Six Color Separation Using the Additional Colorants with Less Dot Visibility

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Abstract

This paper proposes a method of six-color separation using additional colorants with less dot visibility to reduce the color difference and graininess. In conventional six-color separation, the use of light magenta and light cyan is generally an effective way of reducing the visibility of dots in bi-level printing devices, i.e., light magenta and light cyan are used in a bright region instead of magenta and cyan. However, the hue values for light magenta and light cyan differ from those for magenta and cyan in CIELAB space, making the colorimetric reproduction less inaccurate. Therefore, to minimize this inaccuracy, the proposed method uses yellow and light magenta colorants as additional colorants. In a bright region, magenta is replaced with light magenta and yellow, while cyan is replaced with light cyan and light magenta. These combinations reduce the hue difference, as they create colors with a similar hue to magenta and cyan. In addition, a smooth image can be simultaneously obtained due to the lower dot visibility of the additional colorants. In a middle region, magenta is replaced with light magenta and magenta, while cyan is replaced with light cyan and cyan. Since the use of these two colorants with different concentrations makes a coarse dot pattern, this phenomenon is reflected based on a quantitative granularity metric. Finally, in a dark region, only the magenta and cyan colorants are used as usual. Experiments show that the proposed method can simultaneously produce a colorimetric and smooth-tone reproduction.

Introduction

Six-color printers offer the opportunity to achieve the close photographic quality images based on the extra colorants added to the standard C, M, Y, K printer.[1] So far, two strategies have been adopted in six-color printing.[2,3] In the first approach, light magenta (Lm) and light cyan (Lc) are used as the extra colorants. These colorants have the same hues as the standard colorants, yet different concentrations. The use of multiple concentrations reduces the graininess and produces smooth tones in the highlight regions resulting in a greater resolution. In the second approach, orange and green are used as the extra colorants. These colorants have different hues from C, M , Y, K, thereby extending the color gamut and reducing the metamerism.

To implement a six-color printer based on a four-color printer, the most important step is the six-color separation, which can be broadly defined as the computation of the amounts of colorants needed to print the desired color. There are already several six-color separation methods that vary according to the target of the six-color separation, which is mainly to decrease the color difference and graininess. For post-processing, the total colorant limit can be considered in six-color separation.

The traditional six-color separation using the color difference identifies monotonic increasing functions to produce a photo ink separation pass that minimizes ΔE_{ab} for the magenta ramp and cyan ramp, respectively.[4] Although this method obtains an accurate colorimetric reproduction, the quality is inferior as the usage of cyan or magenta in a bright region increases the graininess. As such, six-color separation using the subjective granularity and lightness value have also been proposed.[5,6] These methods can obtain a smooth tone and decrease an abrupt difference in lightness from lighter to darker colors, yet color differences occur in the separated image due to the hue difference between the saturated and diluted colorant in bright regions. For post-processing, the total ink limit can be added to conventional six-color separation.[7] When an excessive amount of a colorant is printed on the page, undesirable image artifacts can appear. To prevent such artifacts, colorants outside the total colorant limit are mapped to colorants inside the total colorant boundary or colorants with the same optical density yet less colorant volume.

Accordingly, to address the above difficulty in obtaining an image with less graininess and a lower color difference, this paper proposes a way of reducing the color difference and graininess at the same time. To correct the color differences in bright regions, additional colorants with less dot visibility are used, whereas to reduce the noisy dot patterns in middle regions, a quantitative granularity metric based on the SCELAB space is used.

