Adaptive Quartile Sigmoid Function Operator for Color Image Contrast Enhancement

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Abstract

This paper proposed a color image enhancement using statistical quartiles and sigmoid functions to compensate perceptually the characteristics of a destination device. Sigmoid functions are usually utilized to overcome the nature loss in perceived lightness contrast that results when an image from a full dynamic range device is scaled into the limited dynamic range of a destination device. The adaptive quartile sigmoid function operator (QSFO) is selected based on cumulative distribution function that was developed from the results of a psychophysical experiment. Final, a two-factor factorial experiment with repeated measures was conducted to verify the effects of six enhanced methods. There was a significant effect of the level of enhanced methods on the ranking score. The results of this study revealed that adaptive quartile sigmoid function operator was possible to enhance contrast of source images into preferred destination images.

Introduction

The conversion from real world luminance to output device luminance is known as tone mapping. Tone mapping ideas were originally developed for photography.[1] In color tone reproduction of pictorial images, the lightness rendition of the mapped images plays a major roles in the quality of the final image. For color tone reproduction tasks, where the goal is to produce a match to the original scene, it is important to maintain the perceived lightness contrast of the original image.

However, a robust algorithm for converting real world luminance to output device luminance has yet to be developed. Recently, Larson et al. proposed a visibility matching tone reproduction operator that reliably maps real world luminance to display luminance.[2] Authors considered two criteria most important for reliable tone mapping. One is that visibility must be reproduced. The other is that viewing the image produces a subjective experience that corresponds with viewing the real scene. Chatterji and Narsimha Murthy expressed the same idea in different words. There are two elementary requirements for color image enhancement. One is to keep the color structure of the original image and the other is to present as much information as the original has.[3] The first requirement can be satisfied by simply keeping the ratios between R, G, and B components of every pixel. While the second requirement can be achieved by using the information contained in the luminance component as well as color components.[4,5]

Up to the present, it is well known that histogram equalization produces maximally contrast enhancement image. In histogram equalization, the gray levels in an image are redistributed more evenly to make better use of the range of the display devices. However, the resulting image is far from the perception by human vision, and furthermore, the extent of enhancement is not controllable. In addition to these drawbacks, the enhancement scheme based on the histogram is very expensive and time consuming.[6]

Mainly, color images in RGB format will have three components, red, green, and blue. Each one of this can be considered as monochrome image. For example, the red component, when considered as monochrome image, the gray levels in it represent the red color information present in the color image. Now, if we enhance this particular component, obviously it effects the red color in the color image. Unfortunately, rare researches have discussed this topic.

The original curve is a diagonal line before image processing. In order to improve the result of brightness contrast and color saturation for a digital image, the tone-mapping curve has to be changed. A basic and effective method is using histogram equalization, which may achieve best result of contrast and saturation, but will destroy the relationships between contents of the image and makes the image unbalanced. Therefore, the S-shape tone scale process curve is recently used for improving the contrast and saturation of image for an image output device, and still mainly remaining balance of contents of the image.[7]

Conventional processes using S curve for transforming tone scale are mainly in three kinds. The first is to use a fixed S curve without consideration of histogram of the image. This manner cannot well adjust every different image. The second is to provide some different kinds (for example, scenery or people) of images with different S curves. But it still cannot accommodate the specific tone scale of each image. The third is to provide an S curve function, such as sine curve or Gaussian function, which can be controlled with an amplitude factor for adjustment of contrast. The third manner can provide a better result.

However, a simple S curve may not be suitable for processing all images, special to the histogram illustrates a strange distribution, such as multiple peak or flat distribution. Therefore, we need a new tone mapping method that provides a robust processing for color image enhancement.

In this study, we present a new color contrast enhancement approach. The approach utilizes simplified histogram information obtained by three quartiles to attain the controllability with much less effort. According to human simultaneous contrast phenomena, we proposed an adaptive quartile sigmoid function. An optimal tone-curve is possible to be found to make the dark colors in an image look darker by make the light colors lighter.

Quartile Sigmoid Function Operator

The main purpose of this research is to develop and evaluate an adaptive quartile sigmoid function operator (QSFO). QSFO contains one major modules, namely, quartile sigmoid function (QSF). The procedure of the proposed QSFO is illustrated in Figure 1. The methodology employed to do so is discussed below.

