) may be used; for the general case, a less stringent level 2 criterion (7.22% of afterimage luminance) may be adequate.

TABLE 6 — Criteria obtained with medium factor levels in each individual image.

Image sticking perception level	Brightness	Chroma	Screen switching speed	Afterimage luminance mode (%)
1	Medium	Medium	Medium	4.3780
2	Medium	Medium	Medium	7.4658
3	Medium	Medium	Medium	9.5934

TABLE 7 — Equal shape parameter test for the different groups.

Image sticking perception level	Occupational groups (General office workers/ Quality evaluation specialists/ Researchers)	Age groups (20s/30s/40s)	Gender
1	0.668	0.168	0.189
2	0.37	0.947	0.837
3	0.381	0.108	0.762
4	0.135	0.051	0.276

3.2 Image sticking perception results and threshold determination for medium factor levels

The earlier-presented criteria were obtained from the integrated response to the full experimental design presented in Table 2. For comparison purposes, an additional threshold evaluation was performed for each perception level with the factors (brightness, chroma, and screen switching speed) of each individual image set at their medium levels. The obtained values are shown in Table 6. The value for perception level 4 is not presented because the obtained number of positive responses was too few. As shown, the obtained results are consistent with the previously obtained criteria.

3.3 Subject dependence of the image sticking perception

Different subjects may have different tolerances for the image sticking effect. To verify whether there is any difference in the level of image sticking perception among the groups, a test for the equality of the shape parameter was performed, considering a base Weibull distribution. Table 7 shows the results of the equality tests obtained for each group. As shown in this table, no statistically significant differences in personal characteristics were found for p-values greater than 0.05.

4 Conclusion

Commercialization of OLED displays has started in earnest; the OLED display market is growing, and the demand is increasing. However, when an OLED TV is used for a long time, the image sticking phenomenon may appear. Considering that no evaluation criterion has yet been established for image sticking, the need for such a criterion has been increasing. Therefore, an image sticking perception evaluation experiment was conducted in this study, taking into account the sample size and characteristics of the subjects, with the aim of proposing an evaluation criterion.

One of the conclusions of this study is that the individual characteristics of the observers do not affect the criterion in a statistically meaningful way. This test was performed with test patterns capable of mimicking the real TV environment, and with a reasonable (and statistically sound) number of testers. Two criteria can be defined as a result of our work: a criterion for level 1 severity (4.46% of afterimage luminance) to be used for high-quality precision screens, and a level 2 criterion (7.22% % of afterimage luminance) to be used in the general case, where no special high-quality, high-precision requirements exist.

The threshold criteria presented in this study are meant to be used for OLED TV products. However, they were obtained for a single sample; for a robust definition of criteria that producers and consumers can trust together, evaluation data must be obtained for a representative diversity of samples. In the future, a comprehensive plan to build a representative database, and therefore reduce the error rate of the obtained image sticking evaluation criteria should be implemented.

References

1 H.-S. Cho *et al.*, "Hardware Implementation of Low-power Display Method for OLED Panel using Adaptive Luminance Decreasing," *J. Korea Inst. Inf. Commun. Eng.*, **17**, No. 7, 1702–1708 (2013). DOI: 10.6109/jkiice.2013.17.7.1702.

2 S.-M. Hong "Analytic Study on Enhancement of Thermal Diffusion and Reduction in Thermal Deformation of OLED Display Multi-layer Flat Plate Structure" Ph.D. thesis, Korea University, Seoul (2014).

3 J. Barlett *et al.*, "Organizational research: determining appropriate sample size in survey research," *Information Technology, Learning, and Performance Journal*, **19**, No. 1, 43–50 (2001). DOI: 10.1.1.486.8295.

4 A. Laaperi, "OLED lifetime issues from a mobile-phone-industry point of view," *J. Soc. Info. Display*, **16**, No. 11, 1125–1130 (2008). DOI: 10.1889/JSID16.11.1125.

5 Y.-T. Choi and J.-R. Cho, "A study on the method of OLED device's lifetime test," *J. Korea Safety Manag. Sci.*, **10**, No. 4, 145–152 (2008).

6 H. Lee *et al.* "Image Sticking Evaluation Methods for OLED TV Applications" *9th International Meeting on Information Display* (IMID 2009), Seoul, 52–54 (2009).

7 A. Johnson *et al.*, "Influence of TV Media Content on Display Lifetime and Image Sticking Measurement Techniques," *SID Symposium Digest*, **43**, 43–45 (2012). DOI: 10.1002/j.2168-0159.2012.tb05704.x.

8 K. Lim *et al.*, "P. 42: Estimation and Evaluation of Image Sticking on OLED Device," *SID Symposium Digest*, **44**, 1152–1154 (2013). DOI: 10.1002/j.2168-0159.2013.tb06431.x.

9 K.-M Mo, "Quantitative evaluation method of image sticking on LCD TV by reflecting cognitive characteristics" M. Sc. thesis, Sugang University, Seoul (2013).

10 W. Nelson, Accelerated Testing: Statistical Models, Test Plans, and Data Analysis. John Wiley & Sons, NJ, (2009). ISBN: 978-0-470-31747-1).

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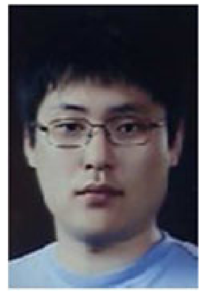

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