Glasses Removal from Facial Image Using Recursive Error Compensation

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Abstract—In this paper, we propose a new method of removing glasses from a human frontal facial image. 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 or 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.

Index Terms—Glasses removal, face recognition, face reconstruction, face synthesis, recursive error compensation.

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 [1].

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.

There are two approaches for solving occlusion problems in face recognition systems. One is estimating nonoccluded facial image as one of the preprocessing steps. The other is identifying nonoccluded local regions and only used those regions. Hwang and Lee [2] tried to reconstruct facial image from partially occluded faces using linear square solution under the morphable face model. But, according to the morphable model, pixel-wise correspondences between input and reference face must be given or calculated precisely. As an example of a second approach, Martinez [3] developed a local matching procedure for robust recognition performance from partially occluded faces by sunglasses and scarf without reconstructing nonoccluded face or removing the occlusions.

Recently, several methods of detecting, extracting, and removing glasses have been reported by different researchers. Lanitis et al. [4] 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. [5] 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. [6] generated a facial image without glasses using PCA (Principal Component Analysis). However, their method left some traces of the glasses frame on the reconstructed facial images. Jing and Mariani [7] also determined the presence of glasses using Jiang et al.'s method [5] and then extracted glasses using a deformable contour combining edge features and geometrical features.

More recently, Wu et al. [8] detected the glasses frame using a 3D Hough transform of trinocular stereo facial images based on the determination of a 3D plane passing through the rims of the glasses, without any assumptions about the facial pose or the shape of the glasses. However, this method requires more cameras and computational time than other 2D image-based methods. Xiao and Yan [9] extracted glasses by decomposing face shape using the Delauney triangulation. But, this method has some problems in the cases where glasses do not cover eyes or glass frames have very low contrast.

In this paper, we propose a new method of removing glasses from a frontal facial image by recursive application of error compensation, in order to obtain a natural looking facial image 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. The proposed glasses removal method consists of three procedures. The first procedure 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.

This paper is organized as follows: In Section 2, we describe the procedure used for extraction of glasses region and discuss two glasses removal methods using PCA reconstruction and example-based learning. Then, in the next section, we explain our glasses removal method, which is based on a recursive process of PCA reconstruction and error compensation. In Section 4, discussions of experimental results with facial images, including various types of glasses, are provided along with an analysis of these results. Finally, we make our conclusions and provide discussions of future works in Section 5.

2 Glasses Removal Methods

In this section, we 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 a natural looking facial image without glasses, we need to find the exact region of glasses occlusion.

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. In 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.

Fig. 1 shows our extraction process of glasses region from input color image. Fig. 1a is a GSCD (Generalized Skin Color Distribution) transformed image and Fig. 1b contains the eye candidate regions. First, we performed an "ADD" operation to Figs. 1a and 1b to roughly remove the eye and eyebrow information in the GSCD image, as shown in Fig. 1c. 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. 1d. Then, the "OR" operation of Fig. 1d and the inversion of Fig. 1c is applied as shown in Fig. 1e. Finally, we extracted the glasses region from Fig. 1e by masking out the lower region of the facial region, as shown in Fig. 1f, where the facial region is determined as a rectangle by normalizing rotation and size according to the location of the eyes. Detailed procedure of extracting facial region is described in our previous work [10].

2.2 PCA Reconstruction Method

A typical method of generating a facial image without glasses is the simple PCA-based reconstruction method developed by Saito et al. [6]. It just combines the upper half of the facial region by means of

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Manuscript received 6 Aug. 2003; revised 18 Oct. 2004; accepted 3 Nov. 2004; published online 11 Mar. 2005.
Recommended for acceptance by K. Yamamoto.
For information on obtaining reprints of this article, please send e-mail to: tpami@computer.org, and reference IEEECS Log Number TPAMI-0213-0803.