Conventional Six Color Separations

Traditional six-color separation using the color difference maps the CMYK space into CMYKLcLm space using one-dimensional lookup tables of C into (C, Lc) and M into (M, Lm),[4] where the tables are constructed by making the monotonic increasing functions to minimize the E_{ab} errors for a cyan ramp and magenta ramp. As such, saturated colorants (M or C) can be used in a bright region, as seen in Figs. 1 (a), with accurate colorimetric reproduction. Figs. 1 (a) shows the photo ink separation passes for traditional six-color separation using the color difference for magenta and cyan, while Fig. 1 (b) is the printed image resulting from this method. The abscissa axis in Fig. 1 (a) represents the input digital value, while the ordinate axis represents the separated colorant usage after applying six-color separation. Yet, the use of a saturated colorant in a bright region creates a coarse dot pattern that appears noisy to the human eye, thereby degrading the image quality. For example, in Fig 1 (b), the cyan colorant is visible to the human eye and increases the graininess. Therefore, the use of the cyan colorant in a bright region is undesirable, even though it creates an accurate colorimetric reproduction.

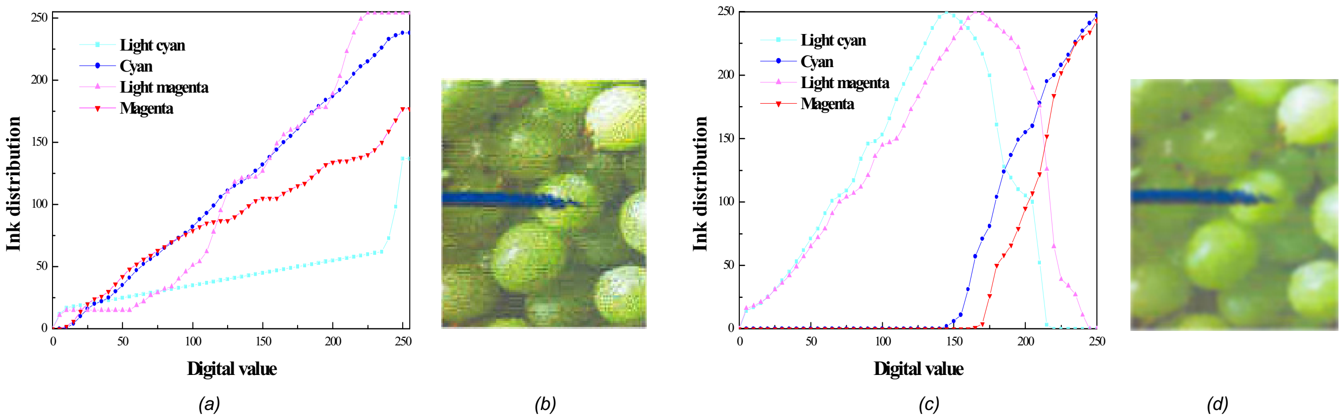


Figure 1. Conventional six color separations; (a) Photo-ink separation pass of the six color separation using the color difference (b) Result of the six color separation using the color difference (c) Photo-ink separation pass of the six color separation using the lightness and subjective granularity (d) Result of the six color separation using the lightness and subjective granularity

Meanwhile, Figs. 1 (c) shows the photo ink separation passes for six-color separation using the lightness value and subjective granularity, and Fig. 1 (d) is the printed image resulting from this method.[5] This method only uses diluted colorants (Lm or Lc) close to the lightness of the input digital value in a bright region, while in a middle region, combinations of diluted and saturated colorants minimizing the granularity under a predefined threshold value for the lightness value are used, and in a dark region, only saturated colorants close to the lightness of the input digital value are used. As a result, a smooth tone image can be reproduced, as only diluted colorants with small dots are printed in bright regions. Also, the resolution of the image is increased, because the area occupied by the diluted colorants instead of the saturated colorants is large. However, there is a further increase in the color difference when a saturated colorant is replaced by a diluted colorant with a different hue value. Figure 2 shows the hue difference between a saturated and diluted colorant for magenta and cyan, respectively. The abscissa axis in Fig. 2 represents the input digital value, while the ordinate axis represents the hue value calculated by $\arctan(b^* / a^*)$ of the CIELAB space. The hue value for a diluted colorant is different from the hue value for a saturated colorant. Therefore, a color difference arises, even though this method reproduces a smooth image with a greater resolution.

