A New Gamut Mapping Method Dependent on Image Characteristics

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Abstract

It is necessary to describe the gamut boundaries of the original and the reproduction properly for gamut mapping. It requires a thorough understanding of color reproduction gamut. Normally, the color values (CIELab) of different points are measured for describing the gamut boundary. For media gamut, it can be done by Kubelka-Munk equations and Neugebauer equation. In the present study, the gamut boundaries of the images are described considering color values of all pixels instead of measuring the CIELab values of sample points, which will minimize the approximation error. The out-of gamut colors are easily found in this way. It has been observed that the out-of-gamut color regions are not similar for different color zones. It has also been observed that the ratio of output gamut to input gamut are different for different images. Considering all these facts, an image-dependent gamut mapping is suggested in the present study.

Introduction

The color gamut of printers are different from that of the input devices. Hence it is not possible to reproduce all colors of the monitor on a printer. The transformation of the color gamut of one device to fit that of the other is known as gamut mapping. It is necessary to ensure a good correspondence of color appearance between the original and the reproduction. Most of the color gamut mapping techniques allow compression of the monitor gamut to printer gamut and is negligent about the color distribution of the images.

The main objectives of gamut mapping[3] are as follows:

a) Preserve gray axis of the image and to obtain maximum luminance contrast – It means that the white and black points of the original should be mapped onto the white and black points of the reproduction respectively.
b) Reduce the number of out-of-gamut colors – Ideally all of the colors of the image should be brought within the gamut of the reproduction.
c) Minimize hue shift – The hue of the colors should remain unchanged.
d) Increase in saturation – As the saturation of the reproduction gamut is limited, efforts should be taken to preserve the saturation difference present in the original.

Image and Device Gamut

The original gamut can be seen either as the gamut of the input device or as the gamut of the input image. (i.e., a subset of the input device gamut). It is more reasonable to use the image gamut as the original gamut to make as few as possible changes to the original image,[3] Morovic and Luo[3] found that the most noticeable trend in the gamut mapping work shows that image-dependent methods are preferred over device-dependent methods.

Parameters of Gamut Mapping

The three attributes of colors are hue, lightness and chroma. CIELab color spaces are preferred to be used for gamut mapping as these are device-independent. As explained by Morovic and Luo,[3] it should be kept in mind that the L,a,b values are not the perceptual attributes e.g., lightness, hue and chroma., but they are only the predictors of the attributes.

Gamut Boundary Description

It is necessary to know the gamut boundaries of the original and the reproduction before gamut mapping. Gamut boundary descriptor (GBD) is some overall way of approximately describing a gamut. It is also necessary to find the intersections between the gamut boundary and a given line along which the mapping will be carried out, i.e., the line gamut boundary (LGB). Till now, most of the gamut boundary descriptors have been made on the basis of sample points of the images instead of considering color values of all points or pixels of the image.

In this study, the L,a,b channels of the image obtained in Photoshop are read by Matlab which shows the color values for each pixel. For getting a 2-D representation, L,a,b values are converted to L (lightness) and C(Chroma) values. Then the L values are sorted in ascending order and

C_{min} and C_{max} are found out for each L. The gamut boundary containing all pixel colors is obtained by joining these points instead of taking the sample points. In this way, gamut boundary description of any image considering all pixels offers accurate representation of the image gamut.

The IT Test target 8.7/3 (Kodak Q60R1) is to be scanned and printed in the test printer, to get the printer gamut. The printed paper is to be scanned with the same condition of viewing input image the gamut of the printer can be found in the same way as described above.

Direction of Gamut Mapping

It is very important to select the lines along which the gamut mapping approaches. The options are

a) lines of constant lightness and hue, constant saturation and hue
b) lines towards single center of gravity
c) lines towards variable center of gravity
d) lines towards the nearest color in the reproduction gamut.

In the earlier studies, the most important criteria was to maintain hue and hence mapping was done along the chroma direction. However, this one-dimensional mapping causes objectionable decrease of chroma.[5] Considering these facts, Morovic and Luo[4] and many other workers suggested two-dimensional gamut mapping where lightness and chroma were compressed and hue was maintained.[5] Mapping in lightness direction reduces the image contrast and mapping in chroma direction reduces the image vividness. Katoh and Ito[5] found that larger changes are acceptable in chroma than in hue and smallest change is tolerated in lightness direction.

In the present study, first compression has been done along the lines where the attributes, lightness or chroma are kept as constant. Then it has been done along the focal line towards the focal point as defined below. As it has been found that the compression along the focal line as LBD offers better result, the work has been concentrated in that direction.

