

Evaluation of Display Color Chromaticity Gamut Efficiency Based on Real Objects Colors

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Abstract

This paper introduces a simple metric for Color Chromaticity Gamut Efficiency (G.E) in terms of color chromaticity in nature. Color Chromaticity Gamut Efficiency is defined as how efficiently a display covers the chromaticity of real objects in nature such as the Standard Object Color Spectra (SOCS) and Pointer's. G.E can be calculated by reproducible area, non-reproducible area and non-efficient area regarding real object colors. G.E is higher when the display's color gamut covers ROC efficiently and accurately. Our study found that Adobe + Display P3 has the best color gamut in terms of G.E among various standards including BT.2020. G.E can serve as a guideline for manufacturers when designing display parameters. For instance, a manufacturer might choose to reduce power consumption instead of expanding the color gamut considering G.E. It is expected that consumers could choose a better display with an efficient color gamut, G.E.

Author Keywords

Color Chromaticity Gamut Efficiency; Gamut Efficiency; Adobe + Display-P3

1. Objective and Background

Color gamut is one of the parameters that determine the image quality of a Display. It has been continuously improving to accurately reproduce the colors that we see in nature, in order to provide better image quality to consumers. Several studies have been conducted to determine the optimal direction for color gamut in terms of coverage of real object's spectral data [1-4]. The Standard Object Color Spectra (SOCS) and Pointer's color has approximately 50,000/ 4,000ea database, respectively [5-6]. They are well-known for their collection of real object's color spectrum (ROC) data and previous researcher above mentioned also approached the optimal color gamut based on these database [1-4]. The color coordinates of BT.2020 which is known as the widest color gamut container in HDR standard are also defined how much covers SOCS and Pointer's as well [3]. However, it is important to note that a wider color gamut does not necessarily mean better efficiency in reproducing ROC coverage, especially for 3-primaries displays. In fact, a wide color gamut without considering the direction of coverage may result in a larger useless area for ROC reproduction, as shown in Figure.1. For instance, BT.2020 has a wide area for reproducing ROC meanwhile, its non-efficient area is also wide simultaneously. To measure the efficiency of how well color gamut of display covers ROC, Gamut Efficiency was introduced in 2014 [3]. The previous paper suggested Gamut Efficiency for color gamut of display in CIE L*a*b* color space. However, the weight for the previous metric was determined empirically in the previous study. Results from Gamut Efficiency was changed depending on a weight. This paper shows that more intuitive and simpler metric regarding Gamut Efficiency in CIE x-y color chromaticity so, it can be easier to approach and interpret results of Gamut Efficiency. Results in CIE L*a*b* color space is also compared to those of CIE xy and u'v' color chromaticity in this paper.

2. Methods

(a) The concept of Color Chromaticity Gamut Efficiency:

Color Chromaticity Gamut Efficiency (G.E) can be defined by three parameters: (a) Reproducible Area (RA), (b) Non-reproducible Area (NRA), and (c) Non-efficient Area (NEA) regarding real object colors. G.E increases when color chromaticity gamut of display efficiently and accurately covers the ROC. Specifically, G.E is higher when RA is larger and both NRA and NEA are smaller. Although BT.2020 has a wide area for reproducing ROC, its non-efficient area is also quite large as shown in Figure 1.

