Adaptive Image Quality Improvement Method for Moving Pictures Using Smoothing Parameter Transition and Scene Cut Detection

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Abstract

This paper proposes a new method for making automatic improvements in digital video image quality. With this method, the quality of digital video sequences captured by TV, DVD, and digital video (DV) cameras can be automatically improved on a monitor without any prior knowledge. The method is developed by applying adaptive quality improvement techniques for still images - entire image correction and selective color correction. Entire image correction improves the feature values of three important factors for color image quality - contrast, white balance and saturation - defined based on human visual perception. Selective color correction ensures preferred color reproduction for three significant categories: facial skin color, green foliage and blue sky. Through the use of scene cut detection and smoothing parameter transitions, this method can smoothly and adaptively adjust the enhancement parameters for image quality. With this technique, each scene in a video sequence can be optimally improved.

Introduction

When digital moving pictures are displayed on a monitor, their quality changes depending on various factors. Illumination conditions affect several quality factors of moving pictures such as white balance, contrast, and saturation. For example, moving pictures filmed on a fine day are more saturated than those filmed on a cloudy afternoon. Image quality factors are influenced by camera performances with which image sequences are filmed. For instance, image sequences from a home-use DV camera do not look as saturated or as high in contrast as those in DVD software sold at stores.

Quality unstableness of moving pictures increases difficulty in adjusting pictures. The optimum improvement settings for one scene or one image sequence are not always the optimum ones for others. Thus, it becomes important to develop a quality improvement method for moving pictures that can be adapted to any scenes or image sequences.

Recently, for improving image quality, we have developed adaptive quality improvement methods for still color images.[1,2] Though the methods produce good results for still color images, they have some problems when applied directly to image sequences. Flickering occurs in the resulting images owing to discontinuity in improvement parameters. We introduce some techniques to solve these problems. In this paper, we present these techniques and report the evaluation results of our improved method for moving pictures.

Basic Adaptive Quality Improvement for Still Images

The proposed method performs image corrections for several kinds of image quality: saturation, contrast, white balance, and color preference. These image corrections are based on improvement methods for still images, which can rate the quality factor quantitatively and improve the quality of still images based on the rated result. In consequence, the correction methods for still images can improve the image quality adaptively. The correction methods are described below.

Saturation Enhancement

Saturation enhancement is realized by stretching a saturation histogram for an input image.[1]

To evaluate the saturation quality for an input image f, this method rates the saturation quality factor SAF for the input image f with the following equation:

$$SAF = \max(S(x,y) \otimes LPF(x,y)), \tag{1}$$

where $S(x,y)$ denotes the saturation image, which represents the spatial distribution of normalized S value (HSV coordinate system[3]) of the input image f, at spatial coordinates (x,y), LPF(x,y) is a low-path filter, and $\otimes$ is a convolution operator. max(f) represents the maximum value among all the pixels in an image f.

To correct the saturation quality for the input image, the desired new saturation values S' are obtained with eq. (2) and an enhancement parameter c.

$$S' = c \times S \tag{2}$$

The enhancement parameter c is calculated with the following equation:

$$c = \frac{SAF_{opt}}{SAF}, \tag{3}$$

where SAF_{opt} represents the optimal SAF as determined in a subjective pilot study.

Contrast Enhancement

Contrast enhancement is realized by stretching a lightness V histogram for an input image.[1]

To evaluate the contrast quality for an input image *f*, highlight characteristic *HL* and shadow characteristic *SD*, which represent the maximum and minimum lightness in the input image *f*, are calculated with the following equations:

$$HL = \max(V(x,y) \otimes LPF(x,y)) \tag{4}$$

$$SD = \min(V(x,y) \otimes LPF(x,y)) \tag{5}$$

where *V*(*x,y*) denotes the lightness image, which represents the spatial distribution of normalized *V* values (HSV coordinate system) of an input image *f*. max(*f*) and min(*f*) represent the maximum and minimum values among all the pixels in an image *f*.

