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LETTER

Real-Time Color Correction Method for a Low-Cost Still/Video Camera

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SUMMARY This paper describes a color correction method of low-cost still/video camera images. Instead of using complex and non-linear equations, the concept of a three-dimensional reduced resolution look-up table is used for the real-time color gamut expansion of low-cost cameras. The proposed method analyzes the color gamut of low cost cameras and constructs 3-dimensional rule tables during the off-line stage. And, real-time color correction is conducted using that rule table. The experimental result shows that output images have more vivid and natural colors compared with originals. The proposed method can be easily implemented with small software and/or hardware resources.

key words: *color correction, color image processing, real-time implementation*

1. Introduction

Currently, a digital still/video images form essential part of digital entertainment. Because of its economical benefits and high versatility, a low-cost CMOS camera chip as in USB camera is widely used as a remote meeting device, mobile phone camera and webcam chatting device. However, in spite of its demands, the low cost camera usually has smaller color gamut than high cost digital cameras and this limited color gamut often causes poor color representation. For example, Fig. 1 illustrates that the image from a USB camera is duller than that of the digital still camera.

In order to enhance the color image quality of a low-cost camera, a color gamut expansion based on existing gamut mapping algorithms has been considered [1]–[5]. For example, gamut compression and expansion algorithm based on observer experimental data are proposed by Kang [1]. This paper suggests three different gamut mapping algorithms and developed an interactive tool for selecting and modifying images to match the original images with the test images. Three-dimensional gamma-compression gamut mapping algorithm (GMA) is proposed by Chen [2]. This paper describes the 3D GMA based on the concept of Image-to-Device (I-D). It is shown that the GMA coupled with 3D gamut compression and multi-mapping directions resulted in the better rendition than 2D nonlinear GMA.

However, gamut mapping is usually highly nonlinear and it requires very high level of computational resources to implement this nonlinearity. Therefore, it is very difficult to adopt above methods in real-time industry.

Kanamori and Kotera [6] introduce a 3D LUT and PRISM interpolator for color processing and it is designed with world first LSI chip operates at a 28-MHz clock rates.

This paper utilizes the structure of a 3-dimensional reduced resolution look-up table [7] to handle real-time color correction for a low cost camera in more cost effective way. In this paper, gamut expansion rule derived from the USB camera gamut information is stored in the form of eight 1-dimensional look-up tables and 3-dimensional interpolation is applied to calculate the color correction rules. The proposed method can conduct real-time color correction with small software and/or hardware resources.

Gamut extraction of the target camera, look-up table construction and on-line gamut mapping will be explained in the next section. Then, experimental results are described in Sect. 3 and finally, the conclusion is drawn in Sect. 4.

(a) Image from the digital camera (b) Image from the USB camera

Fig. 1 Comparison of a sample image "Fruit" from a digital camera and a USB camera.

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2. Color Correction Method for a USB Camera

The overall signal flow diagram of the proposed method is shown in Fig. 2. The color correction method is separated into two major stages. The first block operates during the off-line stage. This analyzes the color transfer characteris-

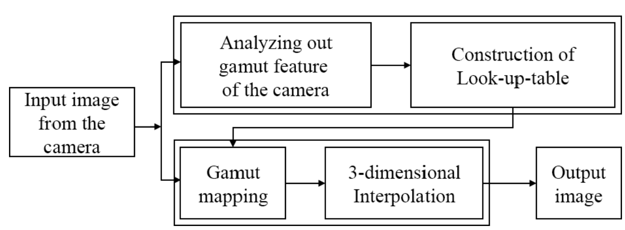
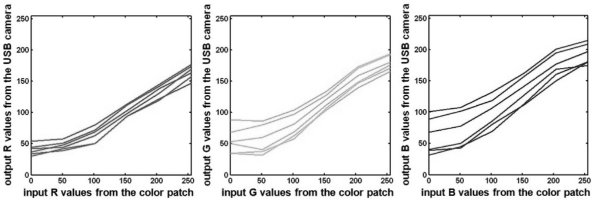
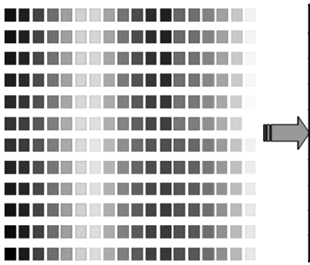


Fig. 2 Signal flow diagram of the proposed real-time gamut expansion system.