Gamut mapping directions are dependent on the positions of focal point. To maintain gray balance of the image after mapping, the focal point is selected on Lightness axis.

The focal point f is calculated from the image histogram using the following equation.

$$f = \frac{\sum_{i=0}^{L_{max}} L_i F_i}{\sum_{i=0}^{L_{max}} F_i} \qquad (1)$$

where Li = lightness value at a particular level, Fi = frequency i.e., the number of pixels at that lightness.

Gamut Mapping Method

Gamut mapping can be broadly classified in two categories–clipping and compression. Clipping only changes colors which are outside the reproduction gamut. Gamut compression algorithms are applied to all colors of the original image to distribute the differences across the entire image. As the clipping can possibly cause loss of gradation in an image,[5] the present work is concentrated on compression.

The gamut compression can be of two types: Linear compression and non-linear compression. Linear compression maintains the gradations in an image but it decreases image saturation.[5] The non-linear compression can minimize the loss of detail. Several researchers[2,5] found non-linear options better than the linear one.

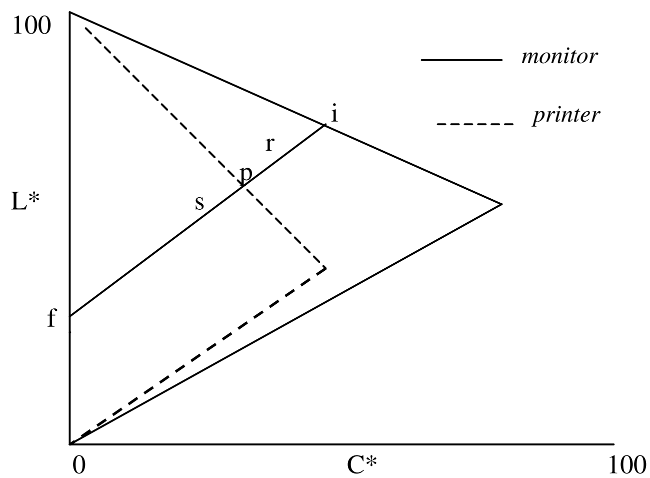

Figure 1. Gamut mapping along the focal line as LBD

Figure 1 states how compression is done along the lines of constant perceptual attributes. The color located at point r which is an out-of-gamut color is compressed to a point s inside the printer gamut where f is the focal point, i and p are the points at the input image and printer gamut boundaries respectively. The compression is done along the LBD towards the focal point f. The linear compression is done by the equation:

$$fp \;/ fi = fs/fr \qquad (2a)$$

The equation for non-linear compression is:

$$fp \;/ fi = (fs/fr)^{\gamma} \qquad (2b)$$

The value of γ taken for this experiment is the ratio of area of printer gamut and input image gamut

Intersection Points on Gamut Boundaries

To determine intersection points to Gamut Boundary a program is written in C++ with the help of Matlab C++

Math Library. In this program input and output Gamut of the image and printer are considered as polygon. At first all pixels positions are determined with respect to each polygon. If a pixel is in polygon, it gives a particular value(1) and if it is outside the polygon it gives a different value(0). For a particular point, its gradient is determined with respect to the focal point. The point of intersection of the focal line (LBD) with gamut boundaries (GBD) is obtained by moving in gradient direction towards outside (if the point is inside polygon) of polygon or inside (if the point is outside of polygon) of polygon and checking each trial point. A transition in the position of the trial point i.e., 1 to 0 or 0 to 1 identifies the point of intersection.

Experiment

Different images are taken from low-key to high-key range according to the histogram. One average key image, two low-key images and a high-key image are taken for the experiment. The images are scanned using Umax Astra 4400 scanner. The L, a and b channels of the images obtained from the Adobe photoshop are read by Matlab. The gamut boundary of the image is defined by the method as described in the section of gamut Boundary description.

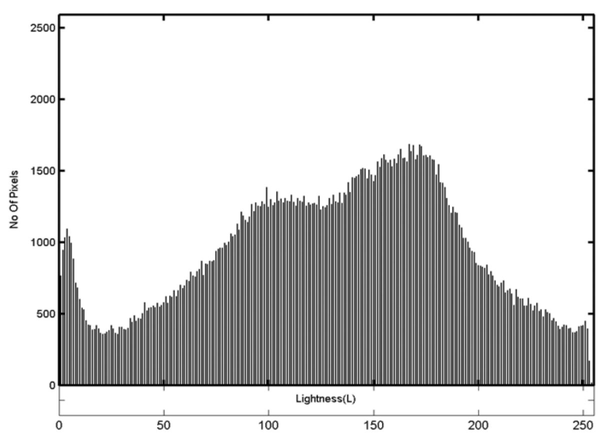

Figure 2. Image histogram of the average-key image

The prints of IT test target 8.7/3 (Kodak Q60R1 used) are taken in HP 930c printer and are further scanned to get the printer gamut boundary. The color values of some additional points are taken to obtain more data for low L and C values. It has been found that the printer gamut generally lies inside the input image gamut.