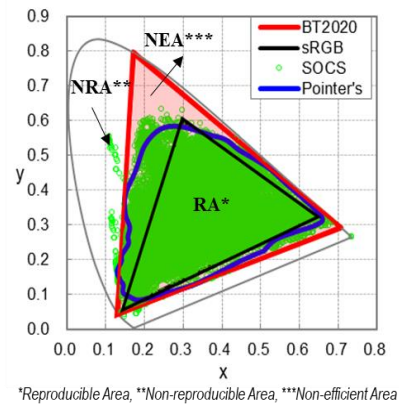


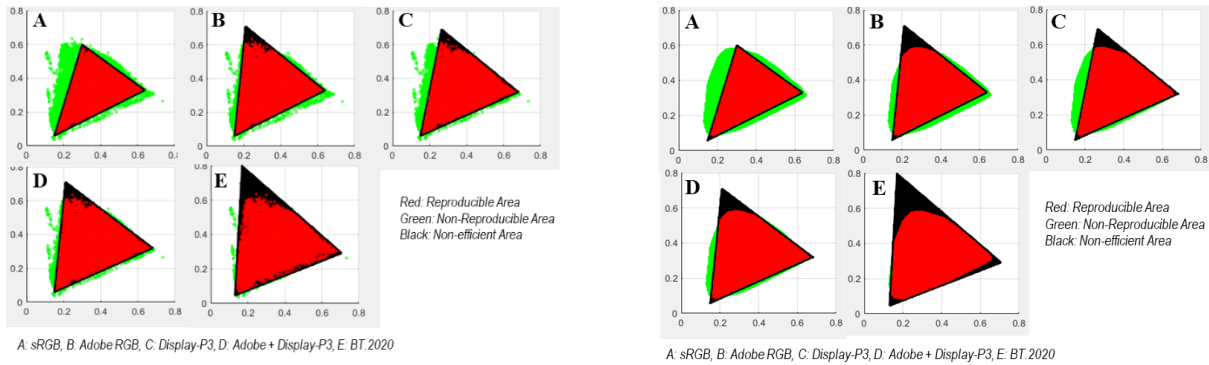
Figure 1. The concept of three parameters for G.E.

In our study, we propose a simple metric for G.E, Equation 1 as below.

$$G.E (\%) = [1 - (NRA + NEA) / (RA + NEA)] \times 100 \quad (1)$$

A Display with a G.E of 100% would be considered as the ideal, having 0 of NRA, 0 of NEA, and 100% of RA. Compared to the previous equation, the proposed metric is more intuitive and simpler [3].

(b) Evaluated Color Gamut: Five color gamut from A to E had been evaluated as shown in Figure 2. A represents sRGB (1996), B is Adobe RGB (1998), C is Display-P3 (2005), D is Adobe + Display-P3, and E (2012) is BT.2020. Excepts for D, all have been standardized in international standards. Adobe RGB and Display-P3 have a wider green and red primary compared to sRGB, respectively. Adobe RGB is commonly used by professionals who require precise color management, such as photographers and publishers. Display-P3 is typically adopted by those involved in content creation, such as filmmakers and content providers. Adobe + Display P3, which satisfies with both, photographers and filmmaker, was evaluated as well. BT.2020 is recognized as the standard with the widest color gamut for HDR, but it remains challenging for manufacturers to produce displays that fully satisfy BT.2020.



(a) RA/ NRA/ NEA regarding SOCS

(b) RA/ NRA/ NEA regarding Pointer's color

Figure 2. Results of RA/ NRA/ NEA with regard to SOCS & Pointer's color

Table 1. Results of G.E regarding SOCS/Pointer's

		A (sRGB)	B (Adobe RGB)	C (Display-P3)	D (Adobe +Display-P3)	E (BT.2020)
Color Chromaticity Gamut Coverage (%)		52.9	71.3	71.7	77.6	100
SOCS Colors	RA / NRA / NEA (%)	71.8/ 28.2/ 6.0	88.5/ 11.5/ 16.3	85.7/ 14.8/ 20.2	92.0/ 8.0/ 22.1	98.2/ 1.8/ 48.7
	Gamut Efficiency (%)	55.9	73.5	66.9	73.6	65.7
Pointer's Colors	RA / NRA / NEA (%)	67.8/ 32.2/ 0.7	84.1/ 15.9/ 8.1	85.2/ 14.8/ 7.5	91.1/ 8.9/ 9.2	99.6/ 0.4/ 29.6
	Gamut Efficiency (%)	51.9	74.0	75.9	82.0	76.7

3. Results

(a) CIE xy color chromaticity (2D): Figure 2 and Table 1 show results of evaluating G.E for A through E. According to our study, Adobe + Display-P3 has the best G.E among A to E, even though BT.2020 offers the widest Color Chromaticity Coverage and Reproducible Area.

(b) CIE L*a*b* color space (3D): Results from CIE xy color chromaticity is compared to the G.E in CIE L*a*b* color space considering L*plane in relation to the proposed metric. In this paper, only the SOCS database in CIE L*a*b* is considered for ROC, not Pointer's. The concept for G.E, as described in Equation 2, is similar as the concept for G.E in Equation 1. The difference is that Equation 2 is calculated at sliced L* in intervals of 10. The concept for approaching by slicing L* is similar to the concept of Gamut ring [7].

$$G.E_{3D} (\%) = \frac{(\sum_{L^*} NRA + \sum_{L^*} NEA)}{(\sum_{L^*} RA + \sum_{L^*} NEA)} \times 100 \quad (2)$$