Proposed Six Color Separation

When using the conventional method, it is difficult to obtain an image that has less graininess and a lower color difference. Thus, to solve this problem, six color separation using additional colorants and quantitative granularity is proposed. The proposed method divides the digital values into three types of region. A bright region extends from the point at which the amount of the diluted colorant reaches its maximum digital value when using the additional colorants. From this point, the amount of the diluted colorant is decreased until it reaches zero. A middle region is then up to the point that the amount of the diluted colorant is zero, and the remainder is a dark region. According to these three types of region, one or two of the saturated, diluted, and additional colorants are used as appropriate to decrease the color difference and graininess.

$$f_i(M) = \begin{cases} \text{Lm and Y} & \text{for } i = 0 \\ \text{Lm and M} & \text{for } i = 1 \\ \text{M} & \text{for } i = 2 \end{cases} \quad \text{or} \quad f_i(C) = \begin{cases} \text{Lc and } Lm & \text{for } i = 0 \\ \text{Lc and } C & \text{for } i = 1 \\ \text{C} & \text{for } i = 2 \end{cases} \quad (1)$$

where f means the function of the separation, i (0,1,2) represents the three types of region (bright, middle, and dark), and M, Lm, Y, C, and Lc indicate the kind of colorant used. Specifically, Y and Lm are the additional colorants used in a bright region to separate the magenta and cyan colorants. Figure 3 shows a block diagram of how the three lookup tables are constructed for the additional, diluted, and saturated colorants involved in the proposed six-color separation. In a bright region, only a diluted colorant is used to improve the graininess in conventional six-color separation. However, the exclusive use of a diluted colorant can cause a color difference, as seen in Fig. 1. Thus, an additional colorant (yellow or light magenta) is added to the diluted colorant to solve this problem. In this type of region, the input digital values (x) for the cyan and magenta wedges are separated into digital values for the additional colorant (k) and diluted colorant (j) to minimize the color difference ($\Delta E_{x,Lut(k,j)}$). In a middle region, diluted and saturated colorants are mixed, which generates graininess due to the deviation of the colorant concentration. To reflect this graininess, a quantitative granularity metric is used. Therefore, the input digital values (x) are separated into digital values for the diluted colorant (j) and saturated colorant (i) to minimize the granularity (*NGS*) below a predefined percentage tolerance for the color difference ($\Delta E_{x,Lut(i,j)}$). In a dark region, the input digital values (x) are only separated into a digital value for the saturated colorant (i) to minimize the color difference ($\Delta E_{x,j}$).