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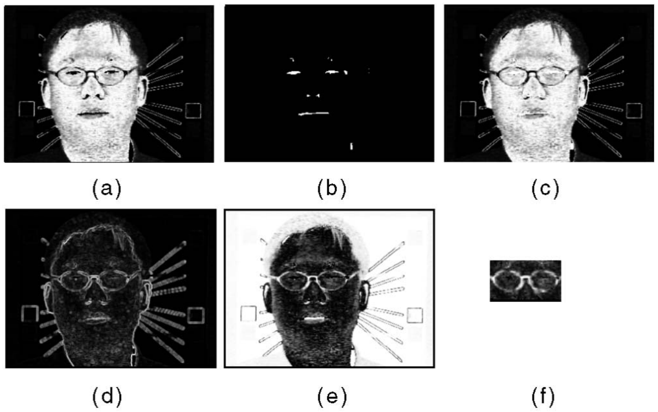

Fig. 1. Extraction of glasses region. (a) Skin region, (b) binarized image, (c) (a) + (b), (d) Sobel of (c), (e) (d) OR -(c), and (f) glasses region.

PCA reconstruction method (Fig. 2) and the lower half of the input face, as shown in Fig. 3.

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.

Fig. 3 shows examples of glasses removal results from two facial images with glasses. Even with eigenfaces that are obtained from a training set of facial images without glasses, it is evident that the simple PCA reconstruction method has some limitations when it comes to generating a natural looking facial image without glasses. For example, the region of the eyes has some traces of glasses frame after reconstruction, as shown in Figs. 3b and 3c.

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 [2], [11].

Suppose that a sufficiently large amount of facial images is available for offline training, then we can represent any input face by a linear combination of a number of prototype faces [11]. 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 a facial image without glasses by applying the estimated coefficients to the corresponding prototype faces without glasses, as shown in Fig. 4. In the method, we can estimate optimal coefficients for a linear combination of prototypes with glasses by solving the least square minimization problem [11].

Fig. 5 shows examples of glasses removal results from the same facial images as in Fig. 3 by applying example-based learning. Even without the postprocessing of replacing input faces of reconstructed lower area, we can generate a natural looking facial image without glasses.

3 Recursive Error Compensation Procedure

We present a new glasses removal method based on a recursive application of PCA reconstruction and error compensation in order to generate a facial image without glasses from one with glasses.

Only one step of reconstruction and compensation is successful for the case of images having small effects of glasses, but, if the large area of images is affected by glasses, the reconstructed images by PCA still have some traces of glasses. In order to compensate for these regions, we developed the recursive process of reconstruction and error compensation.

3.1 Proposed Recursive PCA Reconstruction

The proposed glasses removal method is composed of an offline process which generates eigenfaces from a set of training facial images without glasses and an online 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. The offline process is similar to the training of simple PCA method.

Here, we describe in detail the online procedure depicted in Fig. 6.

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,

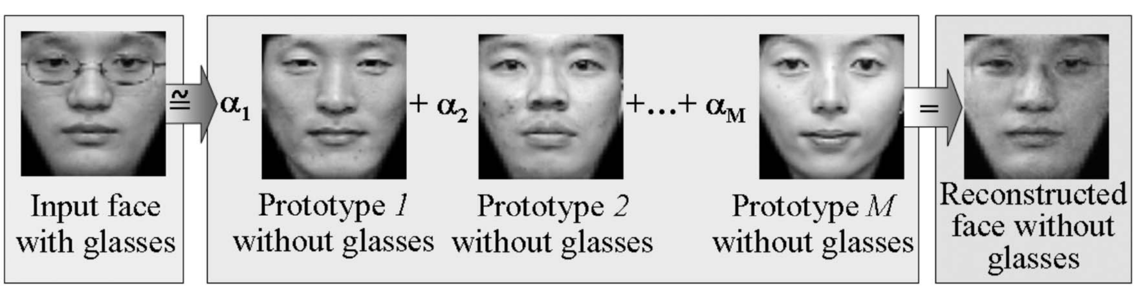

Fig. 2. Basic idea of glasses removal using PCA reconstruction.