According to the analysis in L*a*b* color space, Adobe RGB has the best G.E. Adobe + Display-P3 has also better G.E than sRGB, Display P3 and BT2020. Figure 3 shows results of evaluating G.E for A to E in CIE L*a*b* across L*planes, in intervals of 10. Table 2 shows detailed figures for G.E. Table 3 shows the correlation coefficients depending on the methods of analysis. Correlation coefficient above 0.95 can be interpreted as a "very strong" relationship [8]. Table 3 shows that results of comparison of correlation coefficient between CIE L*a*b* and CIE xy, CIE u'v', respectively. Results from CIE xy chromaticity show better correlation coefficients than that of CIE u'v' color chromaticity when compared to that of CIE L*a*b* color space. From results of the above analysis, a simple metric in the form of Equation (1)

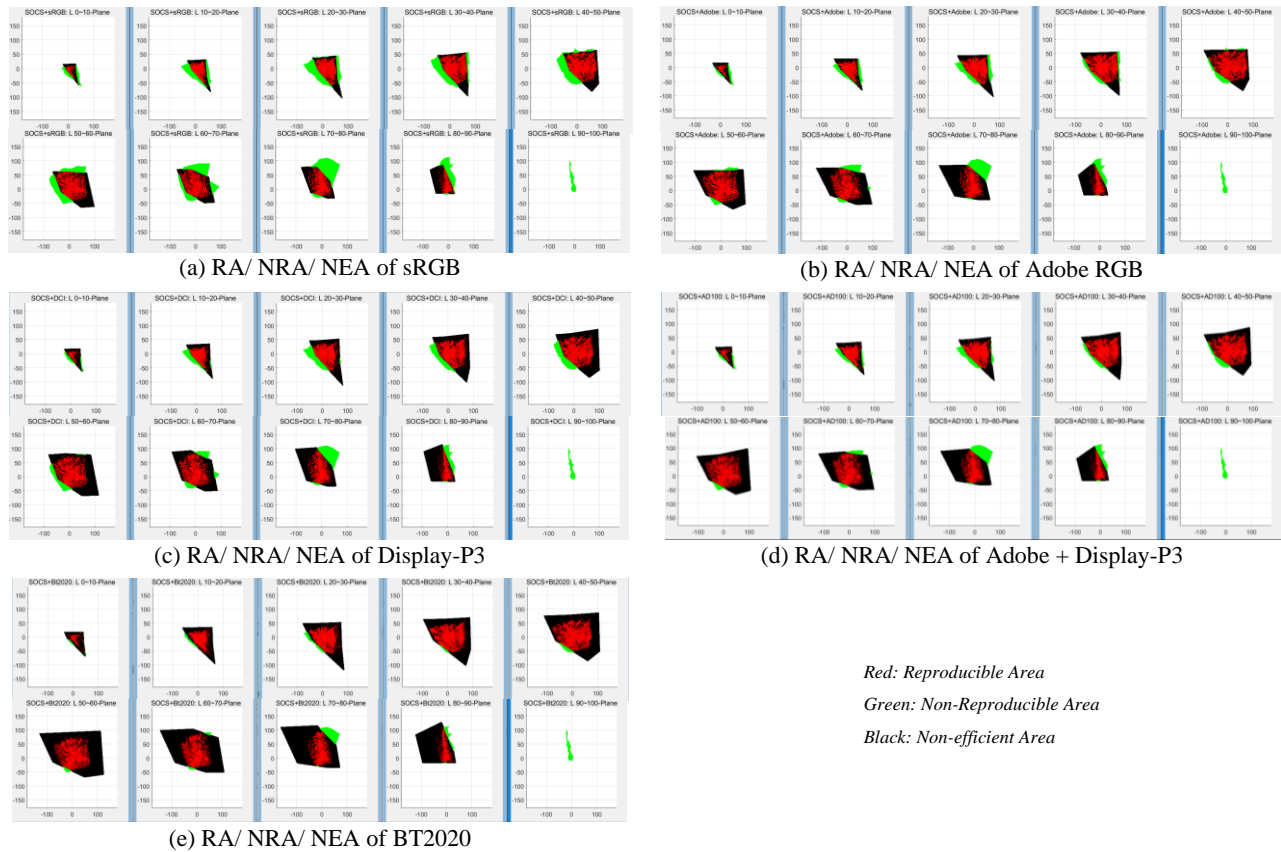
could provide the easier approach that G.E from CIE L*a*b* color space and reliable simultaneously.

