반복적 오차 보정을 이용한 얼굴 영상에서의 안경 제거

박정선O, 오유화, 이성환
고려대학교 정보통신대학 컴퓨터학과
{jsparkO, yhoh, swlee}@image.korea.ac.kr

Glasses Removal from Facial Image using Recursive Error Compensation

Jeong-Seon ParkO, You Hwa Oh, and Seong-Whan Lee
Department of Computer Science and Engineering, Korea University

Abstract

In this paper, we propose a new method of removing glasses from human frontal facial images. We first detect the regions occluded by the glasses, and generate a natural looking facial image without glasses by recursive error compensation using PCA reconstruction. The resulting image has no trace of the glasses frame, nor of the reflection and shade caused by the glasses. The experimental results show that the proposed method provides an effective solution to the problem of glasses occlusion, and we believe that this method can also be used to enhance the performance of face recognition systems.

1. Introduction

Automatic face recognition has become an important topic of research, due to its potential use in a wide range of applications, such as access control, human-computer interaction and automatic search in a large-scale facial image database.

One important requirement for successful face recognition is robustness to variations arising from different lighting conditions, facial expressions, poses, scales and occlusion by other objects. Among occluding objects, glasses are one of the most common occluding objects, and they have a significant effect on the performance of face recognition systems.
Recently, several methods of detection, extracting and removing glasses have been reported by different researchers. Lanitis et al.[1] showed that their flexible model, which is now referred to as the active appearance model, could be used to remove small occlusions caused by glasses. Jiang et al.[2] only determined the presence of glasses using six measures. However, this method requires that the position of the eyes in the facial image be known. Saito et al.[3] generated facial images without glasses using PCA(Principal Component Analysis).

However, their method left some traces of the glasses frame on the reconstructed facial images. Jing et al.[4] also determined the presence of glasses using the Jiang's method[2] and then extracted glasses using a deformable contour combining edge features and geometrical features.

In this paper, we propose a new method of removing glasses from frontal facial images by recursive application of error compensation, in order to obtain natural looking facial images without glasses. To accomplish this, we first locate the regions of glasses occlusion and then generate an image which compensates for this occlusion. In this study, we treat both the problem of occlusion caused by the glasses frame, and that caused by the reflection of the glasses.

2. Glasses Removal Methods

The proposed glasses removal method consists of three procedures. The first step involves face extraction and glasses frame detection and the second is the initial reconstruction of the facial image without glasses by example-based learning. Finally, we recursively update the reconstructed facial image without glasses by error compensation process which will be described in next section.

In this section, we will describe the process of glasses frame detection and initial reconstruction of the facial image without glasses by two kinds of example-based learning methods.

2.1. Extraction of glasses region

The region of glasses occlusion includes not only the glasses frame, but also the reflection made by the lens and the shade caused by the glasses. In order to remove the glasses occlusion and generate natural looking facial images without glasses, we need to find the exact region of glasses occlusion and generate a seamless facial image without glasses.

The extraction of the glasses frame around the eyebrows is an important task because, if the glasses frame is not correctly removed from the input face, parts of the frame can end up looking like eyebrows with low gray-scale values in the reconstructed face. On other words, if the glasses frame is not extracted from the eyebrows in a precise manner, the result after glasses removal does not look natural. Thus, in order to extract the glasses frame around the eyebrows, we resorted to using a process involving color and edge information from the original input face.

In the Fig. 1, (a) is a GSCD(Generalized Skin Color Distribution) transformed image and (b) contains the eye candidate regions. First, we performed an "ADD" operation to (a) and (b) to roughly remove the eye and eyebrow information in the GSCD image, as shown in Fig. 1(c). Next, in order to clearly represent the glasses frame in the facial image, the Sobel edge operation is applied to the image shown in Fig. 1(d). Then, the "OR" operation of (d) and the inversion of (c) is applied as shown in Fig. 1 (e). Finally, we masked out the lower half of the facial region from the extracted glasses frame information as shown in Fig. 1(d).

(a) (b) (c) (d) (e) (f)

Fig. 1. Extraction of glasses region : (a) Skin region, (b) Binarized image, (c) (a) + (b), (d) Sobel of (c), (e) (d) OR -(c), (f) glasses region

2.2 Simple PCA reconstruction method

A typical method of generating facial images without glasses is the simple PCA-based reconstruction method developed by Saito et al.[3]. It just combines the upper half of the facial region in the PCA reconstructed face and the lower half of the input face.

From the concepts of the PCA method, the representational power of the PCA depends on the training set. For instance, if the training images do not contain glasses, then the reconstructed faces of input faces do not represent the glasses properly. In other words, in the case of input faces wearing glasses, the PCA tries to represent the glasses region in the reconstructed face, using eigenfaces which were obtained from a training set of facial images without glasses. Therefore, this gives rise to errors which are spread out over the entire reconstructed face, resulting in some degradation of quality, with some traces of the glasses frame remaining as shown in Fig. 2 (c).

