J. Sci. Soc. Thailand, **4** (1978) 178-188

COLORIMETRIC ANALYSIS AND EVALUATION OF FOUR-COLOR REPRODUCTION BY PHOTOMECHANICAL MEANS

SAKDA SIRIPANT

Department of General Science, Faculty of Science, Chulalongkorn University, Bangkok, Thailand

(Received 20 September 1978)

Summary

The analysis and evaluation of a color reproduction process, in which a color transparency was reproduced by offset lithography, is described. The object was to evaluate a variety of previously known methods of colorimetric and sensitometric analysis, and to compare the results with visual evaluations of the reproduction. The transparency included a picture of a color chart in addition to a portrait, so that it was possible to investigate the relationship of the reproduction to the original scene as well as to the transparency. Possible improvements of the color reproduction process are suggested and its main uses are discussed.

Introduction

Color reproductions are usually analyzed and evaluated by subjective methods, but these visual analysis and evaluations become more meaningful, and ways of correcting the faults in the reproduction become clearer, if they are supplemented by quantitative measurements and graphical analysis. The present paper describes a rather complete analysis of a single printed reproduction with the object of evaluating the methods of evaluation as well as the reproduction process itself. It is hoped that this work will be an aid in the development of improved practical methods for the analysis and evaluation of reproduction processes. The four-color offset reproduction was made for this purpose from a color transparency consisting of a portrait, a color chart, a Kodak Gray Scale and a Silver Gray Scale. The Kodak three-mask system was used for the color separations.

The essential features of the method of analysis, which is a combination of several previously known methods, are as follows: (1) the gray-scale tone reproduction and gray balance are analyzed step-by-step throughout the process; (2) the color chart reproduction is analyzed colorimetrically with the aid of a small-spot colorimeter; (3) visual evaluations of picture quality (without the original) and accuracy of reproduction are made and compared with the quantitative evaluations; and (4) the relationship of the reproduction to the original scene as well as its relation to the original copy (a transparency in this case) is studied.

Materials and Methods

Materials

Since the original scene, which was a studio portrait, did not contain a wide enough variety of color for a complete analysis of the process, a color chart was photographed at the same time and under the same conditions as the original scene.

The color chart consists of a series of constant-hue scales of color patches made from Color-Aid paper. Each scale is supposed to represent the range of tones, from highlights to shadows that might be seen in an object of the given hue, since the proper reproduction of such scales of colors is a most important factor contributing to print quality.

In addition to the six constant hue scales, single patches of intermediate hue were included, and also a set of Kodak ink patches and a gray scale. Finally, a silver steptablet was attached to the transparency (because of the differences in spectral transmittance between a silver scale and a dye scale), and a Kodak three-step scale with its A.M. and B patches.

The combination transparency was reproduced, using the Kodak three-mask color correction system[1] with the so-called "split-mask" method of making the black printer negative.

The reproduction was printed on coated paper on a single color offset press, using the normal Dainippon inks which include a reddish magenta. A reproduced color picture is shown in Plate I.

Methods

The reproduction was analyzed and evaluated by the following methods, comparisons being made with the original color chart as well as the transparency:–

Visual evaluation.

Tone reproduction analysis of the steps of the reproduction process, which involved a separate determination of Equivalent Neutal Density (END) curves of the inks. Densities to be used in the tone reproduction analysis were measured by an electronic densitometer.

Colorimetric measurements of original and reproduction, plotted in terms of gray scale colorimetric density curves, darkness, saturation ratio and hue angle of the color scales. A modified Adams Chromatic Value system was used. The Adams Chromatic value System (modified)[2] is chosen for this project to interpret the color measurements because of its reasonable simplicity, and its quite close correspondence to what is believed to be the actual mechanism of color vision.

The modifications of the Adams Chromatic Value System are as follows:

1. Colorimetric densities of red, green and blue (D_r, D_g and D_b) from the small spot colorimeter (SSC)[3], which are analogous to the CIE tristimulus values X, Y and Z, are used for calculating the chromatic component.

