Colorization for monochrome image based on diffuse-only reflection model

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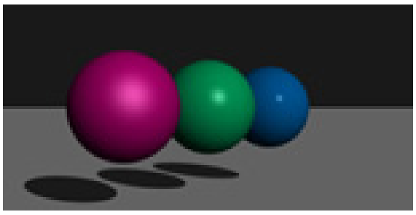
ABSTRACT

This paper proposes a new algorithm for coloring a monochrome image. Recently, a few effective colorization algorithms have been proposed. Those algorithms can colorize monochrome images by given some color hint, and they work well as an intuitive impression. However, a realistic colorization was difficult by those algorithms, because they have not used any physical model. This paper focuses on the dichromatic reflection model and tries to colorize monochrome images by considering diffuse-only reflection components. We demonstrate that high quality colorizations of still images may be obtained from a small number of color seeds given by a user.

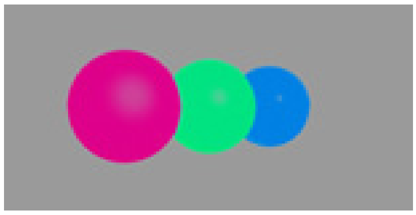
1. INTRODUCTION

Colorization is a computerized process that adds color to a black and white print, movie and TV program. Mapping between intensity and color is not unique, and colorization is ambiguous in nature and requires some amount of human interaction or external information. Recently, simple colorization algorithms have been proposed by a few research groups[1-6]. In authors' previous approach, a small number of color seeds are sown on a monochrome image and the colorization is realized by propagating seeds' color to adjacent pixels[1-4]. Welsh *et al.* colorize a monochrome image by transferring color from a reference color image with a stochastic matching[5]. Levin *et al.* mark a monochrome image with some color scribbles and adjacent pixels are colorized by an optimization method[6]. Those algorithms are very simple and work well as an intuitive impression. However, a realistic colorization was difficult, because any physical models are not considered in the conventional colorization techniques at all.

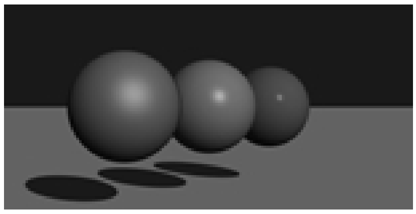
We started development of a realistic colorization technique based on a physical reflection model. As the first step, this paper proposes a new colorization algorithm based on a diffuse-only reflection model.



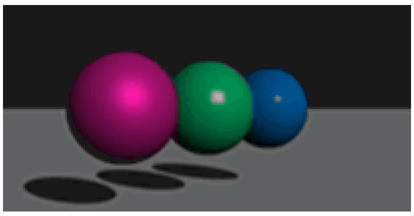
(a) Original color image (512x256)



(b) Normalized RGB image



(c) Monochrome image



(d) Colorized results by the proposed method.

Figure 1: Each channel's image.

2. COLORIZATION METHOD

One of the practical reflection models in a scene is the dichromatic reflection model which states that the light reflected from an object is a linear combination of diffuse and specular reflections. Consider an object with a single surface color. For the diffuse-only reflection component, normalized rgb will be constant regardless of the change of each channel's image intensity[7] as shown in Fig.1. Figure 1(a) shows a synthetic image which includes both diffuse and specular components. Each ball has a single surface color. Figure 1(b) shows the normalized rgb image for Fig.1(a). As shown in the figure, the normalized rgbs within each ball are almost the constant. In our colorization process, the diffuse-only reflection component, that is constant normalized rgb property, is utilized.

Figure 1(c) shows the monochrome image of Fig.1(a). Our approach assumes that we know the conversion method from color to monochrome. In this paper, we use the following typical conversion:

$$Y(x) = 0.299 I_r(x) + 0.587 I_g(x) + 0.114 I_b(x) \tag{1}$$

where $Y(x)$ is an intensity of a particular pixel x, and I_c is the RGB pixel values with index c representing the type of sensor (*r*,*g* and *b*). Then, the following is the proposed colorization process:

(STEP 1) Sowing a color seed pixel $I_c(x)$ (the same as Ref. 2).