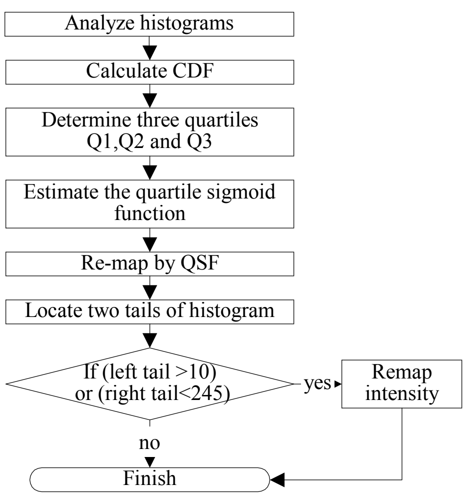

Figure 1. The procedure of quartile sigmoid function operator

Quartile Sigmoid Function

According to prior researches, sigmoid functions for tone mapping could improve lightness contrast and color saturation. The hypothesis of using sigmoid function for lightness remapping is based on the phenomenon of simultaneous lightness contrast. It is possible to make the dark colors in an image look darker and to lighten the light colors. In general, histogram analysis is the first step in the obtainment of sigmoid functions. Braun and Fairchild addressed that lightness histograms were broken down into four categories: low lightness key (skewed toward low lightness), high lightness key (skewed toward high lightness), normal light key (Gaussian shaped histogram), and uniform lightness key (flat histogram).[7] A discrete cumulative normal function was used to determine optimal contrast enhancement function. However, the potential problem is that histograms are not guaranteed to form Gaussian shape in many images.

The hypothesis that histograms follow normal distribution should be test before estimating the mean and variance. In statistics, quartiles are one of basic information for any population. When the probability distribution is unknown, quartiles are better than mean and variance. Therefore, this study proposes QSF to overcome the limitation which histograms should be Gaussian shape.

QSF is performed as follows. First, calculate histograms for lightness and colors. In this research, we used simple combination of RGB histograms intuitively instead of complex calculation form RGB to lightness. For example, a image size of m×n pixels, its combined histogram distribution *f(i)* can be written

$$f(i) = (r(i) + g(i) + b(i))/3 \times m \times n,\ i=0\sim255 \quad (1)$$

r(i), *g(i)* and *b(i)* denotes the number of color value *i* of red channel, green channel and blue channel respectively, as shown in formula (1).

Second, calculate the cumulative distribution function (CDF) of combined histogram distribution. The following formula is used to determine CDF *F(n)*:

$$F(n) = \sum_{i=0}^{n} f(i), \qquad n \geq i;\ n = 0 \sim 255 \quad (2)$$

Third, determine the lowest point (L), the highest point (H), and three quartiles (lower quartile Q_1, median Q_2 and upper quartile Q_3). In General, the i^{th} order statistic x_i is the [(i-0.5)/N] 100^{th} percentile of the sample where N is the sample size. Since the i^{th} order statistic is the 100P=[(i-0.5)/N] 100^{th} percentile. Take the 50^{th} percentile, or the median Q_2, it is the observation with rank (N+1)/2. To find the 25^{th} percentile, which is called the lower quartile Q_1, we take the observation with rank (N/4) + 0.5. Similarly, the 75^{th} percentile, or the upper quartile Q_3, is the observation with rank (3/4)N +0.5. The following expressions is used to determine Q_1, Q_2 and Q_3: $F(Q_1)=0.25$; $F(Q_2)=0.5$; $F(Q_3)=0.75$.

Fourth, estimate the QSF. QSF consists of a dark-color mapping curve (L-Q_2) and a light-color mapping curve (Q_2-H). The transition point T which links up L-Q_2 curve and Q_2-H curve. Q_2 was taken as T in this paper. Here, quadratic curve fitting is used to calculate both mapping functions, as shown in Figure 2. A quadratic curve can be determined by three points. To dark-color mapping curve, we have two points now. One is L (L, L), other is Q_2 (Q_2, Q_2). Consequently, the other point P_1 (x, y) is given by

$$x = (Q_2 + L)/2$$
$$y = \begin{cases} (Q_1/255 - 0.25) \times 255, & (Q_1/255 - 0.25) < 0 \\ (Q_2 + L)/2 & \text{otherwise} \end{cases} \quad (3)$$

Similarly, the point P_2(x, y) for the light-color mapping curve is determined in following formula:

$$x = (Q_2 + H)/2$$
$$y = \begin{cases} (\frac{3}{2} - (Q_3/255)) \times 255, & \frac{3}{4} - (Q_3/255) > 0 \\ (Q_2 + H)/2 & \text{otherwise} \end{cases} \quad (4)$$

Fifth, create the mapping look up table according to both dark-color mapping curve and light-color mapping curve. If range of histogram is narrow, a simple linear intensity re-mapping will be performed.

