Colorization for Monochrome Motion Pictures By Using Reliable Displacement Vectors

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Abstract

Recently, a study of colorization algorithm for monochrome still image has prospered. Considering actual applications, an extension to monochrome motion picture becomes an important subject. In our previous work, a colorization method for monochrome motion picture was proposed. The method consists of two steps. The first step detects displacement vectors by a block-matching of optical flow scheme between time-sequential adjacent frames. The second step transfers color between corresponded pixels. In the first step, error detection of displacement vectors often occurs in the conventional method. The error accumulates from a previous frame to the next frame, and it causes a fall of colorization accuracy. This paper proposes an improved colorization algorithm for motion pictures. In the proposed algorithm, only reliable displacement vectors, which can be evaluated by the luminance difference between corresponding blocks, are used for color transfers between adjacent frames in the second step. In the third step, the reliable transferred color will be propagated to remaining pixels by using a colorization technique for still images. Since the proposed algorithm ignores displacement vectors with low reliability, it becomes possible to decrease error colorization. This paper discusses the performances of the proposed colorization algorithm with experimental results for natural motion pictures.

Introduction

Colorization is a computerized process that adds color to monochrome print, movie and TV program. Since a mapping between luminance and color is not unique, colorization is an ill-posed problem. Due to these ambiguous, human interaction usually plays a large role in the colorization process.

Semi-automatic colorization algorithms for still image were proposed and some improved algorithms have been proposed. Recently, a few colorization algorithms for motion pictures have been discussed. In Ref.[1], Welsh applied a colorization technique for still image to motion pictures. However, the technique did not use temporal information for colorization to image sequences. So, it works well only for the limited image. In Ref.[2] Levin applied another colorization technique to motion pictures. The Levin's algorithm could solve the Welsh's problem by considering corresponding pixels in the next frame as neighbors. However, it is required to annotate image with complicated scribbles for every a few frames. In Ref.[3] the authors proposed a method which seeded a small number of color pixels on specific frames, and the seeded color was propagated spatially and temporary. For temporal propagation, a typical optical flow technique was used for determining corresponding pixels between frames. However, error accumulates from a previous frame to the next frame and it causes a fall of colorization accuracy. Reference [3] detects the most suitable corresponding flows for all pixels even if the reliability is low.

In this paper, we propose an algorithm using only reliable displacement vectors, which can be evaluated by the luminance difference between corresponding blocks, for precise color transfers between adjacent frames. The remaining monochrome pixels are colorized by a colorization algorithm for still images. Furthermore, we investigate the effectiveness of inserting key frames and a reduction method of computational complexity.

Conventional Colorization for Monochrome Motion Pictures

Reference [3] proposed a colorization method which consists of two steps. The first step was displacement vector detection by a block-matching of optical flow scheme between time-sequential adjacent frames. The second step was color transfer between corresponded pixels. This section describes the outline of the algorithm and clarifies a problem.

Displacement Vector Extraction

Consider an image sequence including N frames and a luminance value at (x, y) in n-th frame is expressed as $f^{(n)}(x, y) : 1 \leq n \leq N$. Here, it is assumed that the image sequence must be composed of continuous scenes without scene changing. Scene changing problem may be solved by backward colorization in the future. Let $\vec{I}^{(n)}(x, y)$ be a correct RGB color vector $(R(x, y), G(x, y), B(x, y))$ in n-th frame.

In order to propagate colors from a colorized frame to the next monochrome frame, displacement vector between adjacent frames is calculated for each pixel. In this paper, we use a typical block-matching algorithm in the optical flow scheme. The optical flow of an image sequence is a set of vector fields, relating each frame to the next. Each vector field represents the apparent displacement of each pixel from frame to frame. If we assume the pixels conserve their luminance value, we arrive at the "brightness conservation equation":

$$f^{(n)}(x, y) = f^{(n-dn)}(x + dx, y + dy) \tag{1}$$

where (dx, dy) is the displacement vector for the pixel at coordinate (x, y) and n and dn are the frame and temporal displacement of the image sequence.

