Can image quality enhancement methods improve the performance of biometric systems for degraded face images?

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***Abstract*—The accuracy of face recognition systems is significantly affected by the quality of face sample images. Using degraded face sample images can significantly decrease the performance of face recognition systems. There are not many face quality enhancement methods in the research field. Therefore, it is interesting to investigate whether existing image quality enhancement methods can improve the performance of biometric systems for degraded face images. In this paper, we conduct an experiment to apply nine image enhancement methods to a face database, which contains high quality and degraded face sample images. The experimental results show that some of selected enhancement methods can improve face recognition system performance.**

***Index Terms*—image quality enhancement, biometric system performance, face recognition, degraded face images**

I. Introduction

Face becomes one of the most commonly and successful modalities for biometric recognition in the past decade [1]. The study in face recognition is motivated by the need for reliable, efficient, and security recognition methods in order to perform better identification and forensic investigations. However, face recognition is still a challenging issue when degraded face images are acquired [1]. In recent years, low-cost devices have enabled face recognition systems, and smartphone based face recognition systems received significant attention, such facts make it difficult to ensure the quality of face images. It has been proved that face sample quality has significant impact on accuracy of biometric recognition [2]. Low sample quality is a main reason for matching errors in biometric systems and may be the main weakness of some applications. Biometric image quality enhancement approaches are used for improving image quality and they may help to improve system performance [3]. The number of available biometric face image enhancement approaches is limited. Therefore, it is interesting to investigate whether existing image enhancement methods which are designed for natural images can enhance biometric face images. The structure of the paper is described as follows. We first present related works. Then the experimental setup, followed by the experimental results and their analysis are given. At last, the conclusion and future work are presented.

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II. Related works

There are several face image quality enhancement methods available in the research field. Dadi *et al.* [4] proposed a pre-processing method to enhance face images. Three steps are used in considering the facial images with dark or bad lighting, low contrast. The pre-processing steps are contrast stretching, homomorphic filtering, and image format conversion. Amani *et al.* [5] proposed a face image enhancement approach, which is based on contrast enhancement using high-frequency emphasize filtering and histogram equalization. Wang *et al.* [6] developed a method by using Logarithm transformation and normalization in face images captured under various lighting conditions for face image enhancement. Du *et al.* [7] proposed a region-based face image enhancement method which enhances both the contrast and the edges for each region separately. Rana *et al.* [8] proposed to use histogram equalization, linear least squares, and unsharp masking techniques to enhance face images. In addition to the enhancement methods developed for face images, there are many existing enhancement approaches for natural images. Agaian *et al.* [9] used log reduction zonal magnitude technique and logarithmic transform histogram shifting to enhance image quality. Hu [10] applied content classification and adaptive processing for image enhancement. Rao *et al.* [11] proposed to use histogram modification framework and a content adaptive algorithm for image enhancement. Lee [12] enhanced image by using Discrete Cosine transform (DCT) and Retinex theory. Nguyen *et al.* [13] used video reconstructed from multiple compressed copies of video content techniques to enhance image quality. Gonzalez *et al.* [14] applied global histogram equalization for image enhancement. Dong *et al.* [15] suggested inverting the input low lighting video and dehaze algorithm for enhancement. Wadud *et al.* [16] used adaptive region based method to enhance image. Boudraa *et al.* [17] enhanced image by using 2D Teager-Kaiser energy operator. Hashemi *et al.* [18] applied multi-histogram equalization methods to enhance image. Toderici and Yagnik [19] proposed to apply genetic algorithms in order to enhance image quality. Jafa and Ying [20] used histogram based image enhancement technique. However, the

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number of face enhancement approaches are limited, and these methods were tested on existing face databases, which contain both modality-based and image-based distortions on face images. Yet, techniques that used in previous mentioned methods only concern image-based degradations that may introduce bias in results. Therefore, the objective of this paper is to test existing enhancement methods for natural images on face biometric images containing only image-based distortions.