Figure 2 illustrates an example of tone re-mapping processes using the girl-with-hat image (see Appendix). The dash line is the image's CDF that is calculated at first. Following above the fourth step, two quadratic curves are carried out by P_1 and P_2.

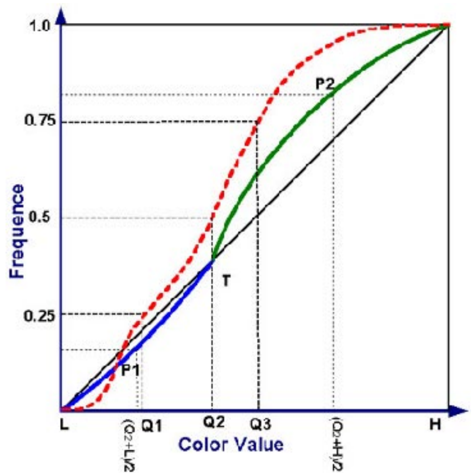

Figure 2. An example of QSF which T is set on 50 percentile (dash line means an actual CDF).

Adaptive Quartile Sigmoid Function

As above section description, QSF only deals with a topic for contrast enhancement of the original image. This study hypothesized that the original images are at normal lightness level.

In order to keep the lightness level of original images, we must take account of the feasibility of taking 50 percentile Q_2 as the segmented point. From previous research, Braun and Fairchild indicated that the 75 percent points of normal lightness-class images' cumulative lightness histograms occurred at about 50 lightness units.[7]

Because of performing QSF on RGB domain not lightness, Q_2 is set on 50 percentile that should be verified. Viewing conditions of displays will influence quality of image shown. Taking sRGB color space as an example, CIELAB L*=50 transform to sRGB is equal to (118, 118, 118) under D50 illumination. Surprisingly, the RGB color values are not 127. This phenomenon is resulted mainly from gamma settings of the destination device. Therefor, in this article, adaptive quartile sigmoid function quotes from the normal exposure images which have balance lightness level at about 50 units. If we want to obtain more contrast images, lower the Q2 on 33.33 percentile to light more pixels and to darken less pixels. However, how to determine Q2 is unknown for observers, which should be examined by experiments. We supposed that 1/3 cumulative probability is an important landmark for enhancing images. According to previous section described, a new quartile sigmoid function operator, QSFO2, is proposed as follows:

(1) Lower quartile Q_1 is on 16.67 percentile,
(2) median Q_2 is on 33.33 percentile, and
(3) upper quartile Q_3 is on 66.67 percentile.

Similarly, the new P_1 (x, y) is given by

$$x = (Q_2 + L)/2$$
$$y = \begin{cases} (Q_1/255 - 0.1667) \times 255, & (Q_1/255 - 0.1667) < 0 \\ (Q_2 + L)/2 & \text{otherwise} \end{cases} \quad (5)$$

and P_2 (x, y) is given by

$$x = (Q_2 + H)/2$$
$$y = \begin{cases} (\frac{4}{3} - (Q_3/255)) \times 255, & \frac{2}{3} - (Q_3/255) > 0 \\ (Q_2 + H)/2 & \text{otherwise} \end{cases} \quad (6)$$

To the girl-with-hat image, the new tone re-mapping curve is shown in Fig. 3. The part of dark-colors is approximately a straigth line because P1 is close to the diagnol line. To a certain extent, to raise curvature means increasing changes of the original image.

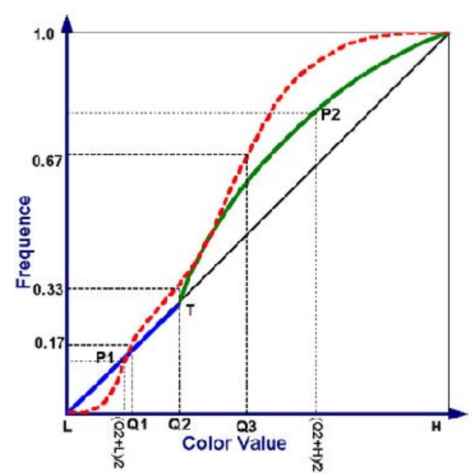

Figure 3. An example of QSF which T is set on 33.33 percentile (dash line denotes an actual CDF).

Here, we assume that the previous quartile sigmoid function operator with 50 percentile T (QSFO1) ignores the characteristics of the destination device. Results of QSFO1 will be lower contrast than QSFO2. In this study, however, an experiment will be conduct to clarify this question and described in detail on next chapter.