The desired new lightness value *V'* is obtained with eq. (6) based on *HL* and *SD* values.

$$V' = a \times V + b \tag{6}$$

in which *a* and *b* are given by

$$a = \frac{HL_{opt} - SD_{opt}}{HL - SD} \tag{7}$$

$$b = HL_{opt} - a \times HL, \tag{8}$$

where HL_{opt} and SD_{opt} represent the optimal *HL* and *SD* as determined in a subjective pilot study.

White Balance Correction

Evaluation values of white balance quality for an input image are average RGB values of the area in which humans sense whiteness in the input image. For the evaluation values, white feature vector WF is given by the form

$$WF = RGBave(\max(I(x,y) \otimes LPF(x,y))), \tag{9}$$

where *I(x,y)* denotes the intensity image, which represents the spatial distribution of I values of the input image *f* at spatial coordinates (*x,y*). In this paper, we assume that *I* value for a pixel is Y value of XYZ color coordinate system transformed from RGB values at the pixel. *RGBave*(*f*) represents the average RGB values of pixels having the maximum intensity in the input image *f*.

Assuming that the RGB values of *WF* are (*wr,wg,wb*) and the corrected white values are (*wr*0,*wg*0,*wb*0), input pixel value (*r,g,b*) is transformed to the corrected RGB value (*r*',g',*b*') as

$$\begin{aligned} r' &= wr0 / wr \times r \\ g' &= wg0 / wg \times g \\ b' &= wb0 / wb \times b. \end{aligned} \tag{10}$$

Preferred Color Reproduction

Preferred color reproduction is performed for three significant categories: facial skin color, green foliage, and blue sky. In this method, a representative color in an object area to be corrected is automatically extracted from an input image, and a set of color correction parameters is selected depending on the representative color. The representative color is obtained as the color having the maximum frequency in a hue histogram weighted existence probability of each categorical color, which is derived in a preliminary subjective experiment. Assuming the representative color for one category is (R_p,G_p,B_p), the enhancement parameters are set to (a_1,a_2,a_3), which are obtained in another preliminary experiment. With these parameters, preferred color reproduction performs selective color correction[4] by transforming arbitrary RGB values (*R,G,B*) to (*R'*,*G'*,*B'*) with the following equation:

$$(R', G', B') = (R, G, B) + hx \times (a_1, a_2, a_3) \tag{11}$$

in which *hx* is a chromatic contribution value that shows the distance between the representative color (R_p,G_p,B_p) and (*R,G,B*). The value of *hx* is given by

$$hx = \frac{pos\left(m - \left|Hue - h1\right|\right)}{m} \times s1 \times v1, \tag{12}$$

where *pos*(*x*) = 0 for *x* < 0 and *pos*(*x*) = *x* for *x* > = 0, and m is a hue range. Hue is a hue value of the HSV coordinate system, and *h1*, *s1*, and *v1* are HSV hue, saturation, and value respectively, calculated from the arbitrary input color (*R,B,G*).

Advanced Adaptive Quality Improvement For Moving Pictures

Smoothing Parameter Transitions

When the improvement method described in the previous section is applied to correct each frame captured from a video sequence, flickering occurs in the resulting image. The thin line in Fig. 1 shows a parameter transition in the case of saturation enhancement. This flickering issue is caused by the discontinuity in the enhancement parameters as shown by the thin line seen in the figure.

To solve this flickering issue, we employ a parameter transition smoothing method. In this study, smoothing is achieved by updating the parameters every N frames and calculating enhancement parameter Val_{new} for a new frame with the following equation:

$$Val_{new} = \min(Val_{old} + d, \max(Val_{old} -, Val)), \tag{13}$$

where Val_{old} is the enhancement parameter for the previous frame, *Val* is obtained for the new frame by the improvement method described in the previous section, and *d* is the no-flicker margin, which means the maximum amount of the parameter change, with which people do not sense flickering, between a new parameter and the previous one. The margin was determined in a subjective experiment.