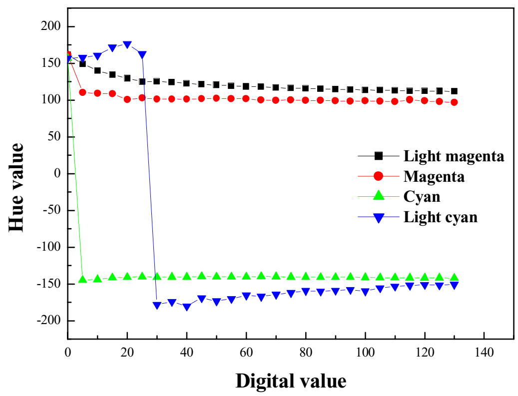


Figure 2. Hue values of the diluted and saturated colorant

Construction of the Lookup Tables in Bright Regions

To solve the problem of the colorimetric error that occurs with the conventional method, an additional colorant (yellow or light magenta) is added to a diluted colorant. Therefore, the input magenta colorant is replaced with light magenta and yellow, while the input cyan colorant is replaced with light cyan and light magenta. This can create a color with a similar hue value to the input magenta and cyan colorants. This can be explained by the Neugebauer mixing model,[9] which predicts the average spectral reflectance of an arbitrary printed patch as the weighted average of the spectral reflectance of the Neugebauer primaries. For example, if the yellow and magenta colorants are printed in stripes at a right angle to one another, the spectral reflectance of the red primary is weighted based on the product of the magenta and yellow areas. The more the magenta colorant is mixed with the yellow colorant, the more the weight of the red primary is increased. Therefore, if the yellow colorant is mixed with magenta, the hue of the magenta approaches that of the red. By the same principle, it can be assumed that mixing an additional colorant with a diluted colorant can create a color with a similar hue to the input magenta or cyan colorant. This assumption will be verified by experimentation. In addition to the above mentioned advantage, the graininess can be lowly maintained because of the natural characteristic of additional colorants with less dot visibility even though an additional colorant is used. Therefore, the use of an additional colorant can simultaneously reduce the color difference and graininess. To process proposed six color separation, the construction of the additional and diluted lookup tables in bright regions can basically be divided into three steps. First, a two-dimensional look-up table is created. All the combinations of fifteen-point light magenta and fifteen-point yellow or fifteen-point light cyan and fifteen-point light magenta are constructed and the CIELAB values measured using a spectrophotometer. These CIELAB values are then stored in the look-up table and interpolated to digital values (total 255.times.255 point) by linear interpolation. Second, input wedges are created. The magenta and cyan are equally sampled based on an interval of 5 (total 52 wedges) to generate input wedges, then their CIELAB values are measured, which are also subsequently used for the other types of region. Third, light magenta and yellow or light cyan and light magenta minimizing the ΔE_{ab} for the input wedges are selected from two dimensional look-up table until the digital value of the input wedges reaches a point defined as a bright region. A bright region is limited at the point where the amount of the diluted colorants reaches its maximum digital value. Finally, these selected digital values are stored in the additional and diluted lookup tables.

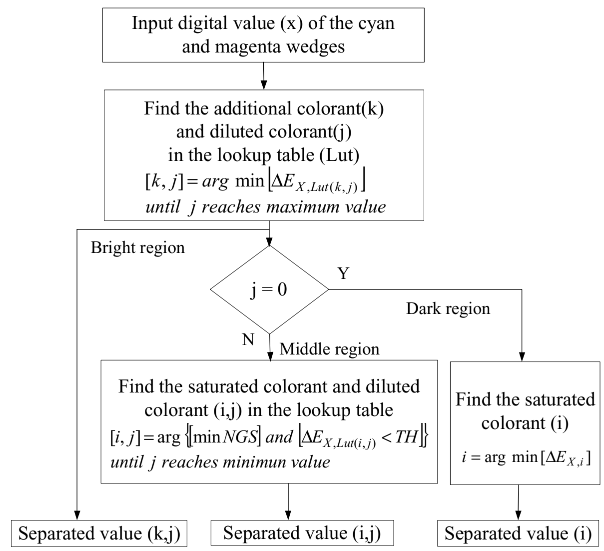


Figure 3. Block-diagram to construct three lookup tables for proposed six color separations

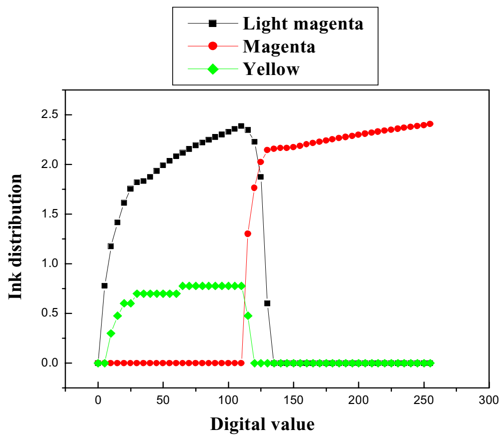
Construction of the Lookup-Tables in Middle Regions

As already seen in Fig. 1 (b), the graininess is increased and a saturated colorant is unpleasant to the human eye when two colorants with different densities are mixed in a middle region. Therefore, the graininess must be considered as well as the color difference in a middle region. This graininess can be subjectively or quantitatively evaluated. Subjective granularity is calculated based on the use of a visual examination score. Since this type of method uses human visual decisions, the results depend on the observers participating in the experiment. Plus, subjective granularity requires repetitive experiments, resulting in physical fatigue. Therefore, quantitative method proposed by the author is used to calculate the granularity.[4] Quantitative granularity is defined as normalized sum of the standard deviation calculated from the lightness, redness-greenness, and yellowness-blueness of the SCIELAB space[10] for experimental wedges.