Methodology

In order to compare with the effects among different algorithms, we collected four methods other than QSFO1 and QSFO2. One of the most popular automatic procedures is histogram equalization.[8, 9] The first method is simple histogram equalization (HE). Here the LEADTOOLS® VCL is used to implement the program. The second method is auto level function of Photoshop® 6.0 (PS-AL).[10] The third method is cumulative distribution function mapping (CDF). CDF was achieved by the accumulation of RGB histograms as described in the section of quartile sigmoid function. The fourth method is semi-s curve (Semi-S). Semi-S is supplied by Lee and Chen.[11] The methodology employed to do so is discussed below.

Experiments

The independent variables were image scenario (portrait, landscapes, close-up, et al.) and enhanced method (Semi-S, QSFO1, QSFO2, HE, CDF and PS-AL). The dependent variable, the subjective ranking scores were recorded in each image scenario. This study applied a two-factor factorial experiment with repeated measures on image scenario.

Fourteen images that were used for testing the above six algorithms (see Appendix). During each scenario, the original image and six enhanced images were shown simultaneously on the calibrated BARCO® personal calibrator monitor. User interface developed for this experiment is shown in Fig. 4. For convenience of comparison tasks, user could drag and rank those images on computer desktop free.

Figure 4.User interface for ranking score measures.

To obtain a measure of performance of enhanced methods, ranking score was used in this study. Ranking call for the respondent to indicate the relative ordering of the members of a presented group of images on quality. By definition, interval scale in which the amount of difference between successive members is not measured, nor can it be implied that successive differences are even approximately equal.[12] Ranking has certain advantages: The idea of ranking is familiar to respondents. Ranking takes less time to administer, score, and code than other type of questionnaires.

The disadvantages of ranking are that: (1) the respondent cannot indicate whether any of the items ranked are effective or ineffective in an absolute rather than just a relative sense. (2) Ranking does not permit respondents to state the relative amounts of differences between alternatives. To overcome these disadvantages, the ranking scores of original images were omitted from experimental records but other ranking scores were remained. Using this technique, we can analyze the effects of individual and image scenarios. Therefore, subjects were asked to rank and score the showed images, which score range was from 7 (excellent) to 1 (worst). This approach also gives more detailed information about the algorithms and it also gives more useful information regarding possible improvements to the algorithms under evaluation.

The reason for choosing this technique over other psychophysical methods is that it requires the least subjecttive and most narrowly defined response from observers. However, the disadvantage is that it requires the subjects to make separate judgements for each combination of enhanced images. This can be very time consuming when a large number of images are compared as 21 comparisons have to be made for each observer-image combination to evaluate the 7 enhanced images. To make the results statistically reliable and to reduce the influence of individual judgements, five observers took part in the evaluation. All subjects who were voluntarily participated in this experiment and those have taken at least two fundamental color course. All participants were normal vision.

Results and Discussion

This section describes the statistical analysis. We recorded each image's ranking score and analyzed those data by two-factor factorial analysis of variances with repeated measures. The results of the ANOVA are summarized in Table 1.

The analysis of variance may be used to confirm the magnitude of these effects. The total sum of squares is 1724.962 and by subtraction 92.5. The analysis of variance is summarized in Table 1, and it confirmed the significance of the enhanced method effects.

The main effects of enhanced method were significant on ranking score ($F_{(5,36)} = 52.59$, $p < 0.01$). The results revealed that QSFO2 and Semi-S methods had higher scores than others ($Mean_{QSFO1} = 5.857$; $Mean_{Semi\text{-}S} = 5.871$; $Mean_{QSFO} = 3.986$; $Mean_{CDF} = 3.657$; $Mean_{HE} = 3.057$; $Mean_{PS\text{-}AL} = 2.629$). However, there was no difference on image scenarios and subjects.

The ranking score results illustrated in Fig.5 are the average ranking scores of the six enhanced methods. From these results, it can be seen that the six enhanced methods can be divided into two groups. One group includes both QSFO2 and Semi-S, other group's member are QSFO, CDF, PS-AL and HE.