III. Experimental setup

A. Selected image enhancement methods

In this paper, we select nine different image enhancement methods for the performance evaluation. The reason of selecting these methods are 1) they are commonly used methods for natural image enhancement, and 2) the implementation source codes for these methods are publicly available. A brief description of selected image enhancement methods are listed:

1) CLAHE [26]: an image enhancement method using contrast limited adaptive histograph equalization technique;
2) DCST [27]: Decorrelation stretching enhances the color separation of an image with significant band-to-band correlation;
3) MEDIAN [28]: use 3D median filtering technique to reduce image noise;
4) MSR [29]: a method of color restoration that corrects for color rendition at the cost of a modest dilution in color consistency;
5) MSRCP [30]: an image enhancement method using V channel from HSV color space for multiscale retinex with color restoration;
6) MSRCP [29]: multiscale retinex with color restoration using grayscale images;
7) SSR [31]: a practical implementation of the retinex without particular concern for its validity as a model for human lightness and color perception;
8) UNSHARP [32]: sharpen image using unsharp masking;
9) WIENER [33]: use 2D adaptive noise-removal filtering to enhance image.

B. Face image quality database

We use a multiple modality biometric database named "**GC^2 Multi-Modality Biometric Database** [21], [22]". This database has three biometric modalities: face, contactless fingerprint, and visible wavelength iris. Three cameras are used for the acquisition: 1) a Lytro first generation Light Field Camera (LFC) (11 Megapixels), 2) a Google Nexus 5 embedded camera (8 Megapixels), and 3) a Canon D700 with Canon EF 100mm f/2.8L Macro Lens (18 Megapixels). There are 50 subjects in the database. For the face modality, 2,150 original face images are obtained in the database. In addition, we introduced image-based different distortions to these original face images: low and high contrast, low and high luminance, motion and Gaussian blur, Poisson noise, and JPEG compression artifacts. Each distortion has been applied using five degradation levels. Therefore, totally 15 samples per subject $\times$ (1 raw + 8 distortions) $\times$ 5 levels $\times$ 50 subjects $\times$ 3 cameras = 101,250 face images in the database. We only use the face modality in this paper. The acquisition is conducted in a normal office with normal luminance. The background is white and no modality-based distortions are in the database.

C. Face recognition system

The open source face recognition system used in this paper is 'The PhD (Pretty helpful Development functions for) face recognition toolbox' [23], which is a collection of Matlab functions and scripts for face recognition. This toolbox was produced as a byproduct of Štruc and Pavešić's [24] research work and is freely available for download. The face feature extraction algorithms is Gabor Filtering (GF) + Kernel Fisher Analysis (KFA). In this feature extraction algorithm, a bank of complex Gabor filters defined in the spatial and frequency domains will be constructed first. Then, the algorithm computes the magnitude responses of a face image filtered with a filter bank of complex Gabor filters. The magnitude responses of the filtering operations are normalized after downscaling using zero-mean and unit variance normalization [24]. After that they are converted as the feature vector. Before we use the feature vector to perform face recognition, a KFA [25] is applied to it. The KFA method first performs nonlinear mapping from the input space to a high-dimensional feature space, and then implements the multi-class Fisher discriminant analysis in the feature space. The significance of the nonlinear mapping is that it increases the discriminating power of the KFA method, which is linear in the feature space but nonlinear in the input space. The analyzed feature vector will be finally used for face recognition.

D. Approaches for the evaluation of face recognition system performance

To evaluate the performance of face recognition systems, many measures exist. Among all of them we can consider the histograms of comparison scores. They are obtained from the genuine (comparison between samples from the same subject) and imposter (comparison between samples from different subjects) comparisons for all image samples. In general, high quality biometric samples could generate relatively 'good' genuine comparison scores (in our case, a score closer to 1 the more similar the two face samples), which are well separated from imposter comparison scores.

An image enhancement method is useful if it can at least give an ordered indication of an eventual performance. Rank-ordered Detection Error Trade-off (DET) characteristics curve is one of the most commonly used and widely understood method used to evaluate the performance of quality enhancement approaches. The DET curve used here plots False None Match Rate (FNMR) versus False Match Rate (FMR).

