

Color Gamut of SOCS and its Comparison to Pointer's Gamut

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Abstract

The Standard object color spectra (SOCS) database was developed for proper evaluation of color-sensor quality of image input devices. The SOCS has been published in a ISO technical report, ISO TR 16066. A CD-ROM is attached to the ISO-TR. The CD-ROM contains more than fifty thousands spectra of objects, such as photographic materials, offset prints, computer color prints, paint (not for art), paints (oil paints, water colors), textiles, flowers and leaves, outdoor scenes, and human skin. Color gamut of SOCS for standard illuminant D65 was calculated and discussed. Color gamut efficiency of SOCS, which is ratios of the area and the volume of color gamut of SOCS to these within optimal color loci, is almost the same as the performance of photographic color reversal film. Also, color gamut of SOCS for illuminant C was calculated and compared to Pointer's gamut.

Introduction

The Standard object color spectra (SOCS) database was developed for proper evaluation of color-sensor quality of image input devices.^{1,2} The SOCS has been published in a Japanese Industrial Standard Technical Report (JIS-TR) in 1998.³ Spectral reflectance or transmittance data of 49,672 objects were stored in the CD attached to JIS-TR, which were classified according to object categories. After the publication, data for other categories were added. Though they are very valuable data even in the original form, the number of data is very large, and their distribution is biased toward some categories. Though many data are needed to statistically evaluate the quality of color image input devices, careful data arrangement is necessary for meaningful use, and a smaller data set for easily evaluating the quality of color image input devices was desired. Only several hundreds of representative spectral data for use instead of the full data set were selected as typical sets and difference sets⁴ and was the principal part of ISO technical report, ISO TR 16066.⁵

A CD-ROM is attached to ISO-TR. The CD-ROM contains more than fifty thousands spectra of objects, such as photographic materials (transparencies and reflection prints), offset prints, computer color prints (dye sublimation printer, ink-jet printer, electrostatic printer), paint (not for art), paints (oil paints, water colors), textiles (synthetic dyes and plant dyes), flowers and leaves, outdoor scenes, and human skin (bare north Asian skin, foundation-applied north Asian skin, bare south Asian skin, foundation-applied south Asian skin, bare Caucasian skin, and bare Negroid skin). The number of collected data is summarized in Table 1.⁴ Each data is 31-dimensional spectral reflectance or transmittance.

It is very interesting and useful to know gamut of SOCS in a color space. We have obtained the gamut of SOCS and discussed, and compared it with the Pointer's gamut.⁶ Also, a useful measure to evaluate the performance of colorant set for color reproduction system, color gamut efficiency,⁷ is applied to the gamut of SOCS.

Table 1 Number of Spectral Data Collected for SOCS

Category	Number of sub-categories	Number of colors
Photographic materials (Transparencies/Reflection prints)	8	2,304
Graphic prints (Offset/Gravure)	33	30,624
Computer color prints	21	7,856
Paint (not for art)		336
Paints (for art)	4	229
Textiles	6	2,832
Flowers		148
Leaves		92
Human faces		8,570
Krinov data		370
Total		53,361

Calculation of Color Gamut

As mentioned above, 53,361 spectra are stored in SOCS CD. A number of colors have been deemed inappropriate for the highest chroma of the segments and removed in this study, as same as Annex C in Ref. 5, as shown in the following.

all colors in files from krinov1 to krinov8 (Krinov)
#39 in pa_o file (Oil paints)
#58, #59, #60 in pa_a file (Water colors)

These are interpolated data, metallic colors, and colors generated with fluorescent colorants. These 374 spectra are not used, therefore 52,987 spectra are used for calculating color gamut in this study.

At first tristimulus values X , Y , and Z are calculated from SOCS spectra.

$$X = k \int_{380}^{780} P(\lambda) R(\lambda) \bar{x}(\lambda) d\lambda$$

$$Y = k \int_{380}^{780} P(\lambda) R(\lambda) \bar{y}(\lambda) d\lambda$$

$$Z = k \int_{380}^{780} P(\lambda) R(\lambda) \bar{z}(\lambda) d\lambda$$

$$k = \frac{100}{\int_{380}^{780} P(\lambda) \bar{y}(\lambda) d\lambda}$$

where, $P(\lambda)$ is spectral power of illuminant D65 or C, $R(\lambda)$ is spectral reflectance or transmittance of SOCS spectrum data, and $x(\lambda)$, $y(\lambda)$ and $z(\lambda)$ are color matching functions. Next, colorimetric values CIE 1976 $L^*a^*b^*$ are calculated from the tristimulus values.

