Specification for Color E-Paper

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ABSTRACT

E-paper has been approached as a “normal” display, and measurements are based on measurements as used for emissive displays, or at the very best reflective monochrome LCD. This may be adequate for grayscale e-paper displays, but as soon as color is added, these metrics are no longer suitable. This paper introduces a better way to evaluate color e-paper displays.

1 INTRODUCTION

Until now, reflective color displays are rare. Several parties have tried to introduce reflective color displays based on RGB color filters, but these displays generally fail to reach the market due to lack of reflectance. Only few examples using CMY colors are known [3]. It is difficult to evaluate the color performance based on the existing specifications. However, focusing on the comparison with printed matter provides better insight in the performance.

Display measurement methods describe ways to determine the performance of a display, in terms of luminance, response time, color gamut / gamut volume etc. Important in these metrics is the interdependence of bright luminance, dark luminance and contrast ratio. In emissive displays (e.g. OLED), dark luminance under measurement conditions is close to zero. This means, regardless of bright luminance, the contrast ration is near infinite. For light valves (e.g. LCD with backlight), the dark luminance is higher than zero, and so the contrast ratio is a finite number and also depends on bright luminance. If for simplicity we assume bright luminance as constant, the target for these displays is to achieve minimum dark luminance, and hence high contrast ratios.

This high contrast ratio is not important for the image in a bright environment: In this case, both emissive and light valve displays will perform sub-optimal because of surface- and array reflections. But in dark environment, with reduced bright luminance, it is important to still achieve deep blacks. Often, LCDs show considerable bleed-through under these conditions and as a result not only the image deteriorates, but also color reproduction suffers. This can be understood once we realize the primary colors red green and blue are attenuated by the display switch, and so if a pure primary must be displayed, the color is contaminated by the residual bleed-through of the other two primaries.

For reflective displays, the situation is very different. The contrast ratio is not dependent on ambient light, since both bright and dark state vary identically with ambient illumination. This is true for additive displays (RGB or RGBW-system) as well as subtractive (CMY) displays. The additive displays, however, will never provide a bright image because of the light loss of the color filters applied, while subtractive displays have a possibility of a very bright image. For both additive and subtractive displays, contrast ratio and color gamut are constant and do not (significantly) depend on ambient light. (luminance, of course, does). For subtractive color reflective displays, the situation is better, since color gamut depends only on the transmission spectra of the primaries and not on the black and white state of a light valve.

2 EXPERIMENT

We have evaluated electrowetting reflective color displays, as reported on previous occasions [1, 2] on the basis of printed matter specifications. As a starting point, we have used SWOP, a “Standard for Web Offset Publications” (Figure 1). This is a standard that defines

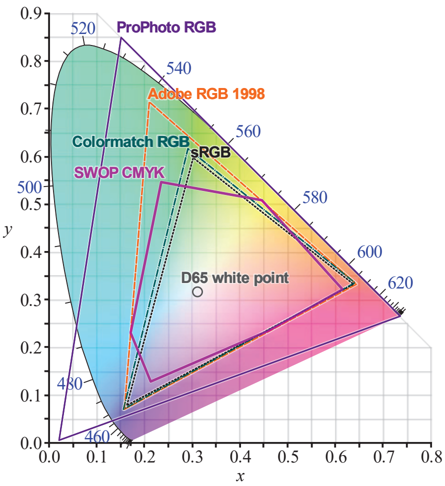

Figure 1 Color system comparison

the result of printed documents based on a number of primary dyes / pigments for cyan, magenta and yellow.

It is safe to say that SWOP describes the state of the art for printing, and guarantees reproducibility of the printed colors. Derived standards as "SNAP" ("Specification for Newsprint Advertising Production") generally follow the same rules, but the SNAP specification allows the printing pigments to be slightly less saturated than the "state of the art". The electrowetting display uses dyes chemically different from the ones in the printing industry. However, in order to achieve the same color specifications as printed matter, the dyes must be as close as possible to the ones specified by SWOP in terms of their optical properties. It has been demonstrated the yellow and magenta dyes are very close to the ones specified by SWOP. The cyan dyes are more difficult to reproduce, but recently significant progress has been made (figure 2).

