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Patch-based Colorization of Grayscale Images

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Abstract

In this paper, we introduced a simple and fast patch-based technique for "colorizing" grayscale images by simply transferring color "*square patches*" between a source colored image and a destination grayscale image. The proposed approach attempt to match the luminance and texture information between the source and target image patches, and transfer the entire color mood, i.e., chromatic information, of the best matching source patches to the target patches. Unlike pixel-based colorization approaches, which require comparisons for each grayscale pixel, the proposed approach helps in reducing the number of comparisons made and eliminating the need for human intervention in the selection of the matching source and target swatches. This simple colorization technique can be applied successfully to a wide variety of images.

Keywords: image colorization, luminance value, chromatic information, patch transfer

Introduction

The problem of coloring a grayscale image involves assigning three-dimensional (RGB) pixel values to an image whose elements (pixels) are characterized only by one feature (luminance). In other words, colorizing technique implies transferring color between a sources colored image to a destination grayscale image.

Colorization, in general, is an active and challenging area of research with several applications. For example, in the image editing and compression community, the luminance information and just some samples of the color (much less than the ordinary sub-sampling in common compression schemes), the color components of the data can be faithfully recovered. This has implications also, in wireless image transmission, where lost image blocks can be recovered from the available channels [1]. Moreover, people can chat with live video using cheap monochromatic web-cams instead of color ones, limited bandwidth by transmitting monochromatic video, and inexpensive and fully automatic colorization software.

In general, colorization of grayscale images has several challenges including ambiguity, fuzzy boundary identification, and user expert. Since different colors may carry the same luminance in spite of differences in hue and/or saturation, the problem of colorizing gray-scaled images (i.e., the problem of inverting a gray palette to a color palette) has no inherently "correct" solution [2, 3]. Thus, this in general a severely under-constrained and ambiguous problem for which it makes no sense to try to find an "optimum" solution, and for which even the obtainment of "reasonable" solution requires some combination of strong prior knowledge about the scene depicted and decisive human intervention. Even in the case of pseudo coloring, where the mapping of luminance values to color values is automatic, the choice of the color map is commonly determined by human decision.

Traditionally, colorization is done by first segmenting the image into regions, and then proceeds to assign colors to each segment. Unfortunately, automatic segmentation algorithms often fail to correctly identify fuzzy or complex region boundaries. Moreover, colorization of movies requires, in addition, tracking regions across the frames of a shot. Existing tracking algorithms typically fail to robustly track non-rigid regions, a gain requiring massive user intervention in the process [4]. Taking the previous challenges into consideration, the proposed patch-based colorization approach attempts to satisfy the following:

1. Quality; it should produce pleasing results.
2. Generality; it should work well for a wide range of images.
3. User-friendly; the number of tunable input parameters should be minimal.

4. Simplicity; the algorithm implementation could be as simple as possible.
5. Efficiency; computational cost should be (if possible) comparable to times required by techniques provided by other authors.

Patch Image Colorization

In this section, we describe a simple and fast patch-based algorithm for transferring colors. The previous published image colorization methods rely on searching luminance information from a target colored image pixel by pixel (so as we loosely called them pixel-based approaches), and applying their chromatic information to pixels of the target grayscale image. Among those published work is the work of Welsh et al [5] in which the color is transferred from a source image to a target image one pixel at a time. Their procedure is simple and work surprisingly well for a large variety of images. Our idea of transferring color form the source image to the target one is inspired by Welsh et al work. However, it transfers colors from a source image to the target image one patch at a time by matching the luminance information between different source and target square patches. The steps of the proposed patch-based algorithm can simply be stated as follows.

First, pre-process both source and target images by converting them to the de-correlated YIQ space, where the Y component is a measure of luminance and I and Q components are the chromatic information. Second, In order to account for global differences in luminance between the two images, we perform a smooth luminance transformation of Hertzmann et al [6] that brings both image histograms into correspondence but at the same time does not alter the luminance value of the target image. Formally speaking, if $L_s(p)$ is the luminance of a pixel in the source colored image S, then remap it as according to the luminance distribution of a target image T:

$$L_s(p) = \frac{\sigma_t}{\sigma_s}(L_s(p) - \mu_s) - \mu_t \ldots\ldots (1)$$

Where μ_s and μ_t are the mean luminance, and σ_s and σ_t are the standard deviations of the luminance, both taken with respect to luminance distribution in S and T respectively.