Table 2. Result of G.E in CIE L*a*b* with respect to SOCS

	A (sRGB)	B (Adobe)	C (Display-P3)	D (Adobe + Display-P3)	E (BT.2020)
Gamut Coverage (%)	44.9	64.8	67.7	73.5	100
RA (%)	67.1	83.0	81.4	87.2	93.8
NRA (%)	32.9	17.0	18.6	12.8	6.2
NEA (%)	14.4	34.6	41.4	46.1	87.6
G.E (%)	42.0	56.1	51.1	55.8	48.3

Table 3. Comparison of correlation coefficient based on methods of analysis for SOCS Colors

	RA	NRA	NEA	G.E
CIE L*a*b* vs. CIE xy	1.00	1.00	1.00	0.99
CIE L*a*b* vs. CIE u'v'	0.99	0.99	0.97	0.75



Red: Reproducible Area
 Green: Non-Reproducible Area
 Black: Non-efficient Area

Figure 3. Results of RA/NRA/NEA in CIE L*a*b* Color space in terms of SOCS

4. Impact

(a) **The proposed metric in CIE xy chromaticity:** The proposed metric for gamut efficiency in CIE xy chromaticity, compared to the CIE L*a*b* color space for gamut efficiency, could provide the faster and easier evaluation. A trend of results from the proposed metric are similar to that of CIE L*a*b* color space so, the proposed is reliable regarding accuracy and reproducibility. As a result of the proposed metric, Adobe + Display-P3 shows the best G.E in CIE xy color chromaticity for both, SOCS and Pointer’s.

(b) **Power Consumption vs. Color gamut:** This paper presents a further study on power consumption and color gamut. Power consumption in displays is becoming increasingly important due to ESG goals. For instance, the EU suggested following the Energy-related Products (ErP) Directive for various electric devices, including displays [9]. The EU announced that displays which do not achieve a specific energy level cannot be imported into the European market. Due to these reasons, the relationship between power consumption and color gamut was studied in this paper. It is known that there is trade-off relationship between power consumption and color gamut when designing display parameters. Displays with wider color gamut typically require higher power than those with narrow color gamut. Therefore, display manufacturers are focusing on developing wide color gamut technologies with low power consumption. Table 4 shows an example of results from the expected power consumption simulation for different displays, based on the reference [10]. Display A has the lowest power

consumption with the smallest color gamut, while Display E has the highest power consumption with the largest color gamut. It was found that a larger color gamut is inefficient in terms of power consumption. The significance of a color gamut lies in how efficiently it covers real object colors in nature. Power consumption could be reduced instead of simply expanding color gamut. In this context, G.E can serve as a guideline for manufacturers to find a balance between color gamut and power consumption. The benefits of lower power achieve by choosing higher G.E could provide a better experience for consumers.

Table 4. The expected result of display power consumption with regard to A through E

	Chromaticity Gamut Coverage (%)	G.E (%)		Power consumption
		@SOCS	@Pointer’s	
A	52.9	55.9	51.9	0.6X
B	71.3	73.5	74.0	0.74X
C	71.7	66.9	75.9	0.74X
D	78.0	73.6	82.0	0.80X
E	100	65.7	76.7	X

A: sRGB, B: Adobe RGB, C: Display-P3, D: Adobe+Display-P3, E: BT2020

5. Conclusion

A simpler, easier and intuitive metric of Chromaticity Gamut Efficiency in CIE xy is proposed in this paper to evaluate how efficiently a display covers colors of real objects, such as those in SOCS and Pointer's database. It was found that Adobe + Display-P3 achieves the highest G.E regarding SOCS and Pointer's in CIE xy, outperforming other color space standards such as sRGB, Adobe, Display-P3, and BT.2020. From the perspective of the proposed G.E, Adobe + Display-P3 color gamut would be more suitable than other color gamut for any type of display such as LCD, OLED, etc. A further study in terms of more real-world colors collected recently will be considered to conduct in the future. The proposed metric could serve as a guideline for manufacturers in designing display parameters, such as color gamut, power consumption. The significance of a color gamut lies in its efficiency in covering the colors found in nature. If a manufacturer chooses the proper color gamut based on G.E rather than just opting for a wide gamut, there would be more opportunities to reduce power consumption or improve luminance. It is expected that consumers could experience better performance when viewing displays designed using the proposed G.E metric.

6. References

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