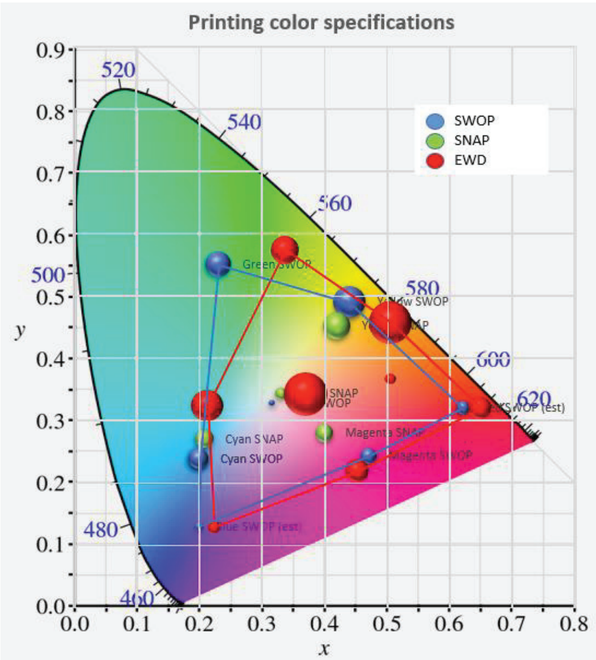

Figure 2: Reflective color gamut: SWOP (blue), SNAP (green) and CMY electrowetting display (red)

With this in mind, also a comparison was made between the "SWOP" standard and color gamut volume, and the final specification demonstrated for both systems. First, we did an assessment of the colors used in everyday images, by measuring the properties of the X-Rite "ColorChecker" chart (figure 3 and 4). It is immediately clear that all measured color coordinates fall within the area laid out by the SWOP color specification, but some are outside SNAP.

Then we compared these colors and the SWOP / SNAP areas with the emissive display RGB color gamuts (i.e. sRGB and Rec. 2020) to investigate possible deficiencies.

Figure 3: X-rite ColorChecker chart

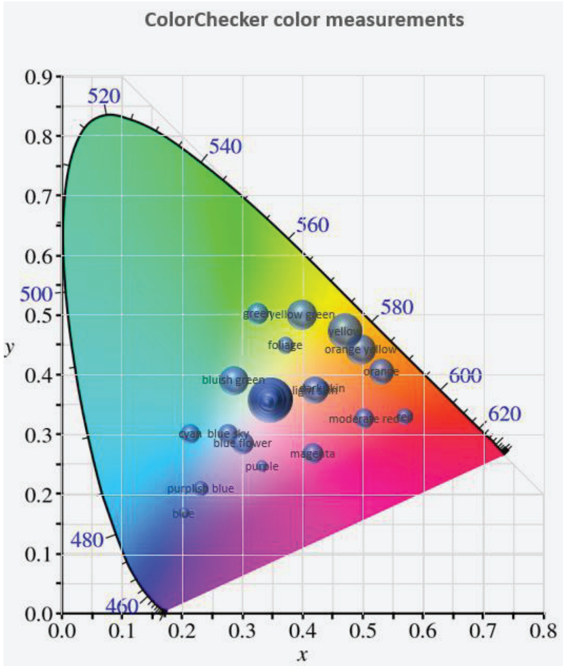

Figure 4: Measured data of the "ColorChecker" reference card

3 RESULTS

As can be seen in Table 1, the results were enlightening. The printed documents were obviously not even in compliance with the sRGB color gamut. In terms

Table 1: Comparison of the various color gamut areas, CMY electrowetting display, and their mutual size differences

System	Area	%NTSC	%sRGB	2020%
NTSC	0.158	100.00	141.19	74.67
sRGB	0.112	70.83	100.00	52.89
REC2020	0.212	133.92	189.08	100.00
Adobe	0.151	95.54	134.90	71.34
SWOP	0.084	52.89	74.67	39.49
EWD	0.103	65.38	92.31	48.82

of gamut volume (not shown), they were even further away. But according to the SWOP color definition they were fully compliant to (and even exceeding) the printing standard, and thus state of the art.