Third, in order to transfer square patches of chromaticity values from the source image to the target, do the following:

- Divide the target image into a number of non-overlapping patches. The patch is non-causal set of local neighborhood of pixels with a pre-selected size. We have experimented with non-causal patches of different sizes (e.g. 3×3, 5×5, 9×9, and 15×15) and we have found that a patch size of 5×5 pixels works well for most images. Increasing patch size results in reducing computation effort but at the expense of reducing result quality.
- For each target patch, scan the source image in raster scan order (from left to right and from top to bottom) in steps of one patch, and select the source patch that satisfy the best patch matching. We report two different variations of patch matching:
  1. in the first approach, we use only the sum luminance differences between the source and target patches as a criteria for patch matching. More concretely; consider a source patch i and a target patch j, each of size $n \times n$ pixels, then the sum of the pixel-wise luminance value difference is calculated as:

$$match(i,j) = \sum_{x=1}^{x=n} \sum_{y=1}^{y=n} \left| l_i(x,y) - l_j(x,y) \right| \quad (2)$$

  2. Alternatively, we can use sum of luminance average difference (50% weight) and luminance standard deviation difference (50% weight) as an indicator for patch matching. Then, $match(i,j)$ can be reformulated as:

$$match(i,j) = 0.5|\mu_S - \mu_T| + 0.5|\sigma_S - \sigma_T| \quad (3)$$

- For each pixel in the current target patch, combines the chromatic components (i.e., I and Q values) from the pixel of the selected source patch that is closest in term of luminance value with the Y value and convert them back to RGB components.

Experimental Results

This section reports some of the experimental results obtained with the proposed patch-based colorization technique. Figures 1 depict some results. All depicted results are obtained using 3×3, 5×5, or 9×9 patch size for both types of patch matching. As can be seen from the results, the technique works well on scenes where the image is divided into distinct luminance clusters or textures. Some cases present problematic in colorization (yet tolerable), where a number of patches are inappropriately colored. Also, patch size affect colorization quality. Increasing patch size leads to reducing number of patch comparisons required and thus reducing processing time but at the expense of increasing quality loss. Time required for the proposed colorization technique varied depending on the size of source image (and thus total number of source patches), target image (which determines the total number of target non-overlapping patches), and patch size and patch matching function. Figure 2 presents some visual comparisons between the results (where some quality loss occur) of the proposed approach with those of Di Blasi and Reforgiato [2] Antipole strategy. Running on a single Pentium IV PC computer, we get time between 2 to 10 seconds using un-optimized VB code. Most images can be colorized reasonably well in under a few seconds. On the other hand, the processing time of classical colorization strategy of Di Blasi and Reforgiato requires from seconds to several minutes which is better than the full search colorization strategy of Welsh et al. With respect to implementation simplicity and processing time, our algorithm is more efficient and simpler than Antipole colorization strategy of Di Blasi and Reforgiatosing optimized code.

Conclusions

In this paper, we have extended the pixel-based colorization approach of Welsh et al to a new, general, fast, and user-friendly patch-based one. Instead of transferring color information from the source color image to the target image one pixel at a time, and instead of letting the user to allocate source swatches and corresponding target swatches for color transfer, the proposed approach transfer one square color patch at a time from the source image to the target image. Patch matching can be determined using either sum of pixel-wise luminance differences or patch luminance average and standard deviation matching.