Then chroma C^* and hue angle h are calculated from a^* and b^* .

$$L^* = 116 \left(\frac{Y}{Y_n} \right)^{1/3} - 16$$

$$a^* = 500 \left\{ \left(\frac{X}{X_n} \right)^{1/3} - \left(\frac{Y}{Y_n} \right)^{1/3} \right\}$$

$$b^* = 200 \left\{ \left(\frac{Y}{Y_n} \right)^{1/3} - \left(\frac{Z}{Z_n} \right)^{1/3} \right\}$$

$$\frac{X}{X_n}, \frac{Y}{Y_n}, \frac{Z}{Z_n} \geq 0.008856$$

Thus colorimetric values $L^*a^*b^*$ and C^* for all SOCS spectra are calculated for illuminants D65 and C.

$$C^* = (a^{*2} + b^{*2})^{1/2}$$

$$h = \arctan\left(\frac{b^*}{a^*}\right)$$

The lightness L^* was divided at intervals of 5 between 5 and to 95, so the number of lightness steps were 19. And hue angle h was divided at intervals 10 degrees between 0 degree and 350 degrees, so the number of hue angle step was 36. Therefore the color space is divided into 684 segments.

The range of lightness is 5 and the range of hue angle is 10 degree for each segment. For example, the segment for chroma 20 and hue angle 30 degrees means the segment of lightness ranging from 17.5 to 22.5 and of angle ranging from 25 degrees to 35 degrees.

The points corresponding to SOCS data exist in three dimensional $L^*a^*b^*$ color space. The space is divided into the segment of lightness and hue angle. The maximum values of chroma C^* in the segment were searched. Color gamut is an area within the loci connecting the highest chroma points.

Color Gamut of SOCS

Chroma C^* and hue angle h of SOCS spectra were calculated for CIE standard illuminant D65. The highest chromas in the 684 segments were searched. None of points was contained in 41 segments. There were no points in 41 segments. Number of highest chromas for each category is shown in Table 2. The category of the largest number of highest chroma is "Computer color prints." More than a half of highest chromas are contained in "Computer color prints." Highest and lowest lightness are 98.3 and 0.62 respectively. Categories, file names and identification numbers of these lightnesses are paints/pa_g.int/1 and paint/paint.int/14, respectively.

The highest chroma points at each L^* level can form a polygon whose vertices correspond to the points. The area inside the polygon represents a cross section of SOCS color gamut for each L^* level. The color gamut of SOCS is shown in Fig. 1. The theoretical limit of object color, optimal color, calculated by a fast algorithm computing optimal color⁸ is also shown in Fig. 1. The fast algorithm uses immediate replication of the visual spectrum in the infrared range to create an extended spectrum.

Table 2. Number of Highest Chroma for Each Category

Category	Number of highest chroma
Computer color prints	379
Graphic prints	101
Textiles	68
Photographic materials	55
Paint (not for art)	31
Paints (for art)	9
Total	643