2. Luminance(Y) $= (R+G)/2$

where $R = 100\ (10^{-D_r})$

$G = 100\ (10^{-D_g})$

$B = 100\ (10^{-D_b})$

3. Darkness (F) = $117-25\ Y^{1/3}$ or $100-8Y$

4. Saturation (S) is defined as the distance between the color and the neutral axis.

$$S = (r^2 + b^2)^{1/2}$$

where the horizontal redness-greenness axis (r) = $2.5\ (F_g - F_r)$,
the vertical axis, blueness-yellowness (b) = $(F_g - F_b)$
and $F_r = 117-25\ R^{1/3}$ or $100-8\ R$
$F_g = 117-25\ G^{1/3}$ or $100-8\ G$
$F_b = 117-25\ B^{1/3}$ or $100-8\ B$

The formula on the right is used when $Y < 1$

5. Hue angle (h) = $\tan^{-1}$ (b/r)

The colorimetric densities, darkness, hue angle and saturation were plotted into four different types of graph, which are found to be useful in analyzing the relationship between the original and reproduced color.

Results

Visual evaluation of the reproduction alone (portrait only)

In most cases it is more important to produce a print of high quality than to accurately match the original. Consequently, the first evaluation of the reproduction should be made without comparing it to the original. When evaluated in this way, the reproduction was on the light side. The skin-tone looked rather good, but the highlight in the face appeared slightly magenta and yellow, the shadow around the neck appeared reddish-brown. Magenta hue looked toward red, cyan and green toward blue. The blue, red and yellow hues were reproduced quite well. The color saturation of the blue was rather high. The magenta, the cyan, the green, the yellow and the red were desaturated. The highlight contrast was relatively high and the shadow area was not dark enough. The aesthetic quality of the reproduction was satisfactory.

Visual comparison with the original scene

Some of faults of the reproduction can be better understood, and the deficiencies of the reproduction process more clearly pinned down, if the reproduction can be compared with the original scene.

The chief inaccuracies seen in the reproduction, compared with the original color chart, were as follows. Hues of magenta, blue, red and yellow were reproduced almost as exactly the original scene. Green and cyan became bluish. All colors were desaturated.

Visual comparison of the reproduction with the transparency

In most practical situations the reproduction is evaluated by comparison with the original copy. For comparison with the reproductions, the transparency was viewed with an opaque white reflective border and the transparency illumination was adjusted until it looked like a good reflection print, as described by Ahrenkilde *et al.*[4] This setting corresponded to an effective highlight density of 0.53, which was later used in the colorimetric computations.

The chief inaccuracies seen in the reproduction compared with the transparency, were as follows: Red, blue and yellow were reproduced quite well. Light greens and cyan became bluish. Magenta became reddish. In general, the colors in the reproduction were less bright and clear than in the transparency. All colors except red magenta were saturated. The silver gray scale became bluish magenta in step 3, 4 and slightly greenish cyan in the middletones and the shadows. The bluish Ektachrome gray scale appeared slightly more cyan in the middletones, slightly magenta in light-tone and brownish in the dark-tone.

Gray scale tone-reproduction and gray balance analysis

Figs. 1 and 2 show tone reproduction analysis in the reproduction process. The color balance shown in graph d of Fig. 2 can be compared with the visual evaluation and with the colorimetric density curves at the left of Fig. 3. The relative positions of the three curves should be similar, although the exact spacing between them would not be the same, because Fig. 3 represents integral density while Fig. 2 represents analytical density. There are, however, some discrepancies which can be attributed to experimental error.

It should be remembered that the silver step tablet reproduction characteristics may not give a true picture of the Ektachrome reproduction because of metamerism, but the steptablet is nevertheless useful in tracing the tone reproduction characteristics through the various steps of the process. In this example the shadow end of the curves may be somewhat distorted by adjacency effects due to the white area at the end of the steptablet. This probably accounts for the unusual toe shape of the characteristic curves of the negatives.

Colorimetric analysis

The colorimetric analysis of the reproduction was carried out as described by Pobboravsky *et al.*[2]. The following graphs were plotted: colorimetric density, darkness, saturation ratio, and hue circle.