(a) Red component (b) Green component (c) Blue component

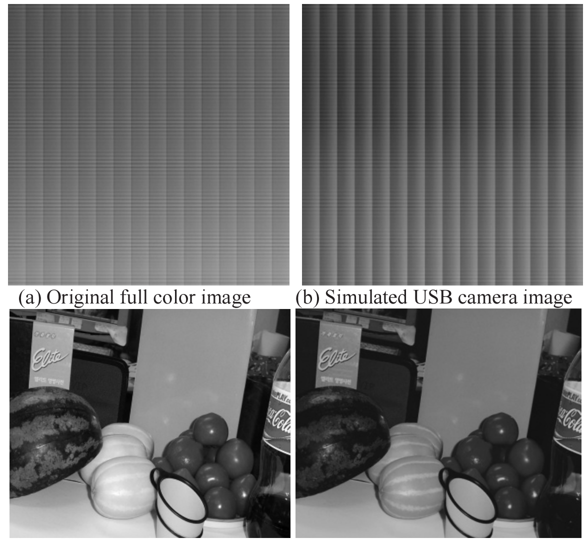
Fig. 3 Color representation characteristics of a sample USB camera for 216-color patch image.



R	G	B	R'	G'	B'
0	0	0	30	35	39
0	0	51	34	35	43
0	0	102	42	50	81
0	0	153	37	53	112
0	0	204	44	68	150
0	0	255	54	88	151
…	…	…	…	…	…
255	255	204	207	208	200
255	255	255	211	213	217

216-color patch Reference RGB RGB signal obtained from USB camera

Fig. 4 Color representation characteristics of a sample USB camera for 216-color patch image.



(a) Original full color image (b) Simulated USB camera image
(c) Original digital camera image (d) Simulated USB output image

Fig. 5 Simulated USB output images.

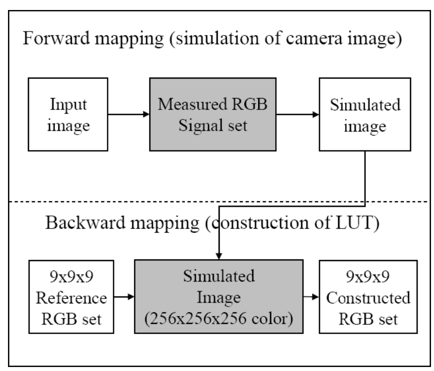


Fig. 6 Off-line process.

tics of the USB camera and constructs the coefficients of the three-dimensional look-up tables. Then, during the second stage, real-time color correction and three-dimensional interpolation are accomplished.

2.1 Gamut Analysis

During the first stage, a standard 216-color patch is captured by an experimental USB camera and its gamut features are analyzed. The obtained color patch image can be considered in terms of the RGB signal set. Figure 3 shows the color display characteristics of a USB camera for standard 216-color patch signals. Each figure shows the forward mappings of each color component with respect to the other two color signals, which are constant. This forward mapping means the measurement-based USB camera characterization.

This signal set plays an important role in generating the simulated USB image. And this signal is used for construction of look-up table in the next step. Figure 4 shows the R, G, B signal set examples of a 216-color patch image and Fig. 5 shows sets of USB camera simulation output images using this forward mapping rules.