The Equal Error Rate (EER) (when FMR and FNMR are equal) is another method we use to evaluate the performance face recognition systems. It would decrease when the system performance is improved by using the enhanced face images.

TABLE I
MEAN OF COMPARISON SCORES AND THEIR DIFFERENCES. RED COLOR REPRESENTS SUCH VALUE IS BETTER THAN THE ORIGINAL.

	Mean Genuine	Mean Imposter	Mean Difference
Original	0.8801	0.0467	0.8342
CLAHE	0.9679	0.0302	0.9377
DCST	0.9129	0.0449	0.8680
MEDIAN	0.8768	0.0473	0.8295
MSR	0.8711	0.0505	0.8206
MSRCP	0.8439	0.0567	0.7872
MSRCR	0.5472	0.0871	0.4601
SSR	0.8712	0.0505	0.8207
UNSHARP	0.9157	0.0415	0.8742
WIENER	0.8478	0.0513	0.7966

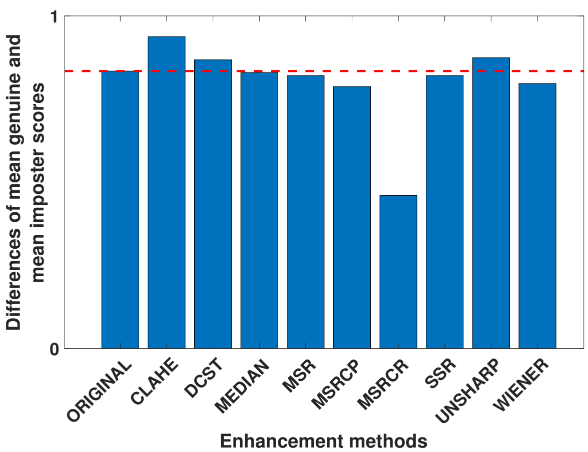


Fig. 1. Differences of mean genuine and imposter scores. The red line is a reference line of the original difference.

IV. EXPERIMENTAL RESULTS

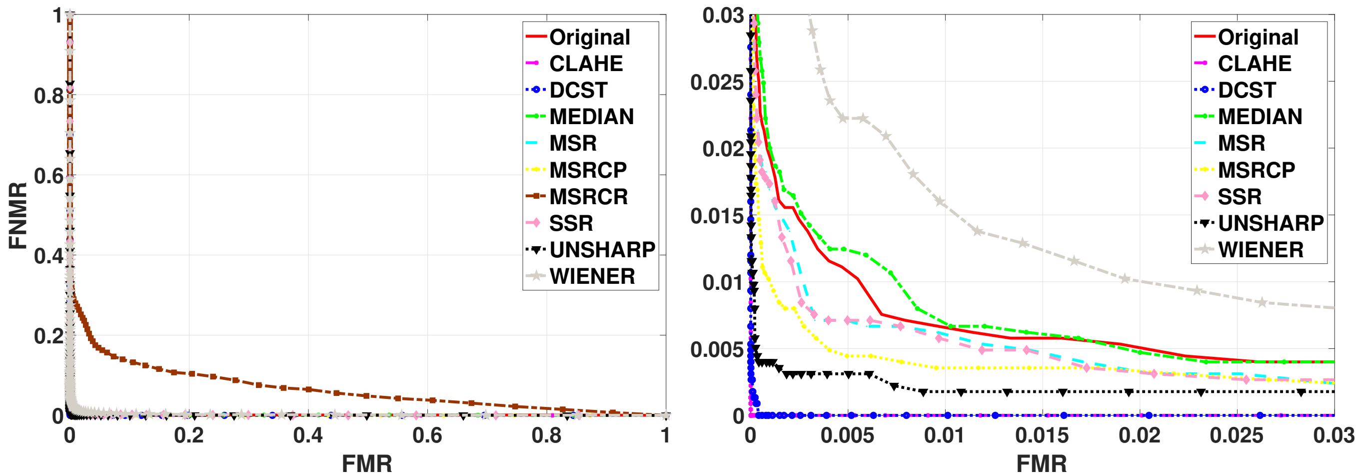
We only present the results for LFC as an example here because the results for smartphone and reflex camera are similar to that of the LFC. In order to evaluate the performance of the selected enhancement methods, we first calculate the mean values of genuine and imposter comparison scores for each method as well as the difference between them in Table I and Fig. 1. As we mentioned before, high quality biometric samples could generate relatively 'good' genuine comparison scores (in our case, a score closer to 1 the more similar the two face samples), which are well separated from imposter comparison scores. In other words, the higher the genuine scores, the lower the imposter scores, and the bigger the difference between genuine and imposter scores, the better image quality. Thus, we mark all mean of genuine scores that higher than the original, mean of imposter scores that lower than the original, and the difference of mean scores that greater than the original as red color in Table I. We also plot the differences of mean genuine and imposter scores in Fig. 1 to have a better overview of the difference of mean values.