Table 1. Analysis of Variance for Image Quality

Source of Variance	Sum of Squares	Degree of Freedom	Mean Square	F_0
Subjects (A)	5.941	4	1.485	0.58
Method (B)	675.676	5	135.135	52.59*
Image (C)	10.562	13	0.812	0.32
A × B	120.952	20	6.048	2.35
A ×C	7.043	46	0.153	0.06
B × C	382.324	65	5.882	2.29
A × B × C	429.964	230	1.869	0.73
Error	92.500	36	2.569	
Total	1724.962	419		

*Significant at 1 percent

Unexpectedly, QSFO1 did not perform better than CDF, PS-AL and HE in statistics. Meanwhile, the variances of ranking scores of CDF, PS-AL and HE are higher than QSFO2 and Semi-S. Subjects were difficult to judge which image is better among CDF, PS-AL, HE and original image.

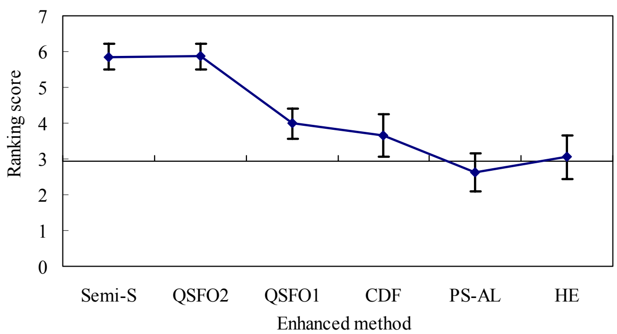

Figure 5. Overall ranking scores for all 14 images (error bars represent 99% confidence intervals). The horizontal located the overall average ranking score 2.9 of the original images.

The results of this experiment demonstrated that the QSFO2 significantly improved the quality of original images. As predicted, the evaluation shows that QSFO2 used 33.33 percentile as the transition point obtained higher rank scores than QSFO1. It confirms the idea that enhanced algorithms shall consider the characteristics of destination devices. CRT displays are targets in this research. We infer that the transition point will be position in somewhere not 33.33 percentile for other devices.

Additionally, both of QSFO2 and Semi-S had similar results. The possible reason is that both methods used the same transition point. The only difference between QSFO2 and Semi-S is how to determinate P_1 and P_2. In order to keep higher contrast effects, Semi-S is not like CDF that will lighten the dark-color. However, QSFO2 preserves the CDF advantage to lighten the dark-color in moderation.

During the experiment, some objects responded those results of CDF and HE presented over contrast in most images. The reasons can be explained as follows. Histogram equalization is that it not only compresses dynamic range in regions where there are few sample, it also expands contrast in highly populated regions of the histogram. Adaptive histogram equalization overcomes this drawback by generating the mapping for each pixel from the histogram in a surrounding window. Alex Stark has set out a concise mathematical description of adaptive histogram equalization.[13] Although adaptive histogram equalization produces excellent results in enhancing the signal components, noise in the image is enhance too.

CDF is so it only re-maps the cumulative distribution function to diagonal line that it has same problems as histogram equalization. It also appears that CDF is a combined RGB cumulative distribution function, not an individual color channel's cumulative distribution function. It remains the original proportion of each color channel to keep image's color tone. Oppositely, PS-AL seems to deal with color channels individually. PS-AL made wrong colors during some image scenarios in this experiment.

Conclusions

The experiment reported here adds to this growing body of empirical research by demonstrating that quartile sigmoid function operator can significantly improve the image quality. Quality and speed are the main purpose of QSFO. QSFO does not employ complicated processes and does not take an extra amount of calculations. It is believed that the approach is applicable to color devices need rapidly operation.

In closing, both conditions of over-lightness and under-lightness will be analyzed in future and the extreme gradient of the cumulative distribution functions shell be investigated in advance so that the relationships of the algorithm and images will be understand completely.

Acknowledgments

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Biography

Chao-hua Wen received his MS and PhD degree in industrial engineering from National Tsing-Hua University, Taiwan, in 1994 and 1998, respectively. He joined Color Technology Section of Opto-Electronics and Systems Division at Opto-Electronics and Systems Laboratories of Industrial technology Research Institute in 1998. His current interests include color reproduction, image quality, and process quality controls issues. He is a member of the Ergomonics Society of Taiwan.

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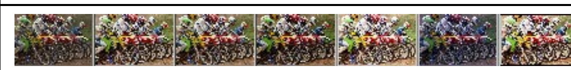
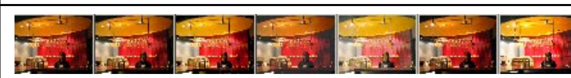
Appendix

Image Scenario List:

Image	Original	QSFO2	Semi-S	QSFO1	CDF	PS-AL	HE
1							
2							
3							
4							
5							
6							
7							
8							
9							
10							
11							
12							
13							
14