https://doi.org/10.2352/ISSN.2169-4451.2017.32.107

A new out-of-gamut determination method of image based on irregular segmentation

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Abstract

*The out-of-gamut determination of images is very important for color gamut mapping which plays an important role in cross-media color reproduction. In this paper, aiming to achieve an accurate out-of-gamut determination of image and exploit the full potential of the reproduction device gamut, we propose a out-of-gamut determination method of images based on irregular segmentation which divides the color gamut into several parts according to the chroma and lightness of colors in CIELAB color space. First, the device color gamut is divided into the high-chroma and the low-chroma color parts, and the high-chroma parts are divided into more segments through the CIELAB a*b* plane when calculating color gamut descriptors. Then, in each segment the radiuses between the color points and the center point are calculated. For the color points located in the high-chroma parts, the color point with the biggest radius is selected as the gamut boundary descriptor, and for that in the low-chroma parts, if the corresponding outer segments are empty, the color point with the biggest radius is selected as the gamut boundary descriptor. Through the irregular segmentation of gamut, the GBDs distribute more uniformly among the color gamut surface than segment maximum method which treats all colors in the same way wherever they are located in the gamut. After that, determination of the out-of-gamut colors can be done by calculating the position relationship between the source colors and the GBDs. Additionally, GMAs would benefit from this accurate out-of-gamut determination of image. GMAs based on this out-of-gamut determination method validate the promising results.*

Introduction

In printing industry, color image reproduction technology has developed within the last decade. The range of reproducible colors varies with each image reproduction device, such as printer and display. Color gamut is the entirety range of colors that can be rendered by a device or that are contained in an image[1-3]. When reproducing an accurate image across media whose color gamuts are different, it is important to modify some sources colors and conduct color transformation technology from the original color gamut to destination color gamut , i.e., color gamut mapping algorithm (GMA). These facts raise the problem of determining whether the source color is out of the destination gamut in GMA, called the out-of-gamut determination whose accuracy has great effect on the performance of GMAs.

In the framework of the out-of-gamut determination of image, the gamut boundary calculation of reproduction media is necessary which can be constructed by gamut boundary descriptors (GBDs). Most GMAs, such as HPminDE and SGCK[4], adopt Segment Maximum Method[5] to calculate the GBDs of devices in the process of out-of-gamut determination of source colors. In Multispectral Gamut Mapping[6], Convex Hull Algorithm[7] is used to determinate whether the source color is out of the destination gamut. In order to give good results of the out-of-gamut determination of image, it is important that the GBDs is as accurate as possible.

At present, several algorithms of GBDs are often used in the process of determining the out-of-gamut of images. The convex hull of a set of points is the smallest convex set, and it is a approximate surface which can realized by quickhull algorithm. Using the convex hull we can get an approximation color gamut which contains all the colors, the color gamut constructed by convex hull algorithm always has larger volume, and also has no concave parts in the constructed gamut surface[8], while there are often gamut concavities where convex hull algorithm fails. The modified convex hull algorithm proposed by Balasubramanian and Dalal[9] is the evolution of convex hull algorithm. In this method, the data of points is processed by a gamma function to make the shape of original points like a convex hull, then the convex hull algorithm is applied before a inverse process to the GBDs of the convex hull algorithm. Results show that with the proper parameters, the modified convex hull algorithm can get an accurate gamut with concaves. However, it is difficult to decide the proper parameters. The use of alpha shape to construct color gamut boundary is first proposed by Cholewo and Love[10]. The gamut is constructed by a subset of Delaunay tessellations of color points which a device can render. The biggest problem in using alpha shape algorithm is that it is difficult to decide the proper α, though Cazals[11] tries to use the dynamic determination of α to improve the performance. The segment maximum algorithm is presented by Morovic and Luo[12]. The color space is divided into m-by-n segments, storing the color point with the maximum radius in each segment as the gamut boundary descriptor. In order to get the color gamut along arbitrary line of constant hue angle, Morovic also develops the flexible sequential line gamut boundary(FSLGB) method[5,12] which makes it easier to be used in color gamut mapping. In this paper, we proposed a new out-of-gamut determination method of image based on irregular segmentation in order to get an accurate description of the out-of-gamut of images.