The next step generates backward mapping rules and constructs the 3-dimensional look-up table. The backward mapping stage converts the device-dependent USB camera signals into the device-independent new RGB values. In this step, we use the full color image to minimize the searching error during backward mapping. Figure 6 shows the previously described forward mapping step and following backward mapping step which are conducted in off-line.

In backward mapping step, the backward mapping rule is approximated by a second order polynomial regression equation. The RGB signal sets obtained from the forward mapping stage are used in this approximation. Let $I = [R_i, G_i, B_i]^T$ and $O = [R_o, G_o, B_o]^T$ be input and output of the backward mapping, respectively. Then, the approximation equation is described as follows:

$$O = M \cdot f(I) \quad (1)$$

where M is a 3×10 coefficient matrix and $f(I)$ is defined by

$$f(I) = \left[1\ R_i\ G_i\ B_i\ R_iG_i\ G_iB_i\ B_iR_i\ R_i^2\ G_i^2\ B_i^2\right]^T \quad (2)$$

To determine the coefficient matrix M, a least square method is applied with the RGB signal sets obtained from the forward mapping stage. Assume that we have N forward mapping RGB signal sets $\{X_1, Y_1\}, \{X_2, Y_2\}, \ldots \{X_N, Y_N\}$, then we have following error equation.

$$E = X - M \cdot F \quad (3)$$

where E is error vector and

$$X = [X_1\ X_2\ \cdots\ X_N] \in R^{3\times N}$$
$$F = [f(Y_1)\ f(Y_2)\ \cdots\ f(Y_N)] \in R^{10\times N} \quad (4)$$

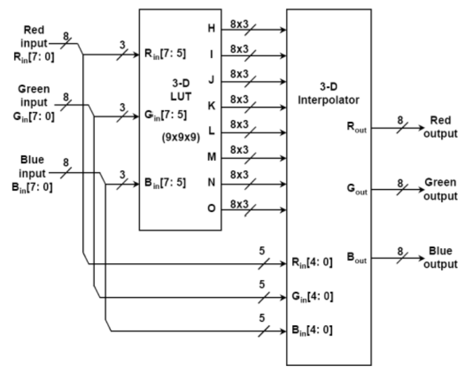


Fig. 7 The architecture of a 3-dimensional reduced resolution look-up table.

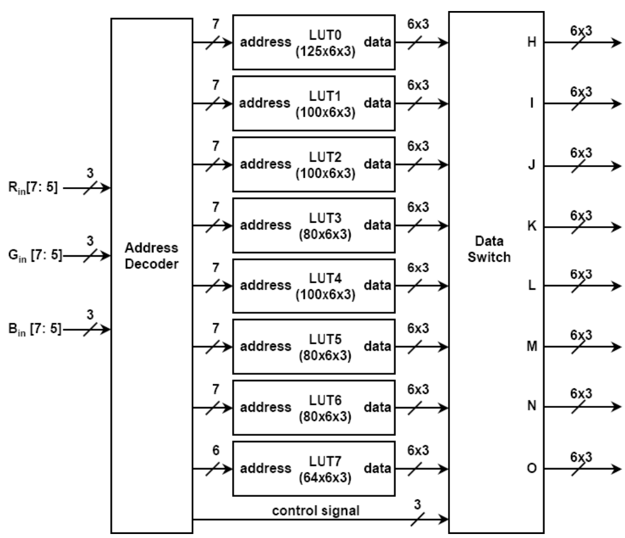


Fig. 8 The one-dimensional decomposed architecture of a 3D LUT.

If the rank of F is 10, the coefficient matrix M which minimizes the error vector E in the sense of mean square can be obtained as follows:

$$M = X \cdot F^T \left(F \cdot F^T\right)^{-1} \tag{5}$$

Using the approximation Eq. (1) with the coefficient matrix M in (5), we obtain inverse characterized gamut mapping rules used for the three dimensional interpolation.