(STEP 2) Propagating the color $I_c(x)$ to a four-connected adjacent pixel $\bar{x}$, if $|Y(x) - Y(\bar{x})| < Th.$ Estimating the color $\bar{I}_c(\bar{x})$ by solving the following simultaneous equations:

$$\begin{cases} 0.299 I_r(\bar{x}) + 0.587 I_g(\bar{x}) + 0.114 I_b(\bar{x}) = Y(\bar{x}) \\ \sigma_g(x) I_r(\bar{x}) - \sigma_r(x) I_g(\bar{x}) = 0 \\ \sigma_b(x) I_r(\bar{x}) - \sigma_r(x) I_b(\bar{x}) = 0 \end{cases} . \tag{2}$$

where $\sigma_c(x) = I_c(x) \big/ \sum I_i(x)$, which shows the normalized rgb value of pixel x. $Th.$ means a partitioning parameter[4] for preventing error propagation. Continuing the propagation until all pixels satisfies the condition $|Y(x) - Y(\bar{x})| \geq Th.$

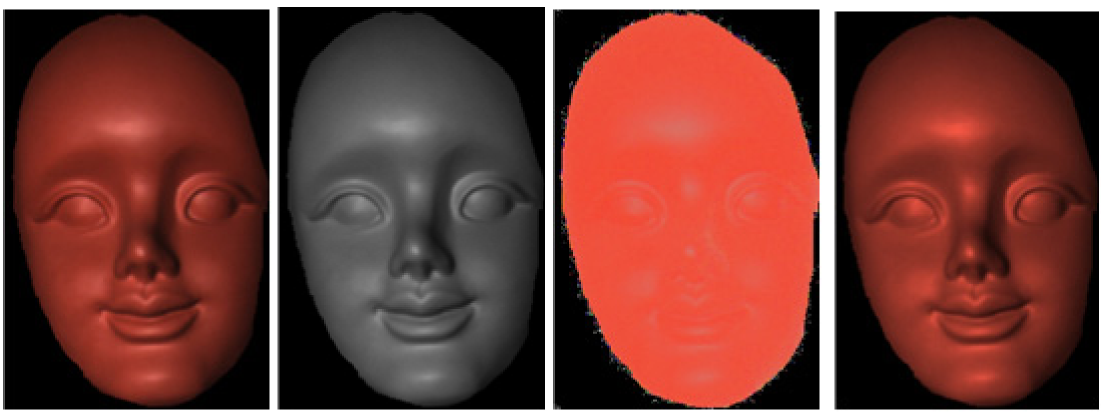
(STEP 3) Going back to the (STEP 1) until all pixels are colorized.

Equation (2) is the core of our algorithm. Each object in the monochrome image is colorized with keeping both normalized rgb values $(I_r(\bar{x}) : I_g(\bar{x}) : I_b(\bar{x}) = \sigma_r(x) : \sigma_g(x) : \sigma_b(x))$ and intensity $Y(\bar{x})$ of each pixel $\bar{x}$. If the solution exists out of the sRGB gamut, the color $I_c(\bar{x})$ can be calculated by simple clipping algorithm.

3. COLORIZATION RESULTS

We now present example of the proposed colorzation algorithm. Figure 1(d) shows an colorized result by giving only one color seed pixel for each ball, i.e. three color pixels were sown on the monochrome image in Fig.1(b). Since diffuse-only reflection component is considered, specular components have error color. But, almost realistic colorization was obtained.

