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Color restoration in the black-and-white video camera

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ABSTRACT

A method of restoring the color information in a black-and-white video camera is proposed in this paper. The method is demonstrated by an experiment. The experiment contains two steps. Firstly, an environmental coefficient matrix is calculated by taking pictures on a calibration plate. Then, a restored picture is estimated by Matlab. The experiments have been done in different settings and in another dual-mode camera. All restored pictures are compared with the original ones. The results indicate that this method has precision, repeatability and adaptability to environment. If the system can be put to practical use, it will give clues to the criminal investigation.

1. Introduction

Nowadays, video cameras have been installed in public facilities for the surveillance [1]. Some of them are black-and-white cameras. When a crime occurs, these video cameras cannot record the colors of the criminal's clothes that may be the important clues to policeman. So if a method for giving ability of obtaining color information to monochrome camera is developed, it will give much benefit to criminal investigation. There are two major types of transformation from monochrome to chromatic color. The first one is pseudo-color process. It transforms different gray-scale of the gray image into different colors with different linear or nonlinear mapping functions [2]. For example, a pseudo-color technique was used in frequency domain to enhance ultrasound images [3], to paint the chromosome contributed to research the binary-coded genetic algorithm [4], and to indicate the seam position and welding penetration of molten pool [5]. Koleini et al. used texture features and a multilayer perceptron artificial neural network to colorize black-and-white films automatically [6]. It is emphasized that the actual color distribution on the object is not reproduced, so we shall call them pseudo-color images [7]. These images are easy to identify details, and the technology is extensively applied in medical treatment, industrial production, aerial photography and many other areas. But they are unfit for our purpose. The second type is true-color restoration. Levin et al. marked a monochrome image with some color scribbles and then colorized it by an optimization method based on a premise: neighboring pixels in space–time that have similar intensities should have similar colors [8]. Horiuchi and Kotera proposed a method that a user sows a small number of color seeds on a monochrome image as a hint, and the colorization was performed based on the diffuse-only reflection model [9]. These methods need to know some color information in advance. Ohta et al. indicated that the spectral reflectance of objects can be estimated if they are taken images by a surveillance camera under different illuminations [10]. But this condition may be hard to control. Jin et al. came up with an experiment that is the color estimation of a suspect's clothes recorded by a monochrome security camera [11]. It can be divided into three stages. The first stage was that a suspect passed through a monochrome camera which was covered by a space-variant filter. The filter was special, consisted of red film on the left side, green film in the middle and blue film on the right side. Then four target areas were chosen to estimate the clothes color. The second stage was that a man in three references color clothes stood at the same position and same angle with the suspected person and took images. The third stage was that the computer software gave out the colors of the target images.

In this paper, we propose another method and conduct an experiment to realize colorization. During our experiment, some immobile subjects are taken pictures by a black-and-white video camera covered with three filters in different frequency bands (red, green, and blue). A calibration plate is used to determine an environmental coefficient matrix. The core of the experiment is a control panel of graphical user interface (GUI), which is developed in Matlab. By loading pictures which pass through three filters, respectively, and clicking the button "Result", the restored picture is shown on the screen at once. The restored color is true and close to the original picture. The system works automatically and rapidly, so it can help the police to solve a case.

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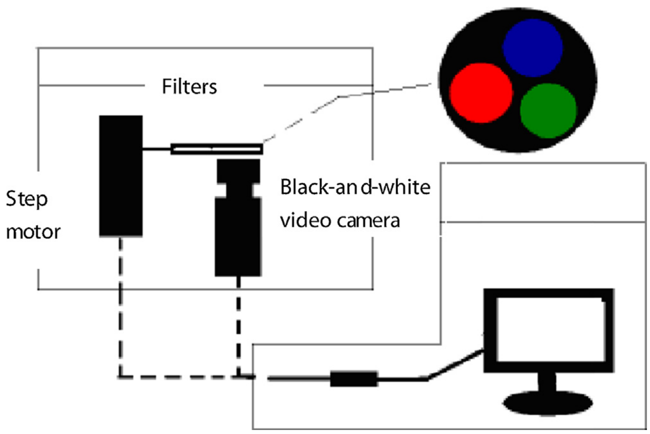

Fig. 1. Experimental setup.

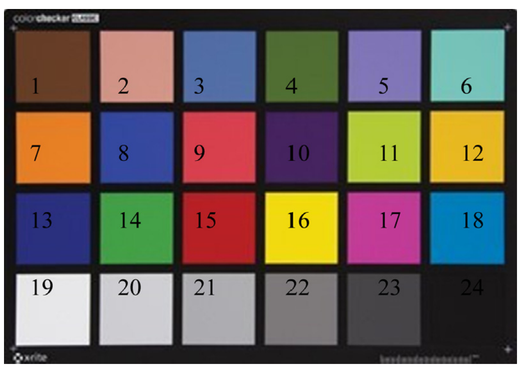

Fig. 2. Calibration plate.