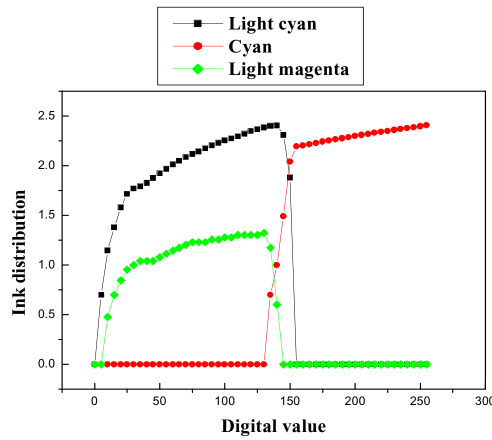
$$X_{sd,z} = \sqrt{\frac{\sum_i \sum_j (X_{i,j} - X_{mean,z})^2}{N}} \quad ,\text{for } z = 0,1,2 \tag{2}$$

$$GS_k = X_{sd,0} + X_{sd,1} + X_{sd,2} \quad ,\text{for } k = 0,\ldots,289 \tag{3}$$

$$NGS_k = 100 \times \frac{GS_k - \min_k}{\max_k - \min_k}, \quad \textit{for } k = 0,\ldots,289 \tag{4}$$



(a)



(b)

Figure 4. Photo-ink separation pass; (a) magenta colorant (b) cyan colorant

where N and (i, j) are the pixel number and spatial coordinate for the *k*-experimental wedges. $X_{mean,z}$ and $X_{sd,z}$ are the average and standard deviation for the lightness, redness-greenness, and yellowness-blueness. GS_k is the sum of the three standard deviations. NGS_k is the normalized value for the experimental wedges. Using this granularity, construction of the lookup tables in a middle region is executed as follows. As with the experimental wedges for a bright region, all the combinations of fifteen-point light cyan and fifteen-point cyan or fifteen-point light magenta and fifteen-point magenta are printed and CIELAB values estimated using the Neugebauer mixing model.[11] The estimated CIELAB values and granularity, as obtained above, are then stored in two-dimensional lookup tables for experimental wedges. If the lightness value of the input wedges is smaller than that of the maximum point of a bright region, the light cyan and cyan or light magenta and magenta minimizing the granularity and no more than a predetermined percentage tolerance of the color difference are selected from the two-dimensional lookup table. These selected digital values are stored in diluted and saturated lookup tables. At this point, monotonicity constraints of the lightness must be also considered and the predetermined percentage tolerance established as hardly perceptible was 3%.[12]

Construction of the Lookup Tables in Dark Regions

The usage of the light magenta and light cyan colorants are decreased and finally reach zero at a certain point under the lightness monotonicity constraint. Thus, if the lightness value of the input wedges is smaller than this point, only a saturated colorant is used to minimize the color difference value with the input wedge because the graininess is not reduced any more when adding a diluted colorant to a saturated colorant in a dark region. These digital values of the saturated colorant are stored in the saturated lookup table.

Experiments

For the experiments, an EPSON STYLUS PHOTO 700 printer was used with a resolution of 360dpi. To print the input image, the input RGB image was converted into CIELAB values using forward characterization, then the CIELAB values were converted into CMY using gamut mapping and backward characterization.[13] The CMY image was then separated into CMYK using a simple gray component replacement (GCR).[14] Then, the CMYK was separated into CMYKLcLm using various six-color separations. Finally, the CMYKLcLm was printed using scalar error diffusion. Figure 4 shows the photo ink separation pass of the proposed six-color separation for cyan and magenta. The abscissa axis in Fig. 4 represents the input digital value, while the ordinate axis represents the separated colorant amount stored in three lookup tables of the additional, diluted, and saturated colorants by the a logarithm scale due to the smaller usage of an additional colorant. As seen, the ink separation pass is classified into three types of region and three kinds of colorant are used. In the bright regions, only a small amount of an additional colorant (light magenta or yellow) is sufficient to obtain the colorimetric reproduction. While in the middle regions, a combination of light cyan and cyan or light magenta and magenta is used, and in the dark regions, only cyan or magenta is used. Using this photo ink separation pass, CMYK input image is separated into CMYKLcLm.