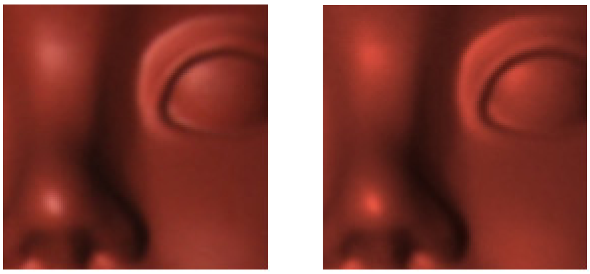
Figure 2(a) shows a real image of a head model in Ref.8 that has a uniformly colored surface and relatively low specularity, illuminated by a Solux Halogen with temperature 4700 K. The image size is 265x400. Figure 2(b) and 2(c) shows the monochrome image converted by Eq.(1) and the normalized rgb image, respectively. Figure 2(d) shows the colorized result by giving only one seed at



(a) Original color image (b)Monochrome image (c) Normalized rgb image (d) Colorized image

Figure 2: An example of colorized result by sowing only one color seed.

the center of the image. From only one color seed, the realistic image was obtained. However, the color at specular part is different between the original and the colorized images. Figure 3 shows the enlarged images with specular components. Since the proposed algorithm assumes the surface of an object reflects only diffuse component, the specular part is also colorized by brawn.



(a) Original image (b) Colorized image

Figure 3: Enlarged image.

In order to verify the result subjectively, the PSNR was calculated as follows:

$$PSNR = \frac{1}{3}(PSNR_{(r)} + PSNR_{(g)} + PSNR_{(b)}),$$
$$PSNR_{(c)} = 10\log_{10}\left(\frac{255^2}{MSE_{(c)}}\right), \quad (3)$$
$$MSE_{(c)} = \frac{1}{N}\sum_{x=1}^{N}\left(I_c^{original}(x) - I_c^{result}(x)\right)^2$$

where, N means the number of pixels. The PSNR between Figs.2(a) and 2(c) was 33.31[dB].

We also used natural images for evaluation. Figure 4 shows test images and their colorized results. Fig.4(a), (b) and (d) were produced by the authors' digital camera, and Fig.4(c) is a test image in Ref.6. All images are color in originally. The test monochrome images were produced from the color images by Eq.(1) as shown in Fig.4 (upper). Figure 4 (middle) shows the normalized rgb images. Figure 4 (lower) shows the colorized result for each image.

In the natural images, there are many regions which have different reflectance. So, more color seeds are needed for each region theoretically. For example, in the case of Fig.4(a), 7 seeds were sown on the monochrome image. Each seed was selected by a user objectively so that it was included in each region one by one.

Table 1 summarizes the colorized results. In the case of *Baby* and *Micky* images, color seeds were sown randomly, because there are several regions in the image. Excellent colorization was obtained for *Backingam* from only 7 color seeds, because the image consists of a small number of regions with the same diffuse reflection. So, for example, colorizing the road was enough by sowing only one seed. The reason why the PSNR to *Scottsdale* image was low is that the color was not able to propagate enough at a lot of texture parts such as the leaf. In the case of *Baby* image, many marks were needed in Ref.6 to get good result. In the proposed method, however, the colorized results with 30.83[dB] was obtained from 0.5% seeds. *Micky* consists of many objects with different reflectance. So, it took 1% seeds to obtain nice colorized results. By both subjective and objective evaluation, we can confirm the effectiveness of the proposed method.

Table 1 Colorized results.

	size	# of seed	PSNR[dB]
Head model	265x400	1/106000	33.31
Backingam	640x480	7/307200	28.08
Scottsdale	640x480	50/307200	24.04
Baby	320x265	400/84800	30.83
Micky	640x480	3000/307200	27.46

4. CONCLUSIONS

This paper proposes a nobel colorization algorithm based on a physical reflection model in order to realize a realistic colorization. In our method, a user sows a small number of color seeds on a monochrome image as a hint, and the colorization is performed based on the diffuse-only reflection model. More concretely the proposed algorithm propagates sown colors by keeping the normalized rgb of the color seeds and the original intensity. We have shown that realistic colorized results can be obtained with a surprisingly small amount of user effort.

In order to obtain more realistic results, we will also consider a specular reflection as a future work.

(a) *Backingam* (b) *Scottsdale* (c) *Baby*[6] (d) *Micky*

Figure 4: (Upper) monochrome images, (middle) normalized rgb images, (lower) colorized images.

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