The colorimetric density curves of the gray scales (Fig. 3) are useful for evaluation of the color balance and tone reproduction. The curves of the reproduction vs. the transparency (Fig. 3 a) indicate that this balance became greenish cyan in the reproduction (except in extreme highlights). The black points in Fig. 3 refer to the reflection steptablet, while the silver gray scale (reproduction vs. transparency) is shown by the open circles, squares, and triangles in Fig. 3 a. One might expect the Ektachrome and silver gray scales to give similar results, but they differ both in

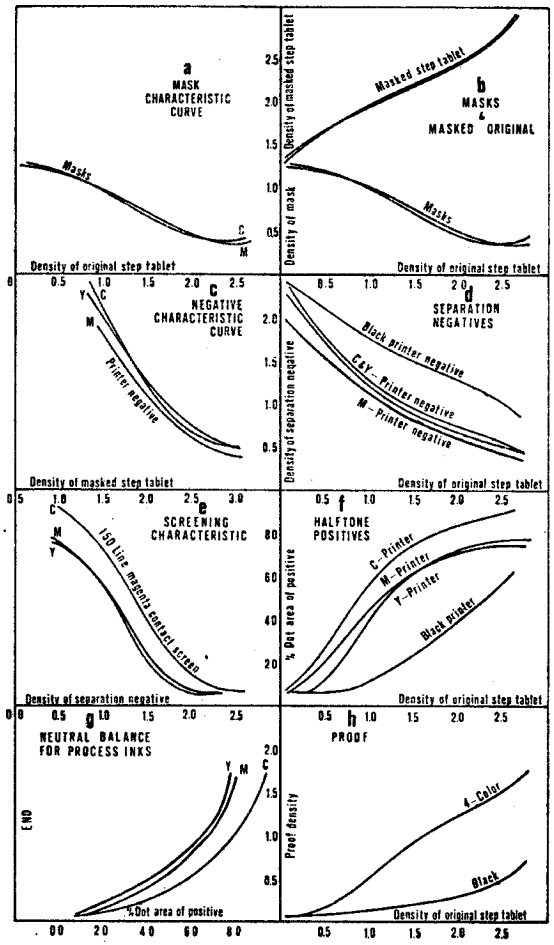

Fig. 1. Tone reproduction analysis in the reproduction process. Densities in graph h are measured directly on the proof, not derived from graph g.

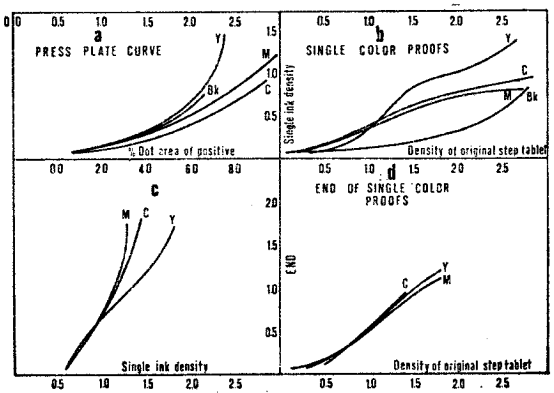

Fig. 2. Tone reproduction analysis of the final steps of the reproduction process, including the single ink densities and the END's of the proof.