In this paper, we proposed a new out-of-gamut determination method of image based on irregular segmentation in order to get an accurate description of the out-of-gamut of images. The remainder of this article is organized as follows: in the next section we describe the framework of out-of-gamut determination of images, including gamut information extraction and comparison and determination. In the subsequent section we describe the principle of the irregular segmentation method. Next we conduct the experiment and discuss the experimental validation results, comparing the irregular method and segment maximum algorithm as well as performing the color gamut mapping based on the proposed out-of-gamut determination method of images.

The framework of out-of-gamut determination of images

Gamut information extraction

The accuracy extraction of color gamut of devices or images greatly affects the determination of the out-of-gamut of images. The process of gamut information extraction consists of two parts, sampling of inputs and transforming into working color space.

For output devices, the gamut is the range of color stimuli they can produce, and for input devices it is the range of color stimuli among which they can distinguish differences[12]. The gamut extraction of these devices requires having access to the entire range of inputs to them. In this paper, we focus on the output devices. For output devices the sampling of inputs needs to access to the entire range of digital data that can be input to them, such as RGB and CMYK digital data, then in order to get the gamut information, transforming these sampling digital data into working color space is necessary by measuring the color represented by color values in working color space of each corresponding output or calculating the color based on ICC profile defining a mapping between two color encodings.

The number of samples from the sampling process is closely related to the choice of the GBD algorithms' parameter. For example, for segment maximum algorithm, if only an insufficient number are available, increasing m and/or n will not increase accuracy of GBDs and is likely to result in false concavity artifacts. As a rule of thumb, Morovic suggests that it is good to use a uniform sampling with no less than 40 (and ideally 60) samples per device color space dimension when describing device gamuts[12]. Additionally the choice of working color space of the gamut also has great effect on the accuracy of gamut information extraction. The color space is used to describe the color attributes, i.e. lightness, chroma, and hue. Its perceptual uniformity is the most important properties. While there isn't a perfectly perceptually uniform color space[13], various approximations have been proposed[14-17]. In this paper, CIE LAB color space is adopted in the out-of-gamut determination of images.

Comparison and determination

After the gamut information extraction, it is essential to compare the colors of image with the GBDs of the output device. Firstly the gamut boundary of the extracting gamut information of output device needs to be found using a GBD algorithm. Then for each color of image, the two-dimensional gamut boundary at its hue angle is calculated in the output device's gamut by intersecting the line connecting the two GBD points adjacent to the image's color with the hue angle plane. Whether the color point of the image is out of the output device gamut can be determined by comparing the color with the intersection of the line connecting the color point and the point in the lightness axis with the line gamut boundary. Through the comparison of the position relationship between the colors of image and the GBDs, the out-of-gamut part of the image can be obtained.

The irregular segmentation method

In the irregular segmentation method which improves the segmentation technique of segment maximum algorithm, the color space in divided by hue angles in hue plane and brightness quantization in vertical.

In the hue plane, the color plane is divided into two parts the high-chroma part and the low-chroma part by the indices β (Figure 1), or more parts if a better accuracy is needed and of course more time will be consumed. In the low-chroma part the plane is divided by a hue angle α， and for the high-chroma part, the hue angle is α/n (n is an integer), in this way the hue plane is divided into [360(1+n)]/α segments.

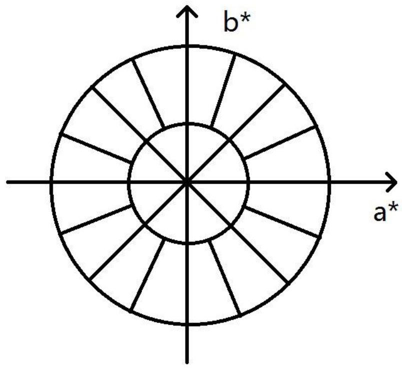


Figure 1. *The segment in the hue plane*

In the vertical the plane is divided by the brightness quantization h, then the brightness axis is divided into 100/h segments(Figure 2).