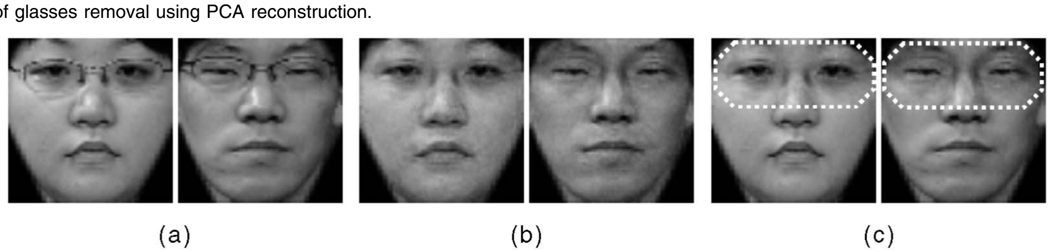

Fig. 3. Results of simple PCA reconstruction: (a) input faces with glasses, (b) reconstructed faces without glasses by PCA reconstruction, and (c) glasses removed faces by combining lower part of (a) and upper part of (b).

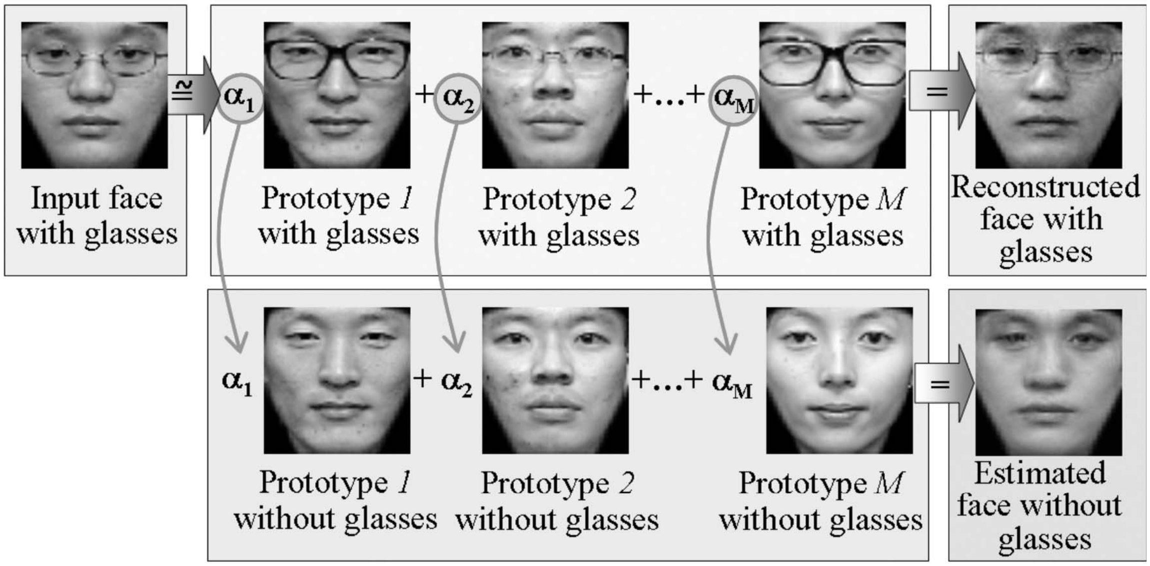

Fig. 4. Basic idea of glasses removal using example-based learning.

(a) (b) (c)

Fig. 5. Results of example-based reconstruction: (a) input faces with glasses, (b) reconstructed faces with glasses, and (c) estimated faces without glasses by applying second estimation of example-based learning.

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

where ω_k is the weight of the kth 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 (2), as shown in Fig. 6b.

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

where, $N \times N$ is the size of the input face. Then, we perform difference stretching using the intensity of the reconstructed facial image in order to clearly represent the glasses occlusion region, as shown in Fig. 6c. That is, by using (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 gray-scale facial images.