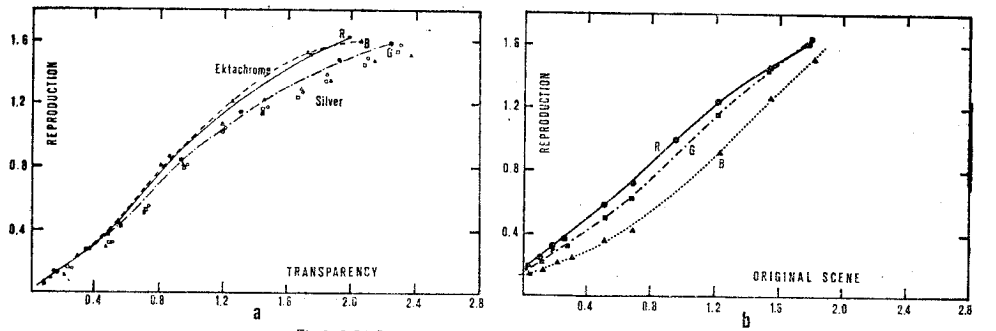

Fig.3 COLORIMETRIC DENSITY OF GRAY SCALE

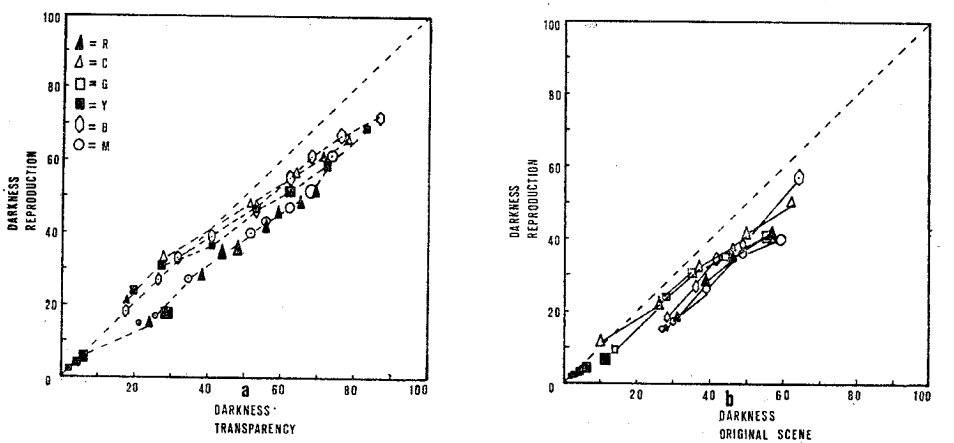

Fig.4 THE DARKNESS GRAPHS

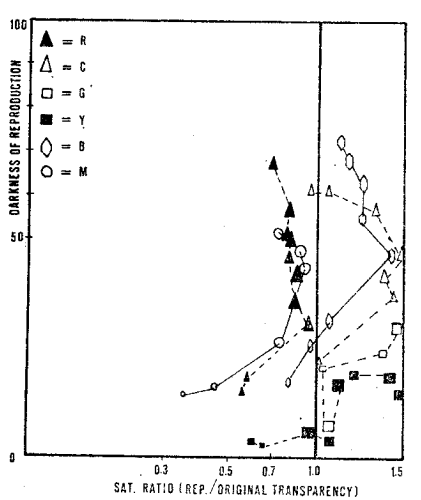

Fig.5 THE SATURATION RATIO

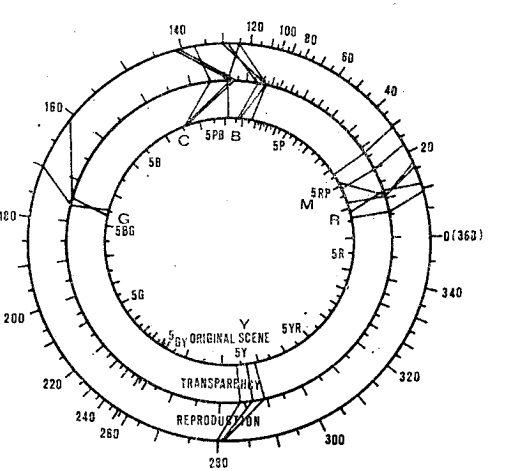

Fig.6 THE HUE CIRCLE

slope (0.75 and 0.65, for the mean of the red and green curves) and in balance. This is probably due to metamerism, because of the difference between the spectrophotometric curve shapes of a transparency dye neutral and a silver neutral gray combined with the low colorimetric quality of the separation filter[5]. However, experimental error, of which the most likely cause is uneven printing, cannot be ruled out.