Figure 2 illustrates eq. (13) schematically. Once one parameter Val_{old} is obtained, the parameter is held for N frames. When N frames have passed, the enhancement parameter *Val* is obtained from the most recent frame image. If *Val* is at (a) in Fig. 2 where the distance between Val_{old} and *Val* is larger than the margin *d*, the new enhancement parameter Val_{new} is set to the nearest value in the shadow area in the figure, which indicates *Val* in the area makes no flickering. If *Val* is at (b), Val_{new} is set to the *Val* since *Val* is in the shadow area. Owing to updating the enhancement parameters by the process described above, image sequences are improved without flickering.

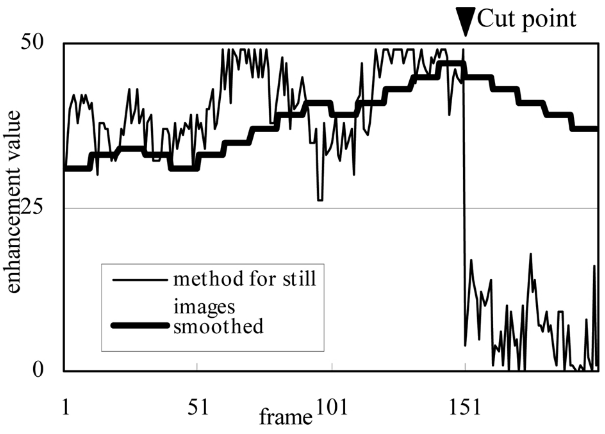


Figure 1. A parameter transition and a smoothed one.

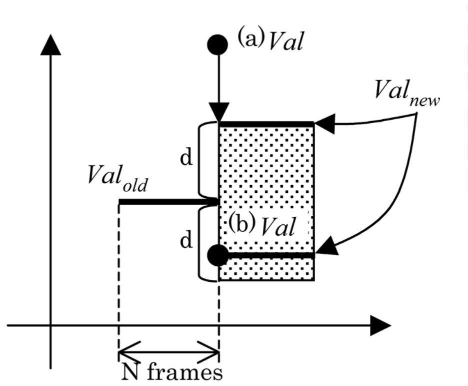


Figure 2. Parameter transition smoothing

The thick line in Fig. 1 shows the parameter transition after employing the smoothing. While the thin line vibrates with short quick steps, the thick line transits smoothly. In addition, the thick line can gradually change depending on the image quality alteration as seen in Fig. 1.

Scene Cut Detection

When enhancement parameters are smoothed, the image quality of the frames at cut points where a scene change is observed is often enhanced excessively or insufficiently, because the parameters change smoothly and may not be appropriate for the new scene. At the cut point in Fig.1, the thick line shows one example in which the parameter cannot adaptively be set for the new frame image.

To obtain the proper image quality after cut points, we introduce a scene cut detection method. This method is performed by comparing the similarity *Sim* between a new frame image and the previous one with a threshold *t*. *Sim* is given by

$$Sim = (1/n)\sum_{i=1}^{n} |h_i - k_i|, \qquad (14)$$

where h_i and k_i are the RGB histogram constituents of the new frame image and the previous one, respectively (an RGB histogram consists of three separate histograms for R, G, and B), and n is the number of histogram ranks. If $Sim > t$, we determine that a scene cut is detected.

With this scene cut detection, the parameters transit smoothly in the same scene, and are refreshed and change greatly at scene cuts.

Figure 3 shows a parameter transition using scene cut detection.

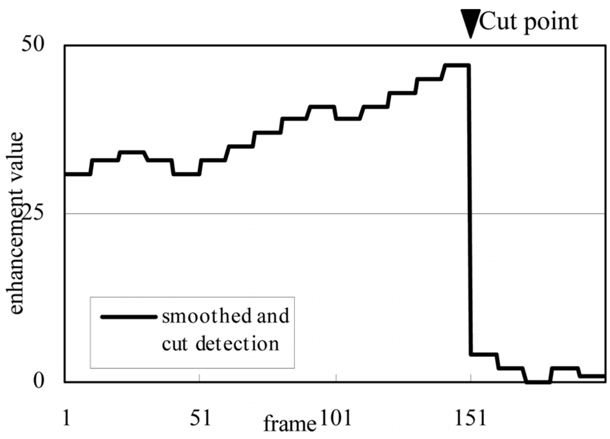


Figure 3. Parameter transition using scene cut detection and smoothing.