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

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. 6d. 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 has been found, this region can be compensated for by using the reconstructed face (or mean face), as shown in Fig. 6e. In the first iteration of the recursive processing, the mean face (φ) is used for the compensation of the occlusion region of input face. From the second iteration, the previously reconstructed face (Γ_t^R) is used. That is,

$$\begin{aligned} \Gamma_t^C &= \omega \cdot \varphi + (1-\omega) \cdot \Gamma, \qquad && \mathit{if}\ (t = 1) \\ \Gamma_t^C &= \omega \cdot \Gamma_t^R + (1-\omega) \cdot \Gamma, && \mathit{if}\ (t > 1), \end{aligned} \tag{4}$$

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.

$$\begin{aligned} &\omega(i) = 1, && \mathit{if}\ (D(i) \geq T_H) \\ &\omega(i) = 1 - 0.5\,\tfrac{T_H - D(i)}{T_H - T_L}, \qquad && \mathit{if}\ (T_L \leq D(i) < T_H) \\ &\omega(i) = 0, && \mathit{if}\ (D(i) < T_L), \end{aligned} \tag{5}$$

where T_L and T_H are the lower threshold for the nonocclusion 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 T_H is determined by the mean value of $D(j)$ for nonskin region.

In (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, therefore, 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 nonoccluded by the glasses and 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.

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

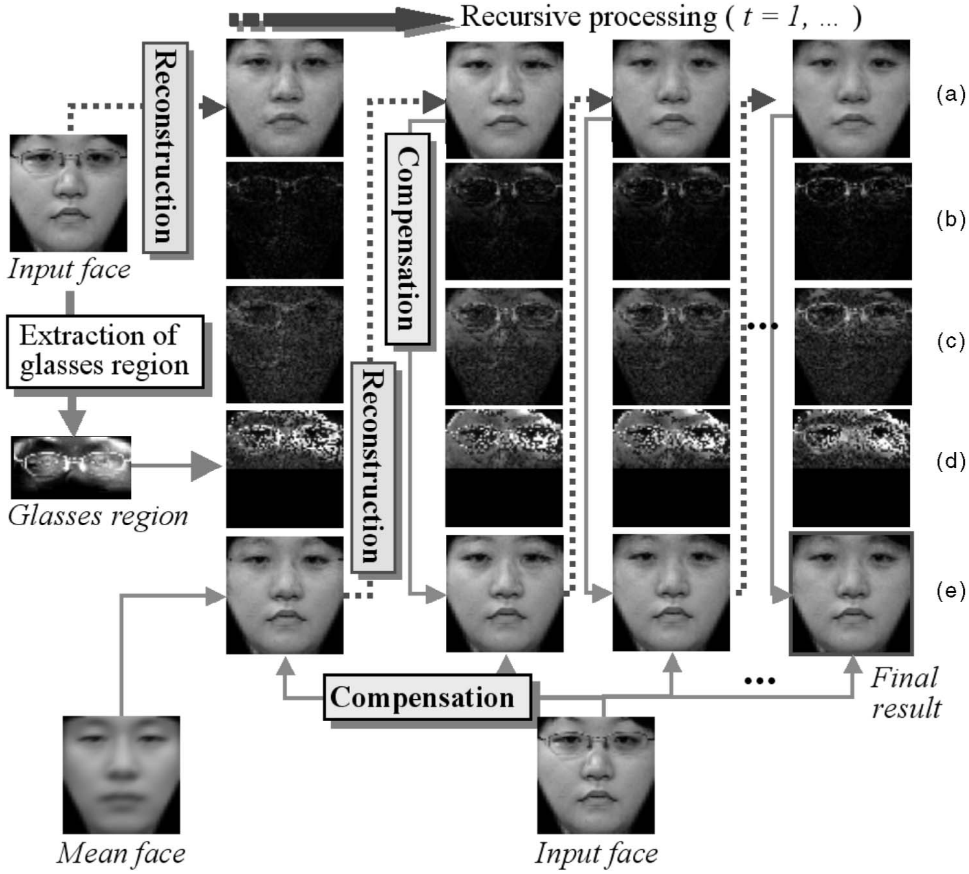

Fig. 6. Glasses removing procedure of the proposed recursive error compensation. (a) Reconstructed face, (b) difference of input and (a), (c) difference stretching, (d) enhanced difference, and (e) compensated face.