This difference between the reproduction of an Ektachrome gray scale and a silver gray scale is important, since silver gray scales are commonly used to control transparency reproduction processes. The errors due to scattering of light in a condenser enlarger are well-known, but metamerism is usually disregarded.

Gammas of 0.65 to 0.75 are considered normal for transparency reproduction processes. The gamma relative to the original scene Fig. 3b was found to be 1.0 and this is normal for good print quality. However, the tone reproduction curve relative to the original scene does not have the toe which has been found necessary for good print quality. This toe is usually provided by the original copy which is to be reproduced, but in this case it was not because the transparency was underexposed. A modification of the tone reproduction scale is needed in this situation for best print quality. If the green and red curves of Fig. 3b had matched the present blue curve which has the required toe, the quality of the reproduction would undoubtedly have been higher in both color balance and tone rendering.

The darkness graphs are shown in Fig. 4. In Fig. 4 a, the reproduction is plotted against the transparency, and at the right it is plotted against the original scene (color chart). In all cases the ideal gray scale dotted curve is included for comparison. If the colors do not fall on the gray scale curve, this is an indication of faulty color correction or experimental error. Fig. 4 a shows that all colors (except blue, yellow and cyan in light middletone (were further lightened in the reproduction, relative to grays. This graph contains some light colors of fair saturation (produced by underexposing a transparency), that were not present in the original scene. Fig. 4 b shows that all colors were lightened in reproduction relative to grays. All these errors, indicated in Figs. 3 and 4, can be compared with the visual evaluations given earlier.

The saturation ratio is obtained by dividing the saturation of the reproduction by that of the original. Consequently, a saturation ratio of 1.0 means that their colors are equally saturated, which is usually desirable. Fig. 5 shows that red and magenta were desaturated; cyan, green, yellow and blue were fairly saturated. Colors in middletone were more staurated than that of highlights and shadows.

The hue circle shown in Fig. 6 incorporates the original scene, the transparency, and the reproduction in a single graph. The cyan appeared to acoount for the bluish direction of most of the hue errors in the transparency. In the reproduction, however, cyan was shifted back towards those of the original color chart, in spite of the fact that the Kodak color correction process used for reproduction was not intended to include corrections for transparency errors. A partial correction for transparency errors (so that the reproduction colors lie between those of the transparency and the original scene), as in this example, probably leads to a more pleasing reproduction.

Some of the differences in transparency hue measurements may be due to differences between the transmission and reflection instruments, which were not precision colorimeters having been converted from ordinary densitometers.

The hues of the full-strength colors are mostly fairly accurate; the paler colors, on the other hand, show much greater errors, partly because they are more sensitive to color balance errors and partly because the light colors in halftone processes are always undercorrected. Red, blue and yellow hues were reproduced quite well. Magenta became slighly reddish. For a given color separation, if the color to be reproduced has a higher density when measured through the separation filter than through the mask filter, increasing the mask percentage will increase the amount of ink to be printed, and vice versa.

Discussion

The color balance can be improved, in order to compensate for the bluish cast of the transparency by modifying the screening characteristics or the separation negative curve shape. To find out how to do this (and to correct the tone reproduction at the same time) the desired END curves may be drawn at the bottom of Fig. 4 b and their effects traced back through the diagram to produce a new set of curves in the step which is to be changed.

The tone reproduction for this particular transparency needs to be adjusted because the reproduction is light. The requirements for this are determined as described under item 1, and should be used whenever underexposed transparencies are being reproduced.

The saturation ratio of the light colors in the color chart is low although this is not evident in the picture. If this were to be corrected (which might be more necessary with normally exposed transparencies), it could be done with color-separated highlight masks[5].

The saturation ratio of the dark colors is low. This could be improved somewhat by exposing the negatives more fully, (to get more color separation in the shadows) and restoring the correct curve shape by combining and undercolor removal mask with the nagatives.

The saturation ratio of red and magenta is low, which as we have already seen can be corrected by increasing the mask percentage for the magenta printer and restoring the contrast by developing the negative more fully. Similar reasoning may suggest curves for other color correction errors.