2.2 Look-Up Table Construction

Derived gamut mapping rules are applied to construct a 3-dimensional look-up table. Figure 7 shows the block diagram of the referenced reduced resolution look-up table [7]. The 3D LUT is disassembled into eight 1D LUTs and Data Switch in Fig. 8. This one-dimensional architecture enables faster implementation and simpler H/W and S/W design. As shown in Fig. 9, each R, G, B component is separated into 8 intervals. The three most significant bits of each component are used to select the corresponding cube position and to generate the eight mapping values of each vertex of the cube. The five least significant bits of each component are used for interpolating the new mapping for each R, G and B input image. Note that the operations described in this paper are fully implemented as software.

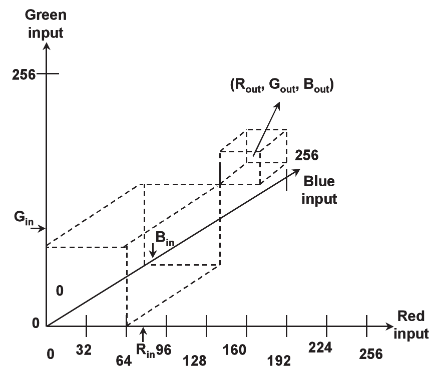


Fig. 9 An example of 3-dimensional mapping.

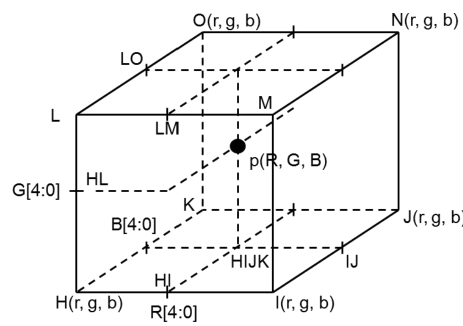


Fig. 10 The three-dimensional interpolation method.

After the derivation of gamut mapping rules for a USB camera, we can easily define gamut mapping rules of a 3-dimensioinal reduced resolution look-up table, for each red, green and blue input and output. Thus, during the off-line stage, the mapping function is stored in the 3-dimensional look-up table.

2.3 On-Line Gamut Mapping

The constructed look-up table during the off-line stage is used to perform three-dimensional interpolation for the real-time enhancement of a USB camera image. Figure 10 shows interpolation process using the five least significant bits from the real time R, G and B signal input.

A simple bi-linear interpolation for each component generates a new mapping at the image input position p. A given R, G, B input, the eight mapping positions $H(r, g, b), I(r, g, b), \ldots, O(r, g, b)$ are generated automatically and the final gamut mapping of red, green and blue signals at point p can be calculated as follows:

$$\begin{aligned} p_{RGB} = {} & H\frac{(32-r)(32-g)(32-b)}{32^3} \\ & + I\frac{r(32-g)(32-b)}{32^3} + K\frac{(32-r)(32-g)b}{32^3} \\ & + J\frac{r(32-g)b}{32^3} + L\frac{(32-r)g(32-b)}{32^3} \end{aligned}$$

$$+M\frac{rg(32-b)}{32^3}+O\frac{(32-r)gb}{32^3}+N\frac{rgb}{32^3} \qquad (6)$$

3. Experimental Results

A low-cost USB camera is tested in this experiment. We implemented the real-time USB color gamut expansion software in the C++ environment, linked by the DirectX SDK software. Several colored objects and images are captured and tested. The 3-D color gamut of the test images are represented by 3D software [8], [9] in CIELAB color space [10], [11]. Figure 11 shows the comparison of an image from a digital camera, a simulated USB camera image and an image from real-time gamut expansion. The color of gamut expanded image is more natural.

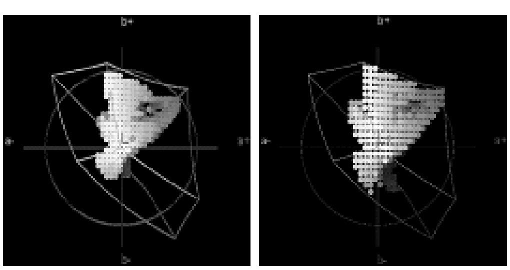
As shown in Fig. 12 (a) and 12 (b), subsequent to expansion, we obtained wider color gamut. Figure 13 shows more test results.