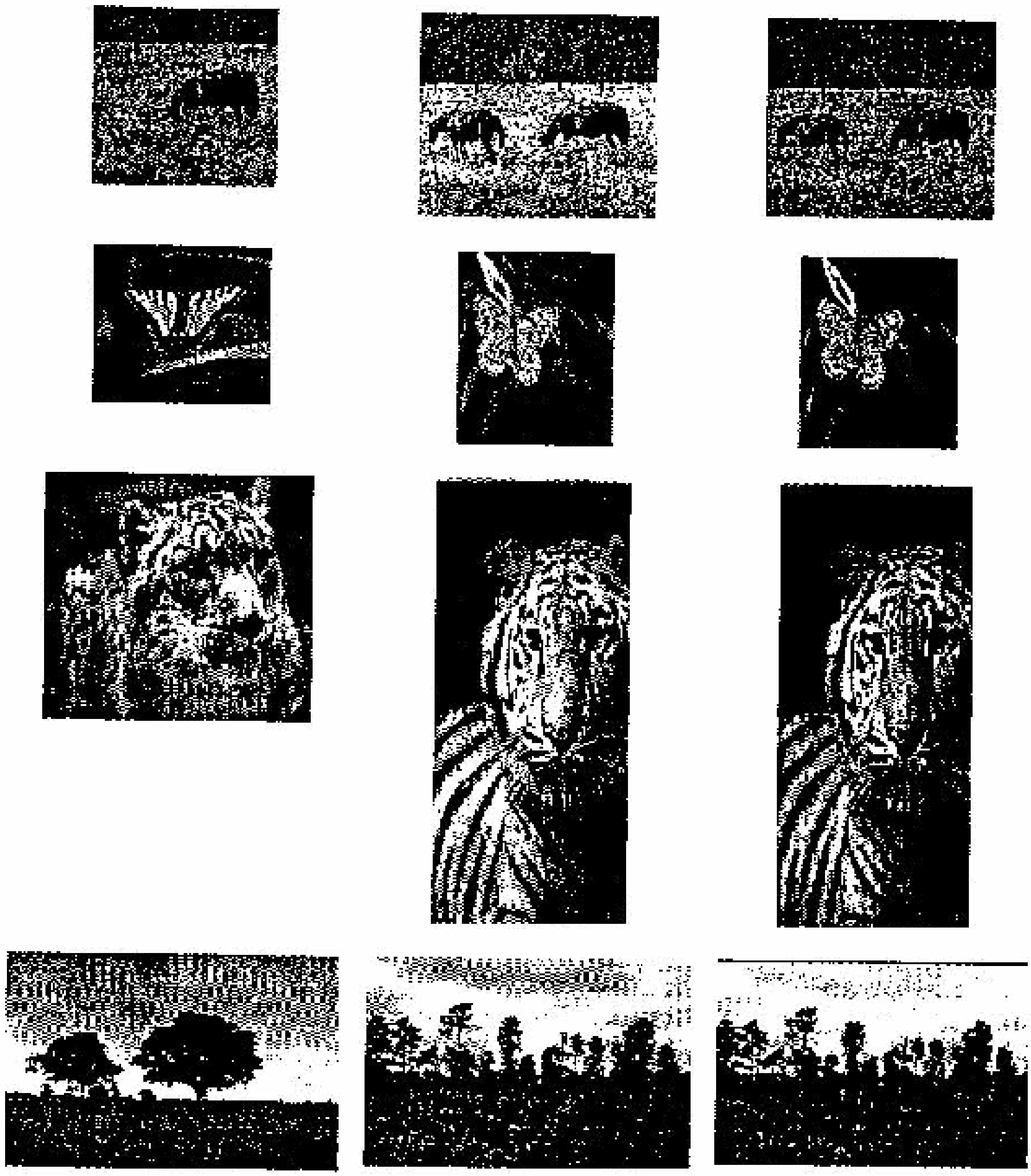


Figure 1: Some Results. For each case, the images are arranged as: left for source image, middle for target image, and right for colorization image

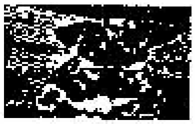
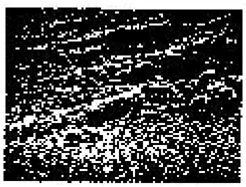
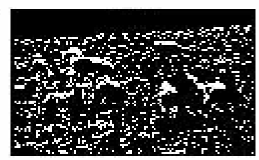
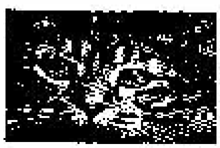
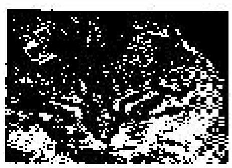
Source Image	Target Image	Patch Method	Welsh Method	Patch Time	Welsh Time
				9	716
				7	635
				7	625
				8	800

Figure 2: Visual comparison results with Welsh et al. colorization algorithm.

References

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المستخلص

يقدم هذا البحث طريقة يقدم هـذا البحـث طريقـة جديدة، بسيطة وسهلة لنقل الألوان من صورة ملونـة الـى صورة هدف رمادية. بوساطة نقل المكونات اللونية مـن رقع مربعة ملونة الى رقع مربعة رمادية. تعتمـد طريقـة التلوين المقترحة على مماثلة الاضاءة بين الرقعـة الهـدف الرمادية وكل الرقع الملونة واختيار الزوج الامثل لعمليـة التلوين. على خلاف طريقة التلوين التقليدية ل ويلش التـي تتطلب مقارنة كل pixel، الطريقة المقترحة ساعدت فـي اختصار عدد المقارنات ولا تحتاج الى تـدخل المـستفيد لاختيار المناطق الجيدة من الصورة المصدر لنقل الالوان. هذه التقنية البسيطة يمكن تطبيقها بنجاح على انواع مختلفة من الصور.