Those possible improvements are merely given as an example of the type of information obtained from an analysis of this kind. Permanent adjustments in the process should not, however, be made on the basis of one reproduction. On the other hand, errors which have been found during this complete analysis can often be detected in future reproductions merely by visual evaluation.

Conclusion

The type of analysis used in this example is time-consuming but it gves a clearer understanding of a reproduction process and its deficiencies than can be obtained by years of experience with visual evaluation and gray-scale graphs only. Its three main uses are: (1) in setting up a production color process, to aid in optimizing the conditions, or for trouble-shooting in a process which is already in operation; (2) for educational purposes, to provide a clearer understanding of the color reproduction process; and (3) as a tool for research on color reproduction.

The analysis could be greatly speeded up by the use of a computer to plot the curves, especially if the colorimeter readings were recorded on tape or cards that could be fed directly into the computer. For analyzing reproductions that do not contain a gray scale and a color chart, a double-headed scanning colorimeter (which might be a modified Vario-Klischograph) for measuring corresponding points on the original and the reproduction is needed.

The evaluation methods seem satisfactory except for some doubts about the mode of viewing for transparencies. However, plotting hue angle versus saturation would be preferable to plotting hue angle alone; and the metamerism problems with a silver gray scale need further investigation.

Acknowledgement

I would like to express my sincere thanks to Dr. John A.C. Yule for his valuable suggestions. I wish to thank Mr. E. Pobboravsky for his assistance in obtaining colorimetric data. I also would like to thank Miss Porntawee Puengrasamee, Miss Tida Jinapan, Miss Vanaree Boonprom Mr. Surapan Chomchan and Mr. Viroj Panichkit for their assistance. This project was financed by the Rachadapiseksompoj Research Followship.

References

1. Eastman Kodak Co. (1960) Masking Color Transparencies for Photomechanical Reproduction. *Kodak Publication No. Q-3*, Rochester, New York.
2. Pobboravsky, I., Pearson, M. and Yule, J.A.C. (1971) The Relationships between Photomechanical Color Reproductions and the Original Copy. Personal Communication.
3. Pearson, M.L., and Yule, J.A.C. (1970) Conversion of a Densitometer to a Colorimeter, *Proc. Tech. Ass. Graphic. Arts.* **22**, 389-407.
4. Ahrenkilde, S., Brent Archer, H. and Yule, J.A.C. (1971) Evaluation of the Lightness and Color Balance of Color Transparencies. *Proc. Tech. Ass. Graphic Arts*, **23**, 172-187.
5. Yule, J.A.C. (1967) *Principles of Color Reproduction*, John Wiley and Sons, New York.

บทคัดย่อ

ในการวิเคราะห์และประเมินค่ากระบวนการผลิตภาพสีจากต้นฉบับโปร่งใสสีโดยกระบวนการพิมพ์ออฟเซท ได้เริ่มต้นการวิเคราะห์และประเมินค่าการผลิตสีของภาพพิมพ์ที่ได้ และเปรียบเทียบเทียบความผิดเพี้ยนของสีในภาพพิมพ์กับของต้นฉบับ วิธีการวิเคราะห์ใช้วิธีการวัดแสงสี และวิธีการวัดความไวต่อการฉายแสง และต่อการล้างฟิล์มทุกขั้นตอนของกระบวนการผลิตภาพ แล้วเปรียบเทียบผลที่ได้จากการวิเคราะห์และประเมินผลนี้กับผลการวิเคราะห์ภาพสีนั้นด้วยตา เพื่อที่จะได้ทราบความสัมพันธ์ระหว่างการผลิตสีในภาพพิมพ์กับต้นฉบับโปร่งใสสีและต้นฉบับเดิม จึงได้ติดภาพโปร่งใสสีของแผ่นสีต้นฉบับไว้ข้าง ๆ ต้นฉบับโปร่งใสที่เป็นภาพคนด้วย นอกจากนั้นได้มีการเสนอแนะเกี่ยวกับการปรับปรุงกระบวนการผลิตภาพสี พร้อมทั้งประโยชน์ที่ได้จากการวิจัยนี้