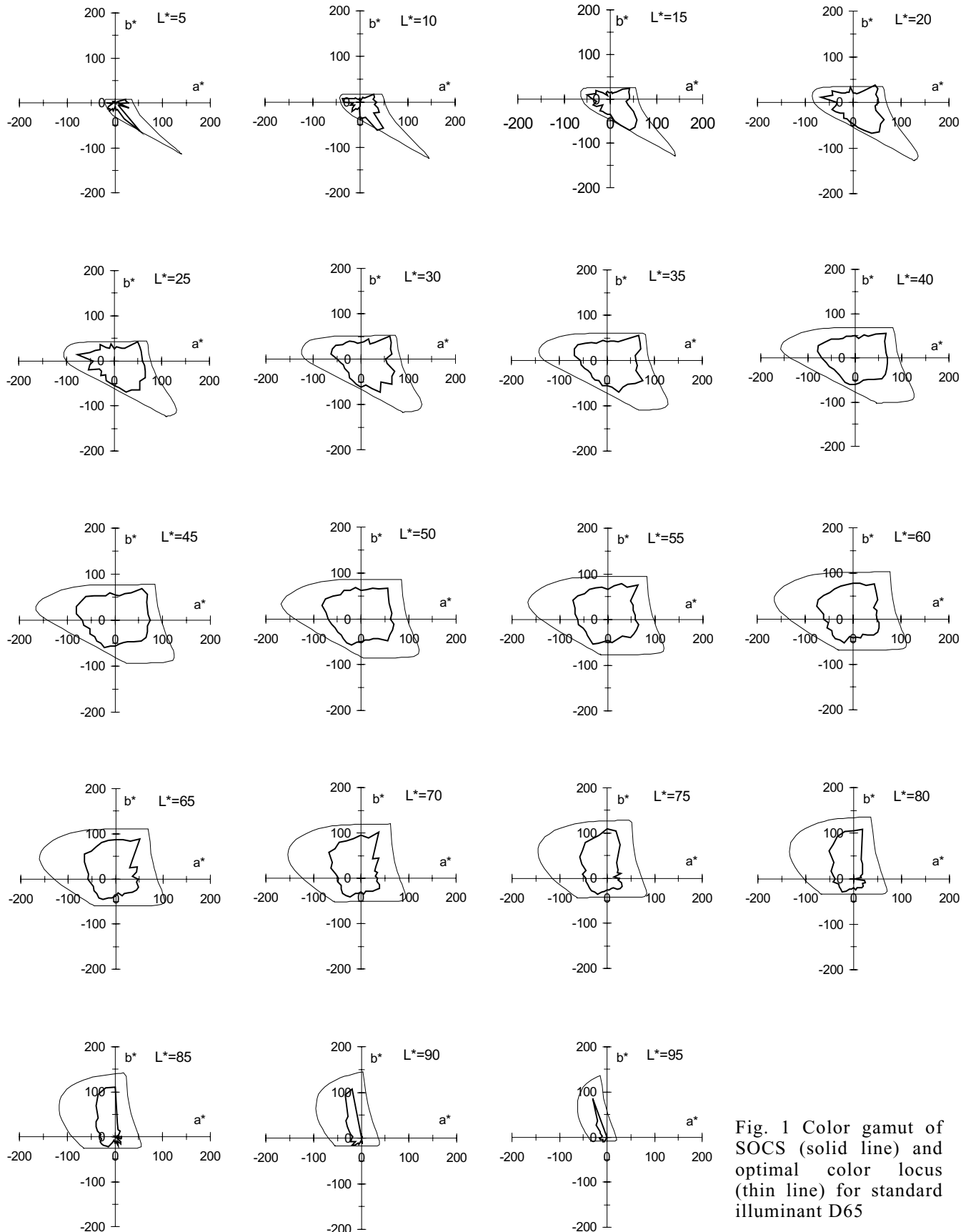


Fig. 1 Color gamut of SOCS (solid line) and optimal color locus (thin line) for standard illuminant D65

In Fig. 1, the color gamut of SOCS for $L^* = 20$ shows higher chroma than the optimal color at hue angle 40 degrees. It appears as if the color gamut of SOCS exceeds the theoretical limit. The color gamut of SOCS shows the highest chroma at the segment, in which the range of lightness is 5 and the range of hue angle is 10 degrees. On the other hand the optimal color loci are calculated precisely for the given lightness, not a maximum value of chroma of optimal colors in the segment. The relationship of these points in a cross section of hue angle 40 degrees are shown in Fig. 2. It is understood that the highest chroma of SOCS in the segment for $L^* = 20$ and hue angle $h = 40$ degrees is not higher than optimal color from the schematic explanation

To calculate a measure to evaluate the performance of colorant set for color reproduction system, color gamut efficiency,⁷ area of color gamut of SOCS and area within optimal color are calculated and shown in Fig. 3. The area color gamut efficiency, CGE_A , is defined by dividing the area of color gamut of SOCS, A_{SOCS} , by the area within the corresponding optimal color locus, $A_{optimal}$, and then expressing the result as a percentage, as in the following equation.

$$CGE_A = \frac{A_{SOCS}}{A_{optimal}} \times 100 \quad [\%]$$

Similarly, volume color gamut efficiency, CGE_V , is defined by the following equation.

$$CGE_V = \frac{V_{SOCS}}{V_{optimal}} \times 100 \quad [\%]$$

where V_{SOCS} is the volume of color gamut of SOCS, and $V_{optimal}$ is the volume within the optimal color loci. Color gamut efficiency of SOCS is shown in Fig. 4. Maximum area color gamut efficiency is about 45%. In the Ref. 8, the maximum area color gamut efficiencies of the hypothetical dye sets lie in the range of 60% to 70%, while the maximum area color gamut efficiency of the real dye set for a photographic color reversal film barely exceeds 40%. The volume color gamut efficiency of SOCS is 35%. This percentage is almost the same as the performance of the real dye set for a photographic color reversal film.

Comparison to Pointer's Gamut

Also the chroma C^* and hue angle h for illuminant C were calculated for comparison to the Pointer's gamut on real surface colors previously reported.⁶ Color gamut of SOCS, Pointer's gamut and optimal colors are shown in Fig. 5. There are no figures for lightness $L^* = 5$ and 15, because there were no such figures in Pointer's literature.