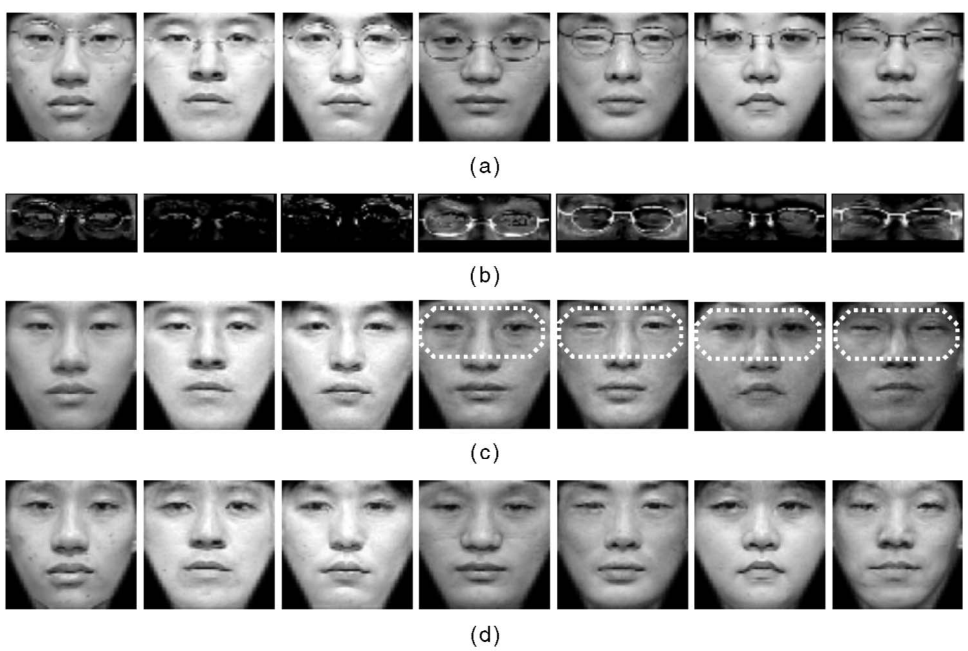

Fig. 7. Advantages of the recursive error compensation. (a) Input faces with glasses, (b) detected regions of glasses, (c) reconstructed faces by PCA, and (d) recursively compensated faces.

As a result of recursive PCA reconstruction and compensation, a natural looking facial image without glasses is generated in the last iteration of the proposed method, as shown in Fig. 6e.

3.2 Advantages of the Proposed Recursive PCA Reconstruction

Fig. 7 shows the effects of the compensation process on the last iteration of recursive process. The compensated facial images are