2. Theory and experiment

2.1. Experiment setup

The experimental setup is shown in Fig. 1. It contains three parts: a step motor used to control three filters in different frequency bands, a black-and-white video camera, and a computer fixed with the image processing software. Once clicking the mouse, the filter plate will be rotated 120° automatically, and then one picture will be taken.

From the experiment setup, suppose that if we put some chromatic objects in front of the lens of the black-and-white camera, some monochrome pictures are obtained. So, the color information is lost. To restore the color, we choose three filters in different frequency bands (red, green, and blue) and a calibration plate, which is shown in Fig. 2.

The calibration plate has 24 different color units, units from 1 to 18 are chromatic and the rest are monochrome. Every unit is a unique color and their *RGB* component values can be found. The color of unit 13, 14 and 15 is blue, green and red respectively. Their *RGB* component values are listed in Table 1.

Table 1
Component values of red, green, and blue units in the calibration plate.

Colors	Component values		
	R	*G*	*B*
Red unit	175	54	60
Green unit	70	148	73
Blue unit	56	61	150

2.2. Theory and experiment

The restoration method is demonstrated by an experiment. The experiment can be divided into two parts:

Step 1: Determine the environmental coefficient matrix.

The step motor regularly drives the filter plate to rotate 120° in every time τ, then one of the three filters in different frequency bands (red, green, and blue) passes through the camera, and then the video camera simply takes pictures on the calibration plate. After 3τ time, three pictures can be obtained as well as 9 equations.

$$
\begin{aligned}
GR(r) &= a(r)R(R) + b(r)G(R) + c(r)B(R)\\
GR(g) &= a(r)R(G) + b(r)G(G) + c(r)B(G)\\
GR(b) &= a(r)R(B) + b(r)G(B) + c(r)B(B)\\
GG(r) &= a(g)R(R) + b(g)G(R) + c(g)B(R)\\
GG(g) &= a(g)R(G) + b(g)G(G) + c(g)B(G)\\
GG(b) &= a(g)R(B) + b(g)G(B) + c(g)B(B)\\
GB(r) &= a(b)R(R) + b(b)G(R) + c(b)B(R)\\
GB(g) &= a(b)R(G) + b(b)G(G) + c(b)B(G)\\
GB(b) &= a(b)R(B) + b(b)G(B) + c(b)B(B)
\end{aligned} \tag{1}
$$

Eq. (1) can be written in the matrix form:

$$
\begin{bmatrix} a(r) & b(r) & c(r) \\ a(g) & b(g) & c(g) \\ a(b) & b(b) & c(b) \end{bmatrix} * \begin{bmatrix} R(R) & R(G) & R(B) \\ G(R) & G(G) & G(B) \\ B(R) & B(G) & B(B) \end{bmatrix} = \begin{bmatrix} GR(r) & GR(g) & GR(b) \\ GG(r) & GG(g) & GG(b) \\ GB(r) & GB(g) & GB(b) \end{bmatrix} \tag{2}
$$

The first matrix on the left of Eq. (2) represents an environmental coefficient matrix: every row stands for the coefficients before *RGB* of three filters in different frequency bands, such as $a(r)$ shows the coefficient before R of the red filter. The secondary matrix on the left of Eq. (2) represents color information of the calibration plate: every column stands for the *RGB* component values of red, green and blue units, such as $R(G)$ shows the R component value corresponding to green unit. These values are listed in Table 1. The matrix on the right of Eq. (2) represents the gray value matrix, $GR(r)$, $GR(g)$, $GR(b)$, $GG(r)$, $GG(g)$, $GG(b)$, $GB(r)$, $GB(g)$, and $GB(b)$ stand for gray values corresponding to three colors units through three filters in different bands, such as $GG(b)$ shows the gray value corresponding to blue unit through green filter. Every value of the gray matrix can be obtained directly from the computer software. Thus, the environmental coefficient matrix can be calculated.

Step 2: Restoration

Under the similar environmental condition, another three pictures are taken as the Step 1 describes. The formula is as below:

$$
\begin{bmatrix} a(r) & b(r) & c(r) \\ a(g) & b(g) & c(g) \\ a(b) & b(b) & c(b) \end{bmatrix} * \begin{bmatrix} R_0 \\ G_0 \\ B_0 \end{bmatrix} = \begin{bmatrix} G_0(R) \\ G_0(G) \\ G_0(B) \end{bmatrix} \tag{3}
$$

The left matrix is the environmental coefficient matrix calculated in Step 1. It is invertible. The middle matrix is a color information matrix, which includes color information of an original picture. R_0, G_0, and B_0 stand for the red, green, and blue components of the picture, respectively. The right matrix respectively represents gray values of three pictures through three filters in different frequency bands. Such as $G_0(R)$ stands for gray values of picture through red filter. As the environmental coefficient matrix is invertible,