4 DISCUSSION

At first instance it looks like the RGB color gamut areas are far superior to the CMY specifications. However, due to the hexagonal shape of the printed areas, the CMY primaries are quite hard to reproduce using an RGB color triangle. As can be seen from Figure 5, sRGB (HDTV) has difficulty reaching some of the colors achieved by SWOP in yellow and red, but even misses the SWOP green altogether. Hence the triangles set up by the RGB color systems have to be extraordinarily large in order to cover all printable colors. Rec. 2020 achieves this by moving the green primary far away from the sRGB green coordinates. The extra area is therefore mostly situated around the green primary. Because of the low sensitivity for color change in these regions, the additional area near the primary does not significantly contribute to the reproduction of colors. The advantages must be in the better reproduction near the CMY primaries.

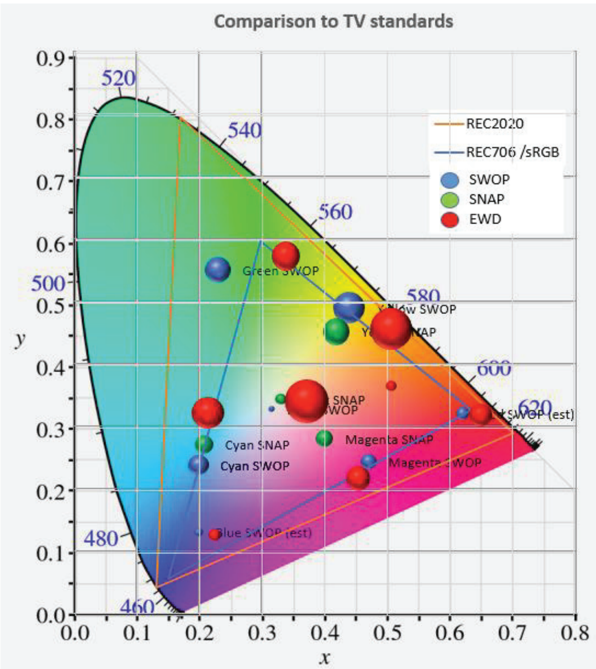

Figure 5 CMY colors compared with sRGB and REC 2020

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However, we are not used to looking at reflective displays in this way. We still use color gamut and contrast ratio to describe the display color performance, even when this doesn't relate to the way colors are made or perceived.

It would be better to look at the way printed matter is specified and use this specification to describe in how far a reflective display can perform on par with a printed document. This makes sense, since in a reflective display the contrast ratio doesn't need to be very high since it will not vary with ambient light. A typical contrast ratio for a printed document is 20:1, which is excellent for all applications.

5 CONCLUSIONS

Displays are generally evaluated using conditions for emissive (transmissive for LCD) displays. This produces a disadvantageous result for reflective displays, since contrast ratio is ~20 where emissive displays show figures >> 1000. Color gamut is 65-70% NTSC / 40-50% Rec. 2020 where some emissive displays nowadays score over 90% Rec. 2020. Despite the large differences, the color reproduction range achievable by printed colors and thus by CMY based reflective displays are not significantly inferior to the reproducible colors of RGB based LCD or OLED displays. Hence, it would be advised to evaluate reflective, subtractive color displays more in the way printed matter is evaluated, and judge the display parameters accordingly.

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REFERENCES

[1] A. Henzen, G.F. Zhou, "Color video e-paper: It's reality now"; Proceedings of the IDW 2018

[2] Alex Henzen, Guofu Zhou, Yuanyuan Guo, Yingying Dou, Hongwei Jiang, Guisong Yang, Biao Tang, "Full Color Active Matrix Video E-paper", proceedings of the SID 2019

[3] Z. L. Zhou, J. S. Yeo, J. Mabeck, G. Combs, D. Henze and T. Koch, "Novel Digital Media with Electronic Inks" The 31st International Congress on Imaging Science (ICIS), May 12- 16, Beijing, China (2010).