Experiments are carried along the constant lightness and constant chroma direction.

The focal point on the lightness scale is found from the image histogram using equation (1). While making the compression towards the focal point, it becomes necessary to find out the intersection points of the focal lines (LBD) with input image gamut boundaries (GBD) and printer gamut boundaries.

The area under the input image gamut boundary (GBD) and the printer gamut boundary are found out. Then γ is calculated as the ratio of the area of printer GBD and input image GBD.

The color of the pixels in the input gamut are compressed inside the printer gamut using equation (2a) and (2b). The color difference formula ΔE_{94} is then used to find the minimum color difference.

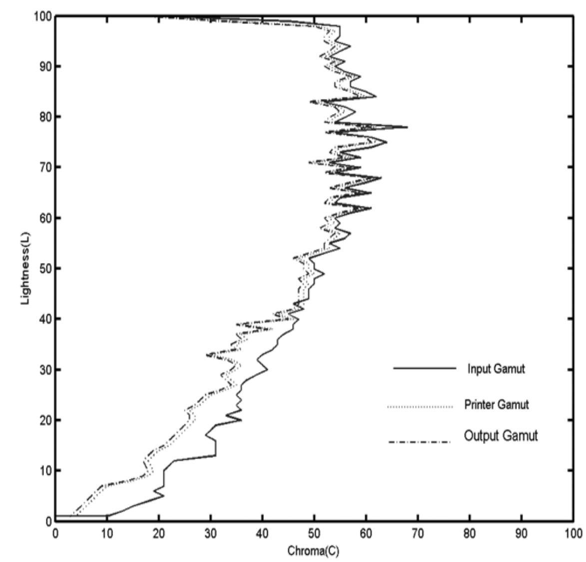

Figure 3. The gamut boundaries of input image, printer and outputof the average key image with $\gamma = 0.96$

A psychophysical experiment has been carried out to compare the color appearance of images after mapping with 10 observers.

Result and Discussion

The four images taken are as follows: two low key images, one average key image and one high key image. Figure 2 shows the histogram of the com average key image. The focal point of the image is calculated from equation (1).