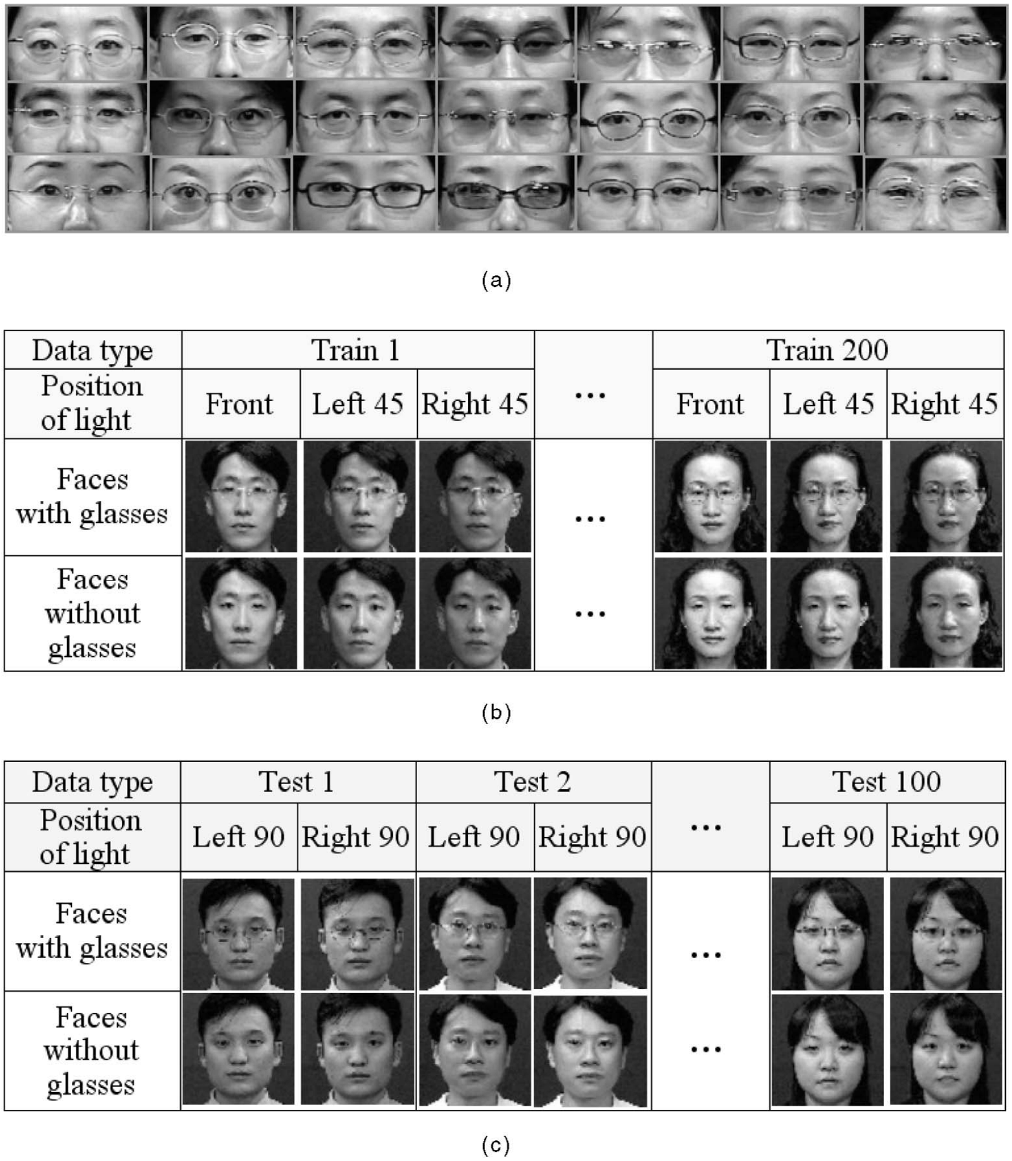

Fig. 8. Examples of various kinds of experimental data. (a) Examples of various kinds of glasses having different shapes, colors, frames, and reflections. (b) Examples of training facial images having different light directions. (c) Examples of test facial images having different light directions.

more natural looking in that they retain the unique personal features such as skin spots and wrinkles.

4 Experimental Results and Analysis

4.1 Experimental Data

We have carried out experiments using a large number of frontal facial images selected from the KFDB (Korean Face Database) [12]. We select the images of 300 people wearing their own glasses from those of 1,000 people. Numerous kinds of glasses are included in the database, as shown in Fig. 8a. In the database, we can obtain pairs of images for the same person captured under the same illumination conditions.

The 1,200 frontal facial images which have three illumination directional changes (i.e., front direction, left/right 45 degree direction) of 200 people used as a training set and the 400 images which have two illumination directional changes (i.e., left/right 90 degree direction) of the remaining 100 people are used as a test set, as shown in Fig. 8b.