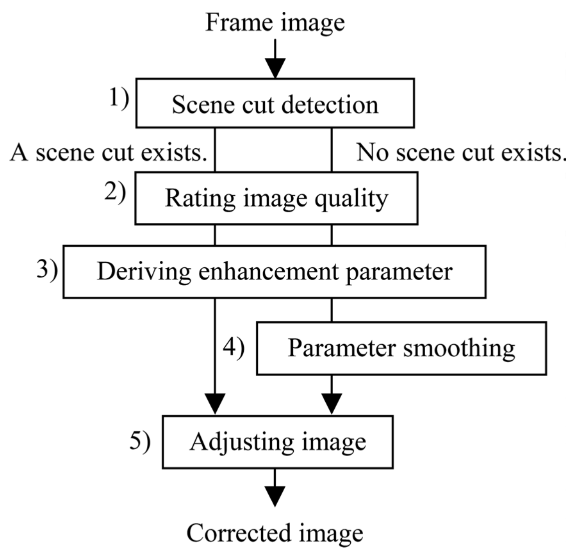


Figure 4. Improvement procedure.

Improvement Procedure

The adaptive quality improvement method for moving pictures improves the quality of each frame in a sequence. It is carried out through the following steps (see Fig. 4.):

1) A scene change is detected by comparing a new frame and the previous one.
2) The quality of the new frame is rated in terms of four factors: white balance, contrast, saturation, and color preference.

(a) Original sequence. *(b) Sequence adjusted by improvement methods for still images.* *(c) Sequence improved by proposed method.*

Figure 5. Example image sequences with and without smoothing parameters.

(a) Original sequence. *(b) Sequence adjusted without cut detection.* *(c) Sequence corrected with cut detection.*

Figure 6. Example image sequences with and without cut detection.

Figure 7. Example of the stimuli used in our subjective experiment.

3) Enhancement parameters are calculated on the basis of the differences between the values calculated for the frame and values determined to be optimal.
4) The enhancement parameters are smoothed by limiting new parameters to a small range from previous parameters if a scene change is not detected.
5) The enhancement parameters are used to alter the frame image.

Corrected Image Sequences

Figure 5 illustrates a sequence of improved by the proposed method. The left column shows the original sequence of images. Since the sequence is captured by a home-use DV camera, the figures are slightly desaturated and low in contrast. The middle column shows the image sequence adjusted by improvement methods for still images. The right column shows the correction results using the proposed smoothing parameter transition method. The three images in each column show a frame transition. These images are captured at frame t, $t + 1$ and $t + 2$ from top to bottom. In Fig. 5 (b), each image is more saturated and higher in contrast than each of the original images. The color of the sky, however, changes frame by frame. These discontinuous changes in color cause flicker in the resulting images. As seen in this case, when the image sequences are adjusted frame by frame independently from other images, the flicker occurs. In Fig. 5 (c), the images are corrected without any independent frame-by-frame color changes. As a result of employing smoothing parameter transition, the proposed method can correct image sequences without flicker.

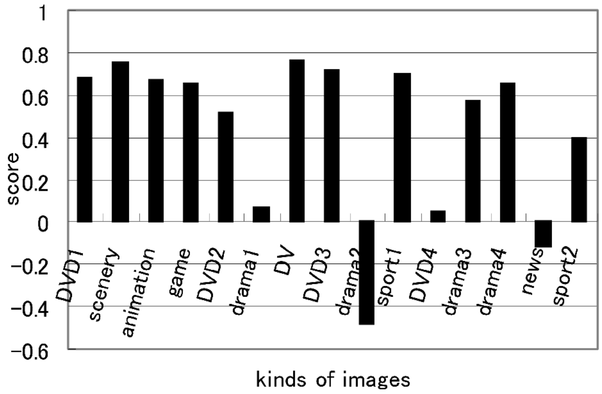
Figure 6 illustrates the results of color correction performed on a sequence including a scene change. The upper images belong to the first scene and the lower ones belong to the second scene after the scene change. The left column shows the original sequence. The middle column shows sequence adjusted by the proposed method without cut detection. The right column shows the result of correction with cut detection. In Fig. 6 (b), the lower image is hardly any more saturated than the original image. In contrast, the lower image in Fig. 6 (c) is more saturated than the original one. The temporary discontinuity of the enhancement parameter transitions made by cut detection makes this image superior to the others.