TABLE II
EER VALUES FOR ORIGINAL AND ENHANCED DEGRADED FACE IMAGES. RED COLOR REPRESENTS SUCH VALUE IS BETTER THAN THE ORIGINAL.

	EER
Original	0.0071
CLAHE	0.0001
DCST	0.0002
MEDIAN	0.0083
MSR	0.0063
MSRCP	0.0047
MSRCR	0.1250
SSR	0.0066
UNSHARP	0.0031
WIENER	0.0134

The red line is a reference line of the original difference. As we can see from Table I and Fig. 1, CLAHE, DCST, and UNSHARP image enhancement methods can improve system performance.

As mentioned before, we also obtain DET curve and EER as another two indicators to examine the performance of enhancement methods. The DET curves are shown in Fig. 2 (a). However, the DET curve of MSRCR is far away from the other curves. In order to provide a better view, we plot the zoom in DET curves for the rest methods and the original curve in Fig. 2 (b). The EER values are given in Table II as well. For each sub-plot in Fig. 2, the red line represents the original DET curve; the magenta line represents the DET curve by using CLAHE method to enhance face images; the blue line represents the DET curve when we use DCST to enhance face samples; the green line represents the DET curve when using MEDIAN method on face samples; the light blue line represents the DET curve by using MSR method to enhance face image; the yellow line represents the DET curve when we use MSRCP approach; the brown line represent the DET curve when using MSRCR enhancement method; the pink line represents the DET curve from SSR approach; the black line represent the DET curve by using UNSHARP enhance face image; and the gray line represents the DET curve when we use WIENER method for face enhancement. If a DET curve is closer to the bottom-left point, it means that this set of data lead to a higher face recognition performance. Meanwhile, the lower EER value the better system performance. From Fig. 2 we can see that, DET curves are closer to the bottom-left point compared to the original curve when we use CLAHE, DCST, UNSHARP, MSRCP, MSR, and SSR methods, however, DET curves moved to top-right point by using MEDIAN, WIENER, and MSRCR methods. The observation here is the same as the EER values in Table II. If we look at the EER values in Table II we can find the values have a significant decreasing when



(a) DET overview

(b) DET zoom in

Fig. 2. DET curves for original and enhanced degraded face images: (a) overview, (b) zoom in view.

using CLAHE and DCST to enhance face images. It means that CLAHE and DCST have the best performance compared to the others.

V. Conclusions and future works

In this paper, we evaluate the performance of image enhancement approaches on face biometric images. From all the experimental results we can conclude that, by using CLAHE and DCST methods to enhance face sample images, the system performance can be improved. The face recognition performance can also be improved when we use MSR, MSRCP, SSR, and UNSHARP approaches. But the improvement is not as much as CLAHE and DCST. However, by using MEDIAN, MSRCR, and WIENER to enhance face images, the system performance decreased, especially for MSRCR method. Therefore, it is possible to improve the face recognition system performance by using existing natural image enhancement methods. The future works could be using more image enhancement methods, and test them on different face databases.

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