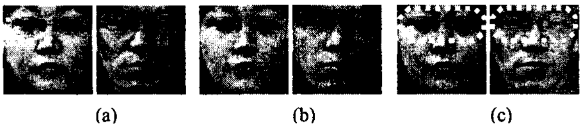

Fig. 2. Results of simple PCA reconstruction : (a) input faces with glasses, (b) reconstructed faces without glasses by PCA reconstruction, (c) glasses removed faces by combining lower part of (a) and upper part of (b)

2.3. Example-based reconstruction method

If we can use the numerous pairs of facial images with and without glasses for the same person, the estimation of facial image without glasses from input facial image with glasses is possible using example-based learning methods[1][6].

Suppose that sufficiently large amount of facial images are available for off-line training, then we can represent any input face by a linear combination of a number of prototype faces[6]. Moreover, if we have a pair of facial images with and without glasses for the same person, we can obtain an approximation to the deformation required for the given facial image with glasses by using the coefficients of prototypes which derived from the example faces. Then we can estimate facial image without glasses by applying the estimated coefficients to the corresponding prototype faces without glasses. In the method we can estimate optimal coefficients for a linear combination of prototypes of glass's prototypes by solving least square minimization problem[6].

Fig. 3 shows examples of glasses removal results from same facial images of Fig. 2 by applying example-based learning. Even without the post-processing of replacing input faces of reconstructed lower area, we can generate natural looking facial images without glasses.

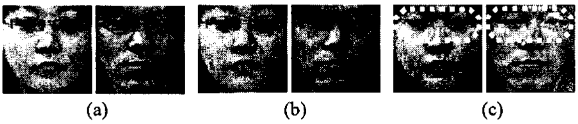

Fig. 3. Results of example-based reconstruction: (a) input faces with glasses, (b) reconstructed faces with glasses, (c) estimated faces without glasses by applying second estimation of example-based learning.

3. Recursive Error Compensation

The proposed glasses removal method is composed of an off-line process which generates eigenfaces from a set of training facial images without glasses, and an on-line process which detects the glasses frame using color and edge information and then recursively compensates the input face by using the recursively reconstructed image without glasses by PCA. Off-line process is similar to the training of simple PCA method.

Here, we describe in detail the on-line procedure depicted in Fig. 4.

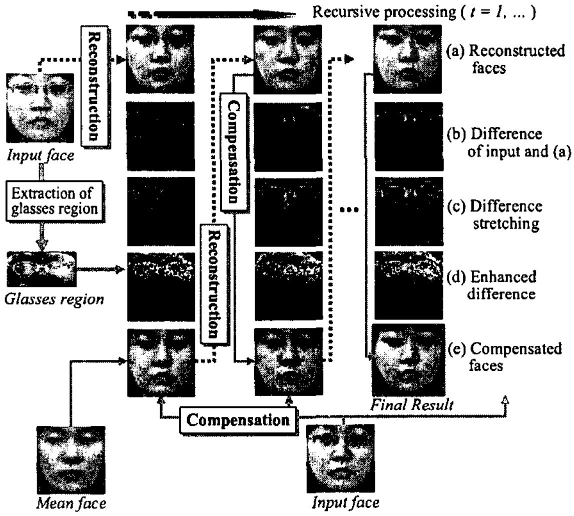

Fig. 4. Glasses removing procedure of the proposed recursive error compensation

First, the input face(Γ) wearing glasses can be expressed as the mean face(φ) and weighted sum of the eigenfaces(μ_k) generated from a set of training facial images without glasses,

$$\Gamma^R = \varphi + \sum_{k=1}^{M} \omega_k \cdot \mu_k, \qquad k = 1,\dots,M \tag{1}$$

where, ω_k is the weight of the k-th eigenface and Γ^R is the reconstructed face.

Second, the difference between input face(Γ) and its reconstructed face(Γ^R) can be calculated by means of Eq.(2) as shown Fig. 4(b).

$$d(i) = \left|\Gamma(i) - \Gamma^R(i)\right|, \qquad i = 1,\dots,N \times N \tag{2}$$

where, $N \times N$ is the size of the input face.

Then we perform difference stretching using the intensity of reconstructed facial image, in order to clearly represent the glasses occlusion region, as shown in Fig. 4(c). That is by using the Eq. (3), we tried to enhance low errors of shadow by glasses in a difference image, and to diminish differences in dark regions such as eye and eyebrows in grayscale facial images.

$$D(i) = \left(\Gamma^R(i) \cdot d(i)\right)^{1/2}, \qquad i = 1,\dots,N \times N \tag{3}$$

A remaining difficult problem consists of finding the glasses frame in the area around the eyebrows. We resort to using the glasses frame image extracted from the original color image, as shown in Fig. 4(d). This image can be used to enhance the differences around the eyebrows by replacing the difference error by the intensity of the glasses frame, if the value of the latter is larger than that of the former in the region having the smaller errors.