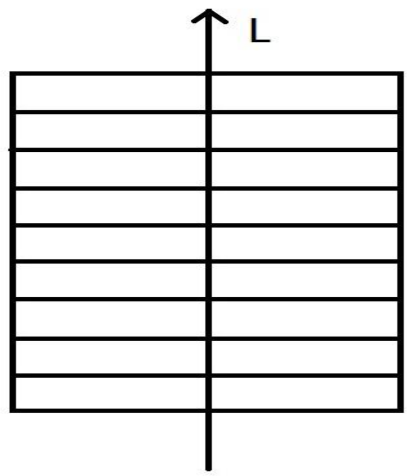


Figure 2. *The segment in the brightness plane*

Thus the color space is divided into [36000(l+n)]/(αh) segments. To calculate the GBDs of a set of colors from color plate or samples of an output device, the segments are labeled first, each inner segment(i.e. the segment in low-chroma part) corresponds to n outer segments(i.e. the segment in high-chroma part), and the GBDs can be stored in a matrix less than [36000(l+n)]/(αh), because in some segments we use the inner segments as the gamut boundary descriptor if no outer available. In each segment the indices r which stands for the distance between the color point and the point with same lightness in the the L* axis is calculated. If the r of the outer segment is not 0, then the color in the outer space with the maximum r is chosen as the boundary of the hue angle in the plane, If the r of all outer segments corresponding to the inner part is 0, then the color in the inner space with the maximum r is chosen as the boundary. In this way, the GBDs of the set of colors can be found.

Experiments and results

Experimental data

In this paper, the gamut of JapanColor2001Coated is selected as the destination gamut. Thus the sampling is performing in the CMYK device color space whose entire range is from 0 to 100 using uniform sampling method where the step size is 2 (i.e. taking 514 samples). Then transforming the data into working color space CIELAB is conducted based on JapanColor2001Coated ICC profile. Finally using the irregular segmentation method calculate the GBDs of the JapanColor2001Coated's gamut, the gamut is shown in Figure 3. The images used is from Kodak Lossless True Color Image Suite which are encoded in sRGB.

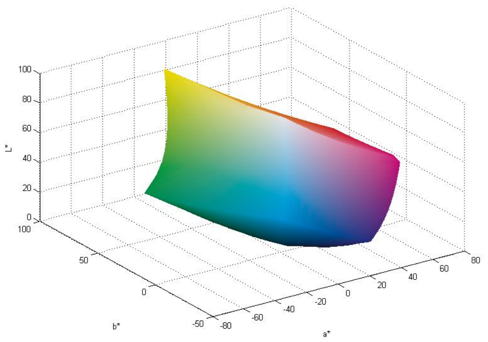


Figure 3. *The gamut of JapanColor2001Coated*

Comparison between the irregular method and segment maximum algorithm

Segment maximum algorithm it treats the outer part and the inner part in the same way without the consideration of the shape of the real device color gamut which is bigger in the middle part and smaller in the two ends across the L* axis, this leads to that the segments is denser in the two ends and sparser in the important middle part, and in the end the GBDs distribute non-uniformly among the gamut surface. Additionally the description accuracy of each segment is different, shown in the Figure 4. The accuracy of gamut boundary in each segment can be expressed by the length of arc across the gamut boundary descriptor. The accuracy of segment OAB can be expressed by arcAEB=α'd1, the accuracy of segment OCD can be expressed by arcCFD=α'd2, where α' is the central angle and d is the radius corresponding to the segment. The accuracy rate between the two parts is d1/d2, as d1>d2 that is to say if a gamut boundary descriptor is located in the inner part such as F, it will be more accurate than color gamut boundary descriptor located in the outer part such as E in describing color gamut.

In addition, the blind area of GBDs exists in the segment maximum algorithm, as shown in Figure 5. Figure 5 shows the first area of a rough device gamut boundary constructed by segment maximum algorithm after interpolation on a*b* plane in CIELAB color space. In this area the color space is divided into 4 segments, in the gamut boundary determination, color H, I, G, K are chosen as the gamut boundary descriptor of segment 1, 2, 3, 4. This leads to the colors in area 5, 6, 7, 8 which located in the real gamut would be determined as the out-of-gamut colors as their distances to the center point are less than those of the gamut boundary descriptors, and this problem would be more obvious as the distance increases.