Stripe Image Experiment

The 'stripe' image was chosen to test the three six-color separation methods. Figs. 5 and 6 show the results of the four-color printing, six-color separation using the color difference, six-color separation using the lightness and subjective granularity, and the proposed six-color separation for magenta and cyan. Figs. 5 (b) and 6 (b) show that the use of saturated colorants in bright regions is very coarse to the human eye, thereby degrading the image quality. Clearly, the use of saturated colorants in bright regions did not take advantage of the six-color printer, which can produce less graininess and a greater resolution, although the colors of the separated results were similar to those of the four color printing. Figs 5 (c) and 6 (c) showed that the separated result was much smoother when using diluted colorants than with the other methods, as the dot pattern was invisible and pleasant to the human eye. In addition, the resolution in the bright regions was higher than in 5 (a) and 6 (a) or 5 (b) and 6 (b) because diluted colorant is printed a lot to make lightness value same as saturated colorant. However, the disadvantage was that colors of the separated results were very different from the four-color printing, due to the hue difference between the diluted and saturated colorants. Figs 5 (d) and 6 (d) show the results when an additional colorant was used in the bright regions, which decreased the colorimetric error in figs 5 (c) and 6 (c). Figure 7 shows the hue values of the diluted, saturated, and separated result when using the proposed method for magenta and cyan in the bright regions. By adding an additional colorant to a diluted colorant, the hue value of the separated result becomes close to the hue value of the saturated colorant. Therefore, the proposed six-color separation can correct the color difference in a bright region. In addition, the graininess in Figs 5 (d) and 6 (d) was also decreased in comparison with that in Figs 5 (b) and 6 (b) when adding an additional colorant with less dot visibility.

Performance Comparison of Various Six-Color Separation Methods

The color difference (E_{ab}) and proposed granularity score (*GS*) were used to compare the performances of the various six-color separation methods. Ramp wedges of magenta and cyan were made based on an interval of 5 (total 52 wedges) and the three six-color separation methods applied. The E_{ab} was then calculated between the original ramp wedges and the separated ramp wedges, while *GS* was calculated as the average sum value of the standard deviation of SCIELAB space for the three separated ramp wedges. Table 1 shows the performance of the three six-color separation methods. As expected based on the above experiments, the results for the six-color separation using the lightness and subjective granularity showed a very small granularity, yet the color difference was very high, while the contrary result was obtained for the six-color separation using the color difference. However, the results for the proposed method had a reduced color difference and less graininess. Therefore, the use of an additional colorant with a diluted colorant was confirmed to create both a colorimetric and smooth tone reproduction.

Conclusion

This paper proposed a method of six-color separation using additional colorants with less dot visibility to reduce the color difference and graininess. In bright regions, yellow and light magenta are used as the additional colorants to decrease the colorimetric errors that occur in the conventional method. Meanwhile, in middle regions, a quantitative granularity metric is used along with the color difference metric to reflect the graininess generated by the combinations of the diluted and saturated colorants. Experiments confirmed that the use of the additional colorants creates a color with a similar hue to saturated colorants and results in an accurate colorimetric reproduction. At the same time, smooth images are also obtained due to the lower dot visibility of the additional colorants and use of the quantitative granularity metric. Accordingly, the use of the additional colorants and granularity metric according to the three types of region can simultaneously produce a colorimetric and smooth-tone reproduction.