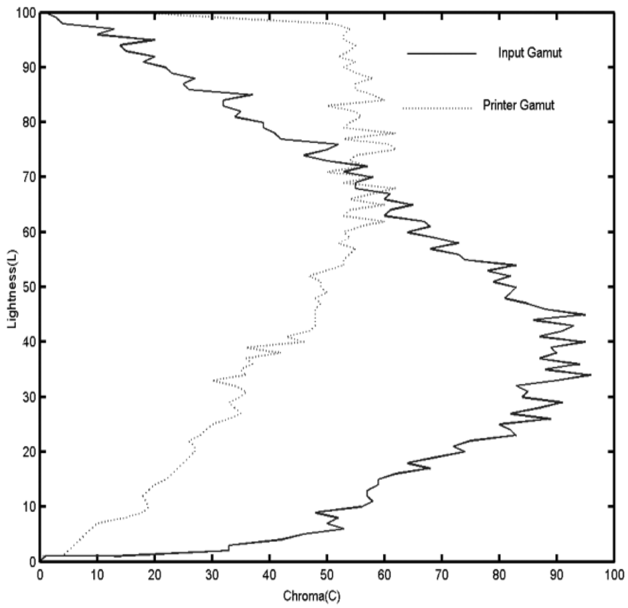

Figure 4. Input image and printer gamut boundary for low key image of γ = 0.72

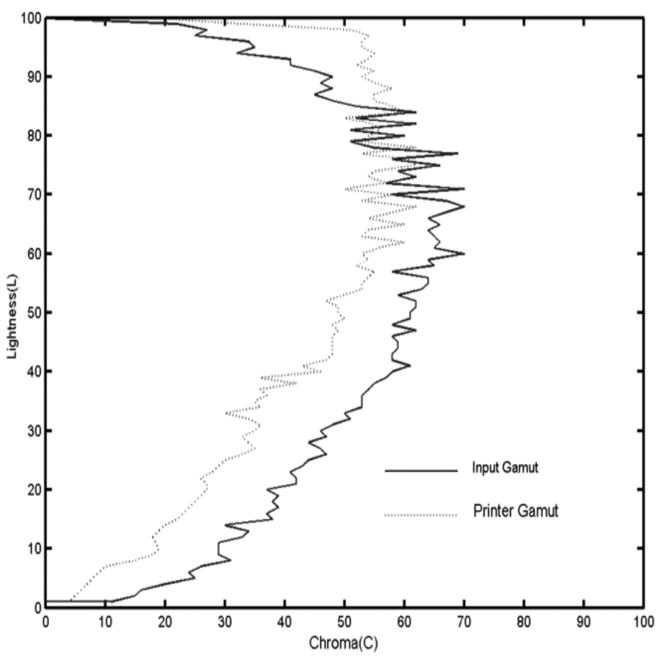

Figure 5. Input image and printer gamut boundary for low key image of γ = 0.88

In the present study, first compression has been done along the lines where the attributes, lightness or chroma are kept as constant. Then it has been done along the focal line towards the focal point. It has been found that the result is better for 2-D compression than 1-D compression.

All of the images are subjected to nonlinear compression. The color gamut boundary of test image (average key) and printer gamut boundary are shown in Figure 3. The focal point is calculated from the image histogram shown in Figure 2. Then the non-linear compression is done for the input image with a γ= 0.96 to fit it inside the printer gamut. The output gamut obtained in this way is shown in the same figure. It appears that the output gamut is fitted within the printer gamut.

The output gamut is also found by applying linear compression and non-linear compression with a fixed value of γ = 0.8(2). Then the color difference ΔE are calculated for all three cases and the value of ΔE is minimum when γ is taken as 0.96 where gamma depends on input image characteristics.

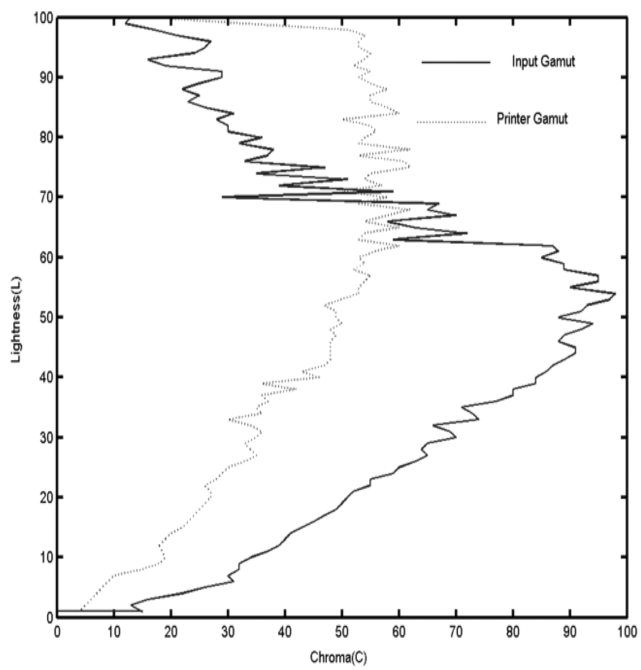

Figure 6. Input image and printer gamut boundary for high key image of γ = 0.79

The results are similar with three other images varying from low key to high-key option with γ=0.72, 0.88,0.79 respectively. The gamut of the input images and the printer are shown in Figures 4, 5 and 6 respectively. It has been observed that the out-of-gamut color regions are not similar for different color zones. All of the images offer better result with non-linear compression with variable γ, where γ is dependant on input image gamut.

The psychophysical experiments with 10 observers indicate the output quality with the proposed non-linear compression is better than the other options.

Conclusion

In the present study, a gamut boundary descriptor is suggested considering all colors of the pixels, which will minimize the approximation error.

It has been found that the gamut mapping methods depend on image content. It is shown that the gamut mapping direction towards focal point offer better result than unidirectional approaches. The image dependant non-linear compression results in better rendition than other 2 D linear and non-linear options.

References

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Biography

Swati Bandyopadhyay received her B.E. degree in Chemical Engineering from Jadavpur University at Kolkata, India in 1987 and Ph. D. (Engg.) from the same University in 1995. Since 1990, she has worked as a lecturer of Printing Engineering Department in Jadavpur University. Now, she is working as Reader of the department. Her work is primarily focused on image quality of ink jet printer and color theories. She is a member of IS&T and IIChE. This work was done under the scheme of AICTE Career Award for young teachers.