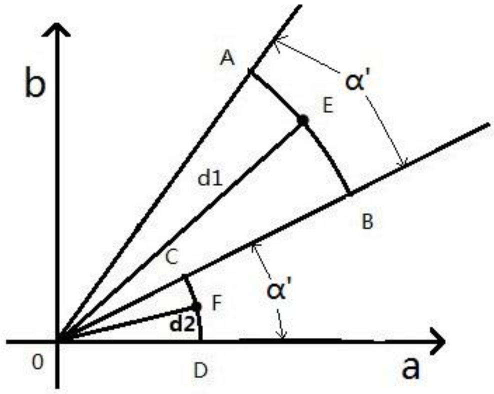


Figure 4. *The calculation error on a*b* plane*

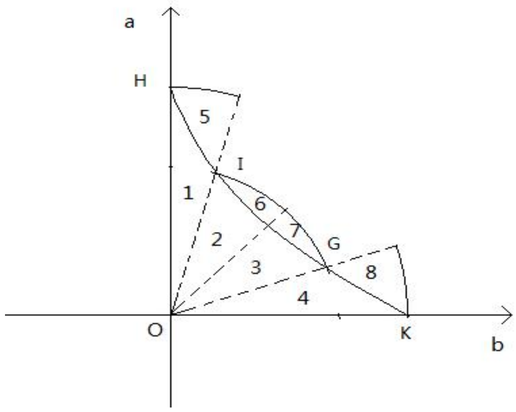
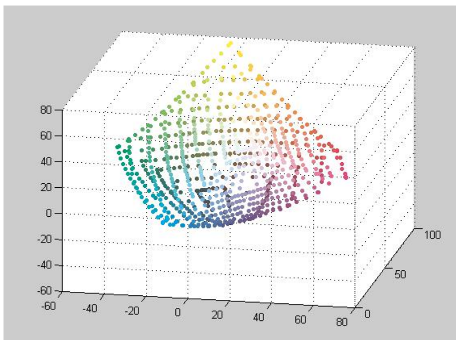


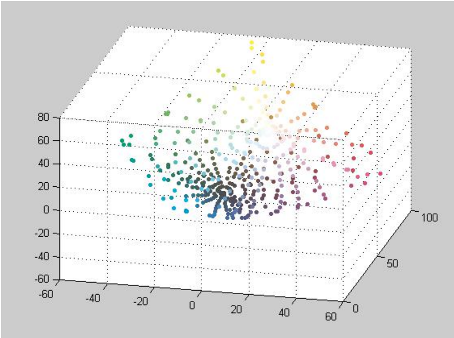
Figure 5. *The rough gamut segmentation on a*b* plane*

While in the irregular segmentation method which divided the color gamut into several parts according to gamut shape. First, the device color gamut is divided into the high-chroma and the low-chroma color parts, and the outer part corresponding to the inner part are further divided into n segments through the CIELAB a*b* plane when calculating color gamut descriptors. Thus in this way the segments in the outer part are n times more than the inner part to avoiding the problem of segmentation non-uniform and making the GBDs distribute uniformly among the gamut surface to some extent.

Figure 6 is the GBDs distribution using segment maximum algorithm and the irregular segmentation method. From Fig.6 the distribution uniform of GBDs is improved using the irregular segmentation method.



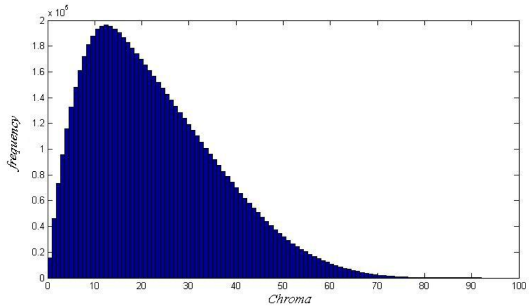
(a) The distribution of GBDs using the irregular segmentation method



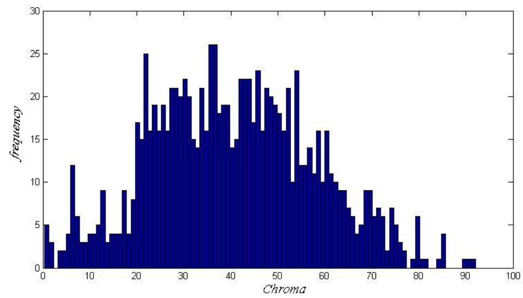
(b) The distribution of GBDs using segment maximum algorithm