It was found that gamut of SOCS is slightly wider than those of Pointer's in the low lightness region and both are

almost same area at the middle lightness. In the high lightness region, gamut of SOCS is slightly wider than those of Pointer's in the blue region, but slightly narrower in red and green regions.

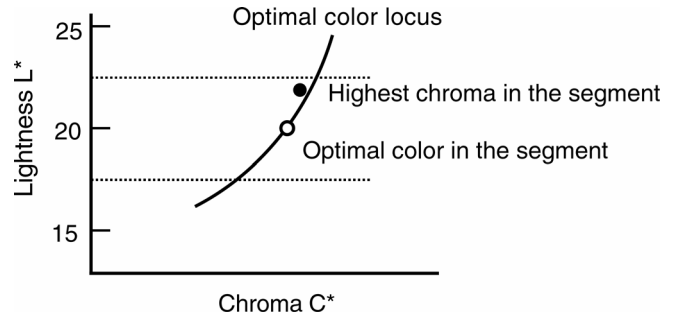


Figure 2. Cross section of hue angle 40 degrees at $L^*=20$

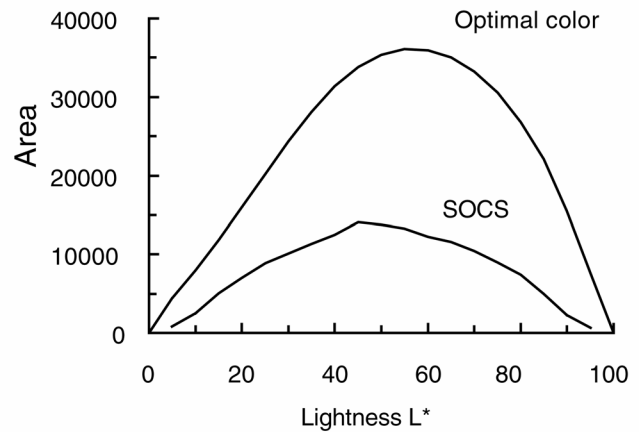


Figure 3. Areas of color gamut of SOCS and within optimal color locus

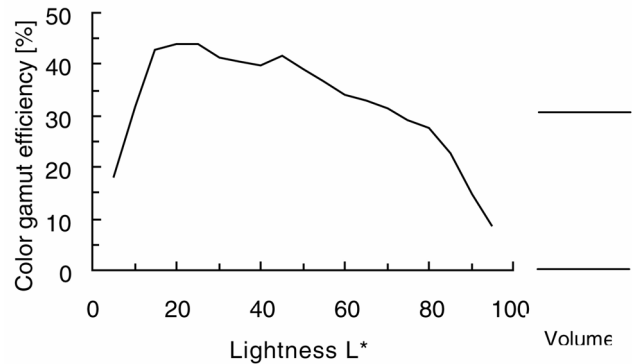


Figure 4. Color gamut efficiency of SOCS, the ratio of the area or volume of color gamut of SOCS to the area or volume within optimal color loci