Experiment

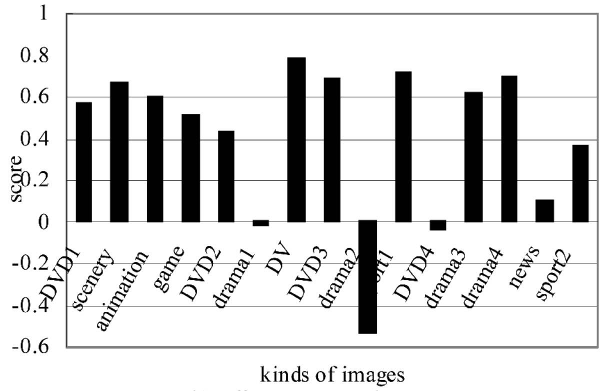
Subjective Experiment Design

To evaluate the performance of this new image improvement method, we carried out a subjective experiment. In the experiment, we used fifteen image sequences captured from TV, DVD, and digital video camera images. The quality of the images adjusted by this method was evaluated on a CRT display with sRGB regulations[5] by 15 subjects. Each subject evaluated the quality by comparing two sequences, the original sequence and the reformed one, which were presented side-by-side simultaneously as seen in Fig. 7. The subjects were shown a set of stimuli comprising 30 image sequences. Half of the stimuli were the original images on the right and other half were the reformed one on the right. These images were presented to subjects in random order. The subjects were not told in advance which sequence the images belonged to. Each image sequence lasted ten seconds and was presented repeatedly until the subject finished evaluating the quality. The subjects were asked to rate the image quality as follows: (1) left is better; (2) left is slightly better; (3) nearly same quality; (4) right is slightly better; and (5) right is better.

To investigate the influence of ambient light, the subjective experiment was performed under two types of illumination conditions, darkroom conditions and office room conditions. Under darkroom conditions, the experiment was performed with no ambient illumination. Under office room conditions, it was performed in a bright room.



(a) Darkroom conditions.



(b) Office room conditions.

Figure 8. Results of the subjective experiment.

Results

The raw data from this subjective experiment were arranged by the rating scale method[6] so that the scores of the reformed sequences could be obtained. Figure 8 shows the results. The top figure shows the results obtained under darkroom conditions, and the bottom figure shows those obtained under office room conditions. In both figures, the taller the bars are, the better the quality of image sequences adjusted by the proposed method is than that of original image sequences. The results indicate that almost all of the reformed sequences had better quality than the original ones. These results did not vary with sequence positions in stimuli. Comparing the results for darkroom conditions and office room conditions, we find that the image quality obtained with the proposed method becomes better regardless of ambient illumination. We, therefore, conclude that this image improvement method can be applied to most image sequences regardless of ambient illumination.

Conclusion

We have developed a new adaptive quality improvement method for moving pictures. Our method was evaluated in a subjective experiment, and the results obtained showed its validity. The new method quantitatively evaluates several image quality factors and adaptively improves the quality. Through the use of scene cut detection and smoothing parameter transitions, the method can improve the quality of image sequences while preventing flickering and improper enhancement. The results obtained in the subjective experiment indicated that this improvement method could be applied to most image sequences.

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Biography

Tetsuaki Suzuki received the BS degree and MS degree in computer science from Tokyo Institute of Technology, Japan, in 1998 and 2000, respectively. He joined NEC Corporation as a research scientist in 2000. His research interests include color image processing and pattern recognition.