The obvious solution to Eq.(1) is to use template-based search strategies. A template of a certain size around each pixel is created and the best match is searched for the next frame. The best match is usually found using correlation, sum of absolute difference or sum of squared difference metrics. In this paper, we use the following criterion:

$$e(dx,dy; x,y) = \sum_p \sum_q \left| f^{(n)}(x+p, y+q) - f^{(n-1)}(x+dx+p, y+dy+q) \right| \tag{2}$$

where (p,q) shows an coordinate in template block. A vector (dx,dy) with the minimum $e(dx,dy;\ x,y)$ is determined as the displacement vector for $f^{(n)}(x,y)$. Such a search strategy is computationally costly and generally does not represent sub-pixel displacements.

Colorization Process

By the displacement vector extraction, a corresponding color pixel $\vec{I}^{*(n-1)}(x+dx, y+dy)$ in a colorized (n-1)-th frame is determined for each pixel $f^{(n)}(x,y)$ in n-th monochrome frame. Reference [3] estimates the color using the following algorithm. $\vec{I}^{*(n)}(x,y)=\vec{I}_i^{(n)}(x,y)$ which minimizes the difference between $\vec{I}_i^{(n)}(x,y)$ and $\vec{I}^{*(n-1)}(x+dx, y+dy)$ at corresponding pixel in the previous frame:

$$J(\vec{I}_i^{(n)}) = \left\| \vec{I}^{*(n-1)}(x+dx, y+dy) - \vec{I}_i^{(n)}(x,y) \right\| \rightarrow \min. \quad (3)$$

Equation (***3***) means that each pixel (x,y) in n-th frame is colorized by selecting the most suitable color $\vec{I}_i^{(n)}(x,y)$ from color candidates $\{\vec{I}_i^{(n)}(x,y)\}$ for the luminance $f^{(n)}(x,y)$. Here, the color $\vec{I}_i^{(n)}(x,y)$ has the minimum RGB difference between the corresponding color $\vec{I}^{*(n-1)}(x+dx, y+dy)$ in (n-1)-th frame and color candidates $\{\vec{I}_i^{(n)}(x,y)\}$. This method has a property to keep the luminance value for the colorized image.

Problem

A problem of the conventional algorithm is that the error accumulates from a previous frame to the next frame, and it causes a fall of colorization accuracy. It is impossible to theoretically avoid accumulation of the error. However, reduction of accumulated error is possible. We propose an improved algorithm for solving the problem in the next section.

Proposed Algorithm

Displacement Vector Detection

Conventional algorithm calculates corresponding pixels using Eq.(2) for all pixels with disregard to the value of the criterion $e(dx,dy;\ x,y)$. In this paper, only reliable displacement vectors, which can be evaluated by the luminance difference between corresponding blocks, are used for color transfers between adjacent frames, i.e. in the case $e(dx,dy;\ x,y) < Threshold$, the color in the previous frame will be propagated.

Colorization Process

The transferred color by reliable displacement vector is colorized by the same way in the previous method [3]. But, the remaining pixels with unreliable displacement vector are still gray. In this paper, the remaining pixels can be colorized using a colorization technique for still images [4]. The gray pixels are colorized by considering transferred color to be seeded color pixels. In Ref.[4], the color can be estimated depending on the Euclidean distance and the luminance distance between seeded color pixels and each pixel to be colorized. So, the method can be successfully applied to a complicated image including texture by a small number of transferred colors.

Computational Complexity Reduction

Colorization algorithm in Ref.[4] requires color of all transferred pixels for determining color for each monochrome pixel. This process needs quantity of a great deal of operation. According to our experiment, transferred pixels of a distant place do not have an influence on decision of color. In this paper, the operation time is reduced by omitting transferred pixels with large Euclidean distance from a target monochrome pixel to be colorized.

Experimental Results

We applied to the proposed algorithm to several motion pictures with 720x480 pixels. Figure 2 shows a few frames in a monochrome test picture. The frame rate is 12[frame/sec] and we use 60 frames. The test pictures were prepared by transferring original color pictures to monochrome images. So, we know the correct color pictures. In our experiment, we gave only the first frame color information as a key frame. Then, remaining 59 frames were colorized by the proposed algorithm.