Figure 6. *The distribution of GBDs*

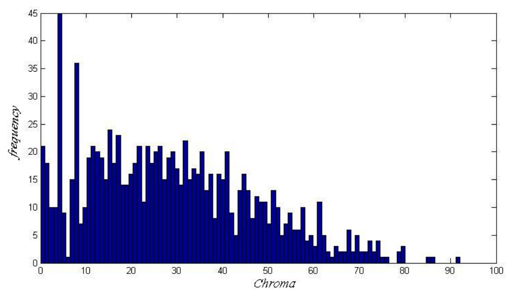
Figure 7 shows the chroma distribution histogram of the colors in the gamut of JapanColor2001Coated. Figure 7(a) is the chroma distribution histogram of all samples, Figure 7(b) is the chroma distribution histogram of GBDs using the irregular segmentation method, Figure 7(c) is the chroma distribution histogram of GBDs using segment maximum algorithm. From Figure 7, the GBDs in high-chroma part are improved using the irregular segmentation method.



(a) The chroma distribution histogram of all samples



(b) The chroma distribution histogram of GBDs using the irregular segmentation method



(c) The chroma distribution histogram of GBDs using segment maximum algorithm

Figure 7. *The chroma distribution histogram of gamut*

Results

Through performing the above framework of out-of-gamut determination of images, Figure 8 shows the result of out-of-gamut determination where white colors represent the out-of-gamut colors of the image.

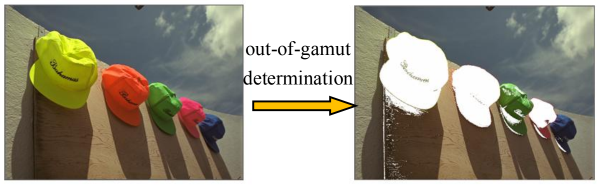
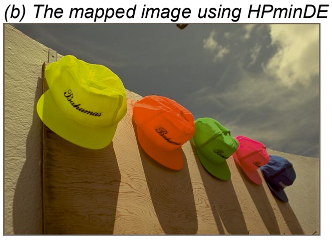


Figure 8. *The process of out-of-gamut determination of image*

In addition, the HPminDE color gamut mapping algorithm is developed by using the proposed out-of-gamut determination based on the irregular segmentation, the result is shown in Figure 9.

(a) The original image

(b) The mapped image using HPminDE



(c) The mapped image using GMA based on the proposed out-of-gamut determination method

Figure 9. *The mapped images of different GMAs*

At the same time, six images are mapped using the same GMA, the original images are shown in Figure 10. The evaluation of the images adopts the ranking method of psychophysical experiment according to the CIE's Guidelines for the Evaluation of Gamut Mapping Algorithm comparing the GMA based on the irregular segmentation method with HPminDE and SGCK algorithms. The result is shown in Figure 11, here UHPminDE represents the GMA using the proposed out-of-gamut determination based on the irregular segmentation. From Figure 11, the quality of the mapped image using the UHPminDE is improved.

Figure 10. *The original images*

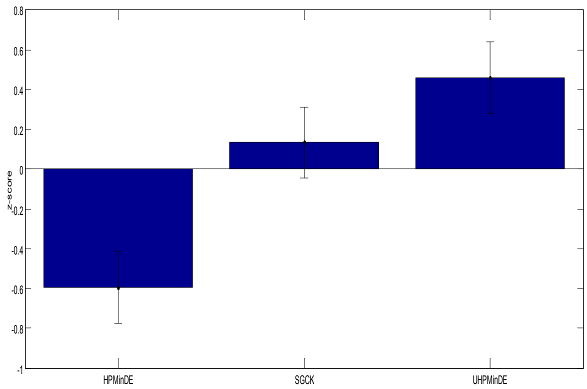


Figure 11. *Z-score values of the evaluation of GMAs*

Conclusion

We have introduced a new out-of-gamut determination method of image based on irregular segmentation, and validated it through the GMAs, the comparison between the segment maximum method and the GBD algorithm based on irregular segmentation was conducted, the results indicated that the gamut boundary descriptors using the irregular segmentaion based GBD algorithm were distributed uniformly to some extent among the gamut surface and also guaranteed a good accuracy especially in the saturated parts. Additionally, GMAs benefit from this accurate out-of-gamut determination of image. GMAs based on this out-of-gamut determination method validate the promising results and improve the quality of mapped images.

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