Once the region of glasses occlusion referred to in the previous step has been found, this region can be compensated for by using the reconstructed face(or mean face), as shown in Fig. 4(e). In the first iteration of the recursive processing, the mean face is used for the compensation of the occlusion region of input face. From the second iteration, the previously reconstructed face is used. That is,

$$\Gamma_t^C = \omega \cdot \rho + (1-\omega)\cdot \Gamma, \qquad if(t=1)$$
$$\Gamma_t^C = \omega \cdot \Gamma_t^R + (1-\omega)\cdot \Gamma, \qquad if(t>1) \tag{4}$$

where t is the iteration index used for recursive error compensation process.

The weights for compensating each occluded region of the previously reconstructed face are determined by the following equation.

$$\omega(i) = 1, \qquad if(D(i) \geq T_H)$$
$$\omega(i) = 1 - 0.5\frac{T_H - D(i)}{T_H - T_L}, \qquad if(T_L \leq D(i) < T_H) \tag{5}$$
$$\omega(i) = 0, \qquad if(D(i) < T_L)$$

where T_L and T_H are the lower threshold for the non-occlusion regions and the upper threshold for the occlusion regions, respectively. In this process, T_L is determined by the mean value of $D(j)$ for skin region, and of and T_H is determined by the mean value of $D(j)$ for non-skin region.

In Eq.(4), a value of $\omega(i) = 1$ means that the input region, Γ_i, is regarded as being within the region occluded by the glasses and, therefore, that this region is compensated for by using the mean face(φ) or previously reconstructed face(Γ_t^R). On the other hand, a value of $\omega(i) = 0$ means that the input region, Γ_i, is regarded as being a region non-occluded by the glasses and so is only compensated for by using the input face. The other remaining regions are regarded as uncertain regions and are compensated for by a linear combination of the input and previously reconstructed faces.

The iteration stops if the difference between the currently reconstructed face and the previously reconstructed face becomes less than a given threshold, ε.

$$\left\| \Gamma_t^C - \Gamma_{t-1}^C \right\| \leq \varepsilon \tag{6}$$

As a result of recursive PCA reconstruction and compensation, a natural looking facial image without glasses is generated at the last iteration of the proposed method, as shown in Fig. 4(e).

4. Experimental Results and Analysis

We have carried out experiments using the large number of frontal facial images selected from the KFDB(Korean Face Database)[7]. We select the images of 300 persons that wearing one's own glasses from those of 1,000 persons. Also we selected 10 frontal facial images with/without glasses which have 5 changes of illumination directions (front 0 degree, left/right 45 degree, left/right 90 degree) from total 52 images for each person.

The 1,200 frontal facial images which have 3 illumination changes(i.e. front 0 degree, left/right 45 degree) of 200 persons used as training set and the 400 images which have 2 illumination changes(i.e. left/right 90 degree) of the remaining 100 persons are used as test set. Numerous kinds of glasses are included in the database.

In the experiment, we compared the proposed method with previous PCA reconstruction method[3] and an example-based method. In this figure, each number indicates the average pixel-wise distance to original facial images without glasses.

The glasses-removed faces using the previous PCA reconstruction method (b), have still some traces of glasses in many cases, also those with the example-based method are unnatural links upper and lower of faces(c). On the other hand, the results of the recursive compensation method have no traces of glasses and are looking seamless and natural as shown in (d). The proposed method also has advantages in the aspect of quantitative comparison as shown in the figure, but still has some restriction about removing glasses of dark frame and gradated color of lens as shown in 4-th column in Fig. 5.

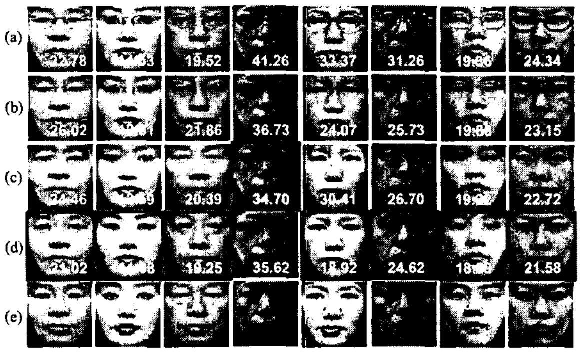

Fig. 5. Examples of glasses removal : (a) input faces wearing glasses, (b) glasses-removed faces by simple PCA reconstruction[3], (c) glasses-removed faces by example-based method, (d) glasses-removed faces by the proposed recursive PCA, (e) original faces without glasses

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