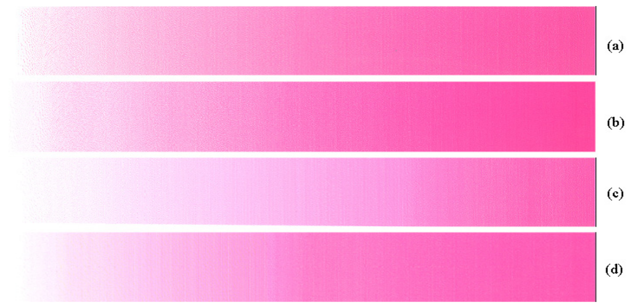


Figure 5. The results of six color separation for magenta wedges; (a) four color printing (b) ref. [4] (c) ref. [5] (d) proposed six color separation

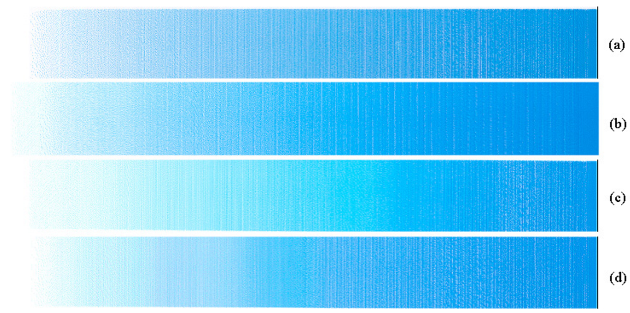


Figure 6. The results of six color separation for cyan wedges; (a) four color printing (b) ref. [4] (c) ref. [5] (d) proposed six color separation

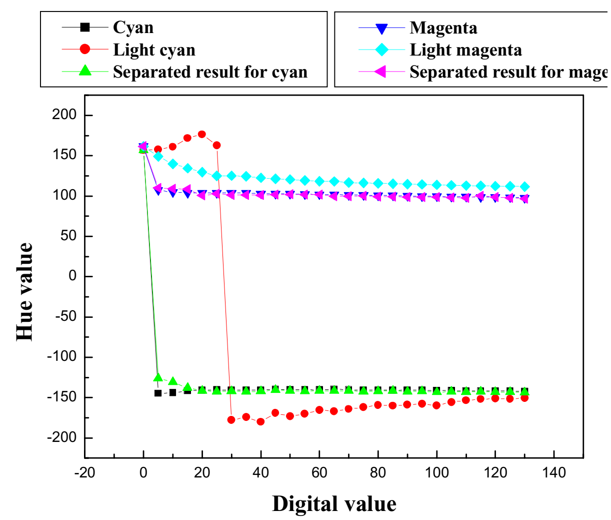


Figure 7. The hue values of the diluted, saturated, and separated results using the proposed algorithm

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Table 1: Color Difference and Granularity Score for Cyan and Magenta Wedges

Various methods	Cyan		Magenta	
	ΔE_{ab}	GS	ΔE_{ab}	GS
Six color separation using the color difference	1.64	6.81	1.22	3.83
Six color separation using the lightness and subjective granularity	6.07	3.80	10.06	3.74
Proposed method	1.24	5.40	1.25	3.49

Author Biography

Yeong Ho Ha received the B. S. and M. S. degrees in Electronic Engineering from Kyungpook National University, Taegu, Korea, in 1976 and 1978, respectively, and Ph. D. degree in Electrical and Computer Engineering from the University of Texas at Austin, Texas, 1985. In March 1986, he joined the Department of Electronic Engineering of Kyungpook National University, as an assistant professor, and is currently a professor. He served as TPC chair, member, and organizing committee chair of several IEEE, SPIE, and IS&T conferences including IEEE International Conference on Intelligent Signal Processing and Communication Systems (1994) and IEEE International Conference on Multimedia and Expo (ICME 2000). He is now chairman of IEEE Taegu section, vice president of the Institute of Electronics Engineering of Korea (IEEK), and president of Korea Society for Imaging Science and Technology (KSIST). He is a senior member of IEEE, and a member of Pattern Recognition Society and Society for IS&T. His main research interests are in color image processing, computer vision, and digital signal and image processing