Figure 3 shows the colorized results by using the conventional method [3] and the proposed method. The proposed method improves from the conventional method in the whole chrominance component such as on a flag. Figure 4 shows the PSNR evaluation. The PSNR is calculated between the original color picture and the colorized result. The colorization accuracy was improved objectively. However, it is impossible to colorize objects which appear from an intermediate frame using only one key frame. For example, the proposed method cannot colorize

Figure 2. Monochrome frames in a test picture. (top) 20th frame, (middle) 40th frame, (bottom) 60th frame.

men appearing from the right hand side as shown in Fig.3(c). In order to solve the problem, we investigate addition of key frames and propagating direction of color in the key frames.

Figure 5 shows colorized results by inserting key frames every 15 frames. Figure 6 shows comparison of PSNR by the insertion of key frames. By inserting a key frame in every 15 frames, the colorization more than about 30dB can be realized for all frames. Figure 7 shows colorized results by setting two key frames to the first and the last frames. Then the color propagation was performed from both side, and the final colorized result was obtained by blending both colorized results. As shown in Fig.7, all objects can be colorized by bi-directional propagation. Figure 8 shows comparison of the PSNR by the propagation direction of color. By dealing with the transferred pixels within the radius of 100 pixels from a target pixel, the computational time was reduce from 30 to 40 percent with keeping the colorization quality.

Conclusions

In this paper, we improved the colorization accuracy for monochrome motion pictures by considering with only reliable displacement vectors. In addition, we investigated the effectiveness of inserting key frames.

The proposed method has a few parameters. We have to investigate the optimum parameters depending on an input image.

References

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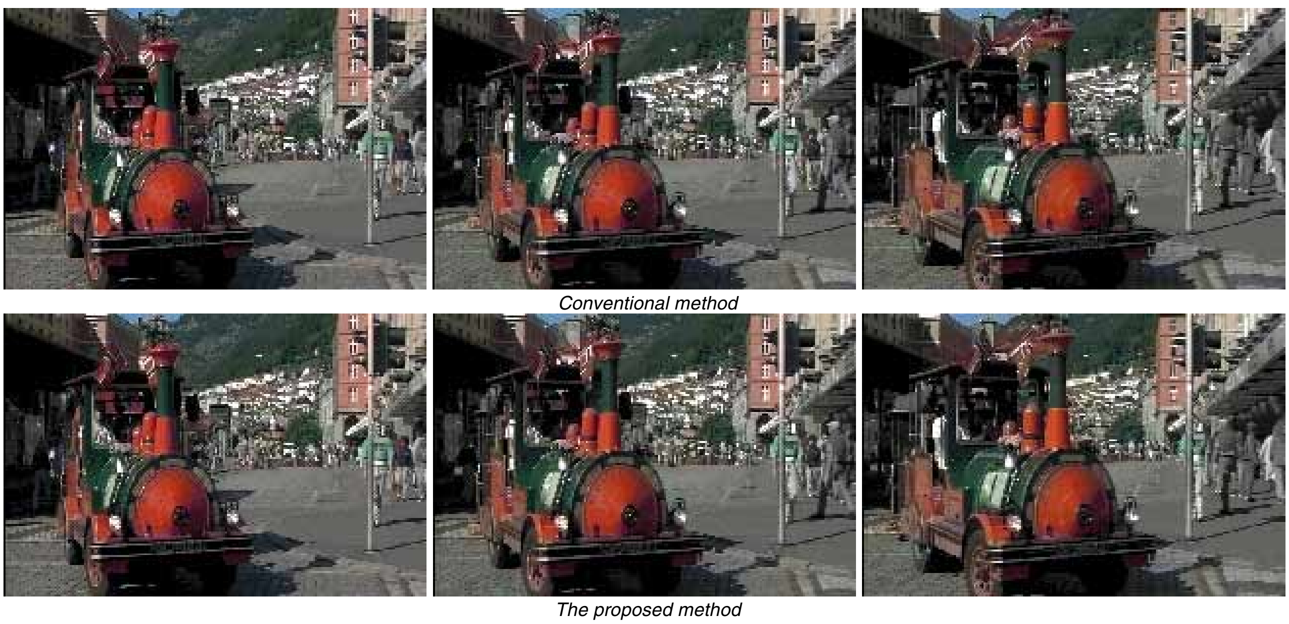
Author Biography

Tomoyuki Murakami received his B.E. degree from Chiba University, Japan in 2005. Since 2005, he has been a graduate student in the Master's Program in Science and Technology of the same university. His current research interest is colorization for motion pictures.