From Table 1, it is clear that the PSNR results of post-gamut expansion are better. During software implementation, processing predominantly involves a simple integer operation. The proposed method is completely implemented as software and operates in real-time in a Pentium-IV, 1.0 GHz notebook environment.

(a) Digital still camera image: fruit

(b) Simulated USB image (c) Subsequent to gamut expansion

Fig. 11 An example of real-time gamut expansion for a USB image.

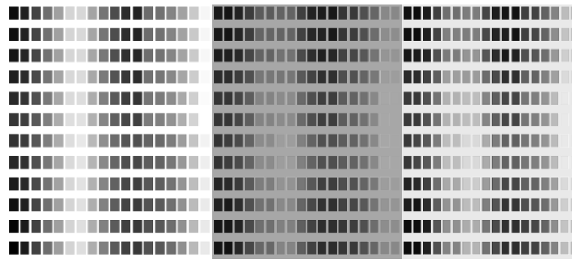


(a) Fruit : Prior to expansion (b) Fruit : Subsequent to expansion

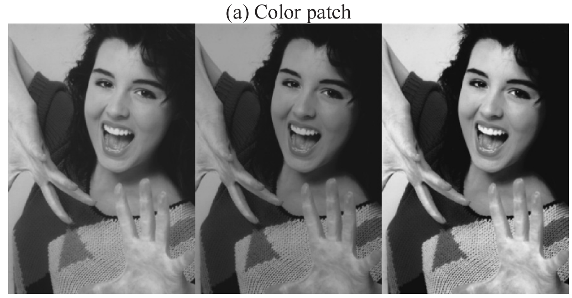
Fig. 12 Representation of the color gamut boundary of "Fruit" image in CIELAB color space.

4. Conclusions

This paper describes a real-time color correction method for a USB camera image. Instead of using a complex and

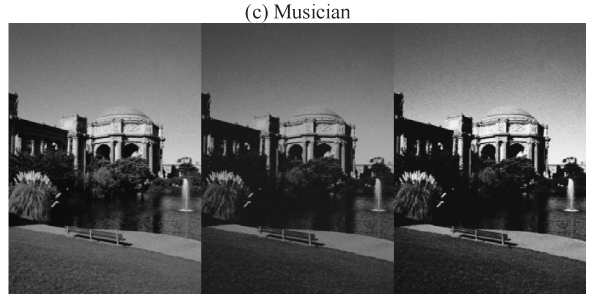


(a) Color patch



(b) Smile

(c) Musician



(d) Nature

Fig. 13 Examples of real-time gamut expansion (left-hand side: original image, center: simulated USB image, right-hand side: gamut expanded USB image).

Table 1 Comparison of PSNR results.

Images \ comp.	PSNR_R		PSNR_G		PSNR_B	
Fruit	15.92	26.07	18.61	25.59	19.13	26.14
Smile	16.78	26.35	22.85	32.67	24.41	27.69
Musician	17.10	25.44	21.11	23.33	22.94	26.50
Nature	19.53	25.83	19.41	23.86	20.82	28.90
	before	after	before	after	before	after

non-linear equation such as a conversion from CIEXYZ to CIELAB color space, the three-dimensional reduced resolution look-up-table is used for color gamut expansion. We used a CMOS type USB camera and analyzed its color gamut features. Then, gamut features are used to construct a three-dimensional look-up table. The proposed method enhances the gamut of a USB camera and renders colors which are more vivid and natural than the originals.

The proposed color gamut expansion operates in real-time for a USB camera image in video mode. Hereafter, we will improve the proposed method to enable it to be a device independent algorithm and adapt it to different types of camera and/or display devices.

Acknowledgements

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