4.2 Experimental Results and Discussion

In the experiment, we compared the proposed method with previous PCA reconstruction method [6] and an example-based method, as shown in Fig. 9. In this figure, each number on a facial image indicates the average pixel-wise distance to the corresponding original facial image without glasses. The numbers in the final columns represent the mean values of pixel-wise distances of a total 100 test images.

The glasses-removed faces using the previous PCA reconstruction method in Fig. 9b, still have some traces of glasses in many cases, also those with the example-based method are unnatural links of upper and lower of faces in Fig. 9c. On the other hand, the results of the recursive compensation method have no traces of glasses and look seamless and natural, as shown in Fig. 9d.

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 fourth and fifth columns in Fig. 9.

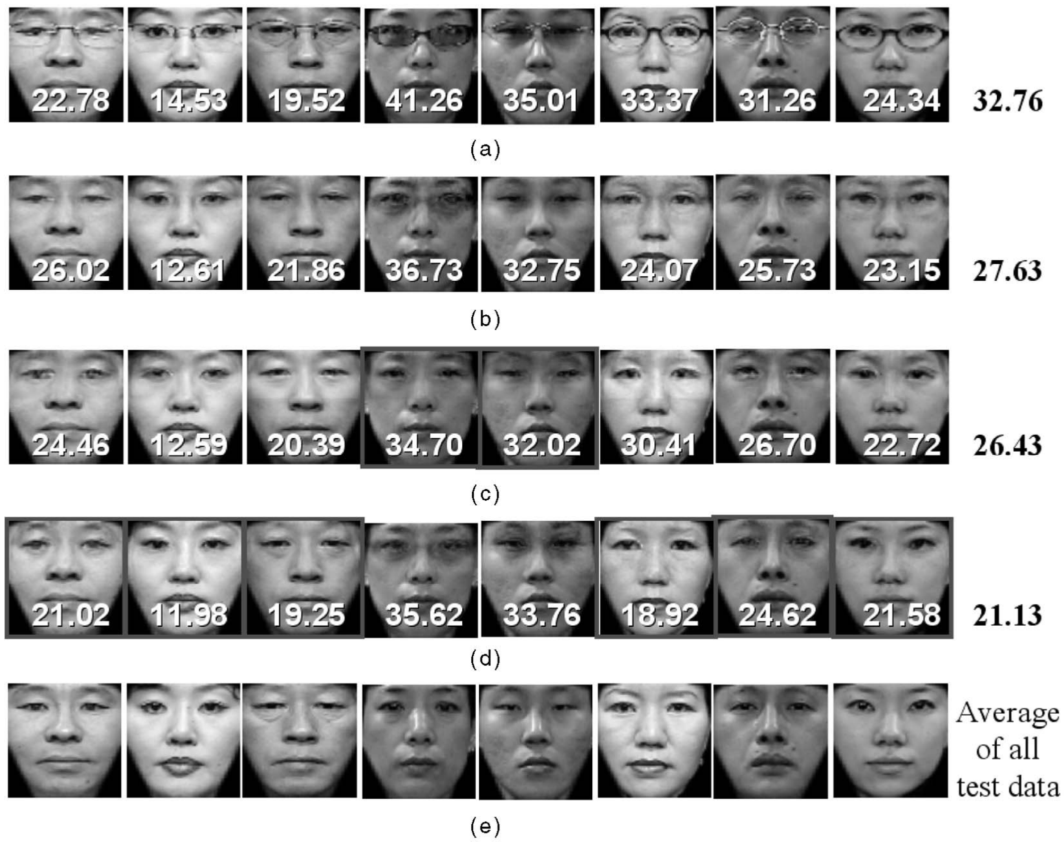

Fig. 9. Examples of glasses removal: (a) input faces wearing glasses, (b) glasses-removed faces by simple PCA reconstruction [6], (c) glasses-removed faces by the example-based method, (d) glasses-removed faces by the proposed recursive PCA, and (e) original faces without glasses.