(a) 20th frame *(b) 40th frame* *(c) 60th frame*

Figure 3. Comparison of conventional and proposed method

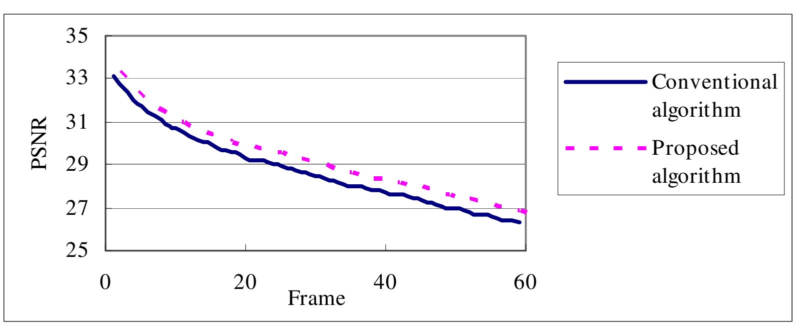


Figure 4. Comparison by PSNR of the conventional method and the proposed method

(a) 20th frame (b) 40th frame (c) 60th frame

Figure 5. Colorized result by inserting key frames every 15 frames.

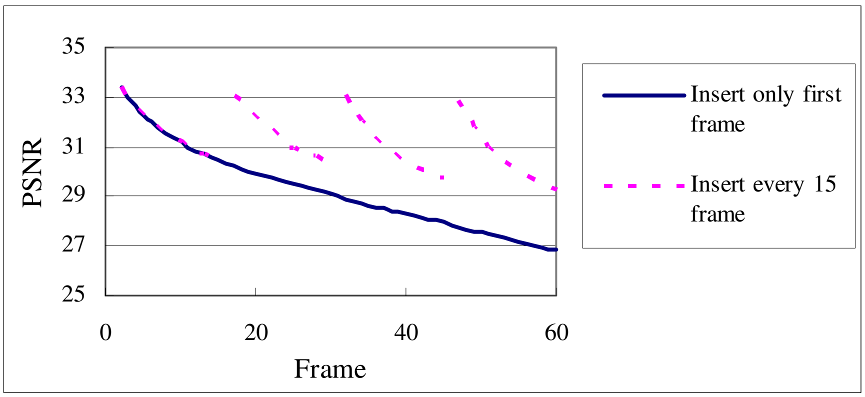


Figure 6.Comparison of PSNR by the insertion of key frames.

(a) 20th frame (b) 40th frame (c) 60th frame

Figure 7. Colorized result by bi-directional propagation.

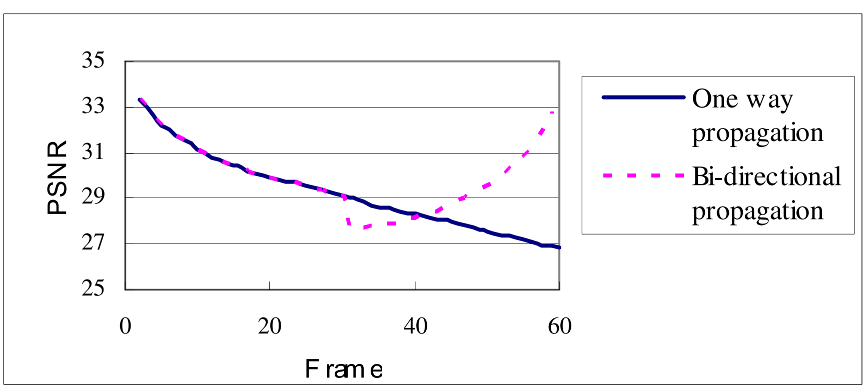


Figure 8. Comparison of PSNR by the propagation direction of color.