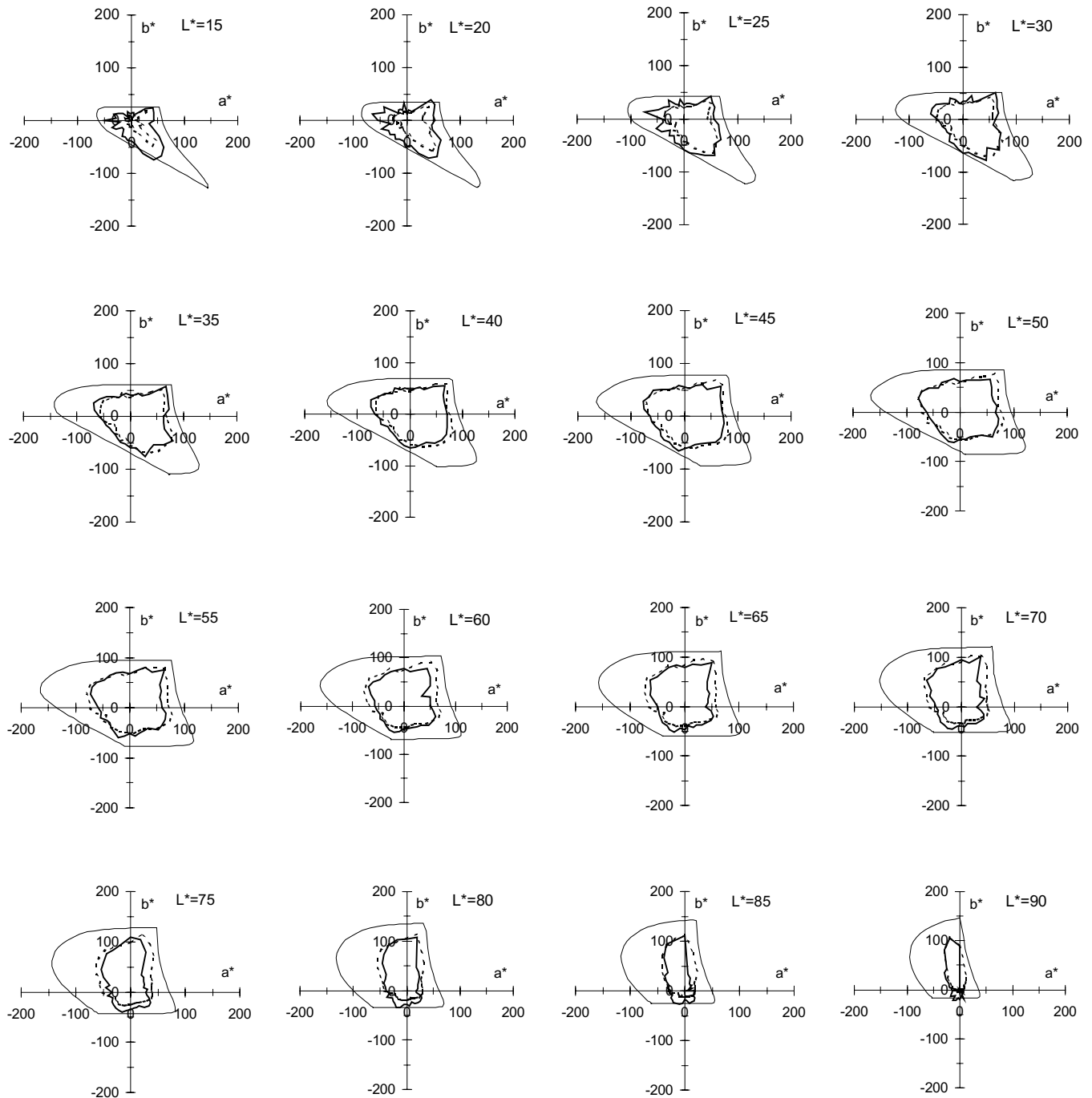


Fig. 5 Color gamut of SOCS (solid line), optimal color locus (thin line), and Pointer's gamut (broken line) for illuminant C

Summary

Color gamut of SOCS were calculated and compared to Pointer's gamut. Consequently there is no great difference between the gamut of SOCS and Pointer's gamut. Also, color gamut efficiencies were calculated and compared to these of photographic color reversal film. Maximum area color gamut efficiency of SOCS is about 45% and is slightly greater than one of the film, and both of volume color gamut efficiency is almost the same.

The authors would be pleased to hear from anyone who is able to offer spectral data of objects color and measure calibration color patches with the colorimeter, which is used to measure the spectral data.

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Biographies

Masao Inui received his M.Eng. from Chiba University in 1973 and joined the University staff there in the same year. In 1986, he joined Konica Corporation, where he advanced to the position of Chief Research Associate. In 1993, he received his Ph.D. from Chiba University, and in 1998, Dr. Inui took a professorship at Tokyo Polytechnic University. and his special interests include image analysis, evaluation, design, and processing. He is a member of the IS&T, The Royal Photographic Society, and The Society of Photographic Science and Technology of Japan.

Tomotaka Hirokawa is a student of Tokyo Polytechnic University. His research interests include analysis and modeling of color reproduction of hardcopy print.

Yoshihiko Azuma received a BS degree in physical engineering in 1979 and a MS degree in information processing engineering in 1981, both from Tokyo Institute of Technology. After graduation, he joined DaiNippon Printing Company where he engaged in development of digital prepress systems. He has been an assistant professor at Tokyo Polytechnic University since 1995. His research interests include color reproduction model in halftone image, cross-media color matching and color imaging based on characteristics of human color perception.

Johji Tajima graduated from the Faculty of Science, the University of Tokyo, in 1971 and received a doctorate in 1990. From 1971 to 2003, he was a research member of NEC Corporation. He is a professor of Graduate School of Natural Sciences, Nagoya City University, from 2003. He has been engaged in research on image processing and pattern analysis, especially color image processing and 3D vision. Prof. Tajima is a member of the IEICE, IIEEJ, the Information Processing Society of Japan (IPSJ), and IEEE Computer Society. He is a fellow of IAPR (Intl. Assoc. for Pattern Recognition).