In order to verify the convergence property, we measured four distances by increasing the iteration counts. In the comparison, the distance between two images is calculated as follows:

$$Distance(A, B) = \sum_{i=1}^{N \times N} |A(i) - B(i)|. \quad (7)$$

We measured the following four kinds of distances while the iteration count is increased.

- Distance 1 = Distance (original image without glasses, reconstructed one without glasses)
- Distance 2 = Distance (original image without glasses, compensated one without glasses)
- Distance 3 = Distance (input image with glasses, reconstructed one without glasses)
- Distance 4 = Distance (input image with glasses, compensated one without glasses)

In Fig. 10, decreased distances at the second iteration are due to the first compensation process of using average face. From this graph, we can verify the convergence of our recursive method.

In order to verify the effect of the glasses removal, we carried out simple face recognition experiments using 200 test images. The 100 original facial images without glasses were registered, and the original faces with glasses and glasses-removed faces are used as novel images for the template matching algorithm. The matching criterion used is a simple nearest classification rule by using the distance measure of (7).

Table 1 shows the accumulated correct recognition rates of face recognition experiments. As we can see, the recognition performance is improved by using glasses removal methods. In particular, the proposed glasses removal method achieves better results than others.

5 Concluding Remarks and Further Research

In this paper, we proposed a new glasses removal method based on recursive error compensation using PCA reconstruction. First, a glasses region is automatically extracted using color and shape information and then a natural looking facial image without glasses is generated by means of recursive error compensation using PCA reconstruction.

Since the proposed method can extract and remove various types of occlusions caused by glasses and generate a more natural looking facial image without glasses compared to other methods, in cases where the occluded regions include not only the frame of the glasses but also the reflection made by the lens and shade

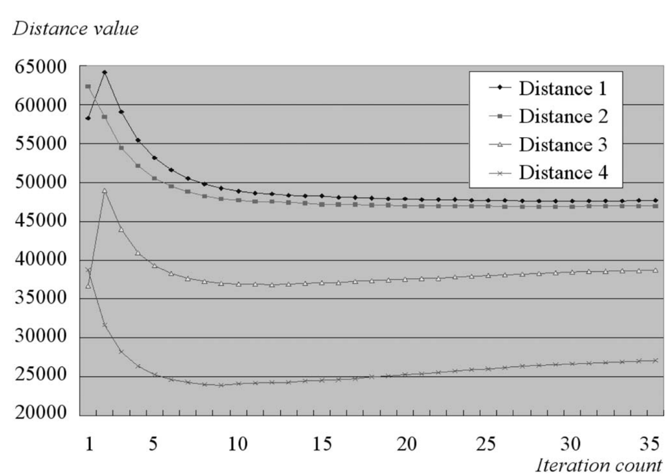

Fig. 10. Comparison of distances as the iteration count is increased.

TABLE 1
Accumulated Correct Recognition Rates (%)

Candidates	Input faces with glasses	Previous PCA method[6]	Proposed example-based method	Proposed recursive method	Original faces without glasses
1	55	55	57	65	72
2	75	77	78	87	90
3	100	100	100	100	100

caused by the glasses. All regions, except for the areas occluded by the glasses, can be compensated for by using the input face so that the output face after glasses removal is made to be similar to the input face without losing the inherent features. Moreover, by applying this technique to face recognition systems, it is anticipated that their performance can be enhanced.

Further research on the performance evaluation using more general facial databases such as the Yale DB or ORL DB is needed in order to verify the removal accuracy of the proposed glasses removal method.

ACKNOWLEDGMENTS

This research was supported by the Intelligent Robotics Development Program, one of the 21st Century Frontier R&D Programs funded by the Ministry of Science and Technology of Korea. A preliminary version of this paper has been presented at the International Conference on Audio- and Video-Based Biometric Person Authentication, Guildford, U.K., June 2003.

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