Matching Digital and Scanned Face Images with Age Variation

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***Abstract*— Existing face recognition systems have demonstrated success in constrained settings with limited variability in illumination, pose, and expression. However, these incremental improvements are not sufficient to transcend the challenging applications such as identifying missing persons or matching individuals with photo ID. These applications require recognition of face images with aging variations and matching digital to scanned photo images. This paper presents a preprocessing framework to enhance the quality of the input scanned and digital face images and minimize the aging differences. Three face recognition algorithms are used to evaluate the efficacy of the proposed framework. Experimental results computed on a digital and scanned database of 310 subjects show that the framework improves the accuracy of all three algorithms by minimizing the quality differences and the variations due to aging.**

I. Introduction

Law enforcement agencies such as Crime and Record Bureau, Homeland Security, and Federal Bureau of Investigation regularly require matching a digital probe image with a scanned image (i.e. image scanned from photograph). Generally images are matched manually since automatic matching is very challenging in such applications and there is high probability of getting false rejects. There are several factors that lead to such errors: there may be only one reference document photograph available, photographs may not conform to standard sizes, image resolution may vary, individual's features may change over time, and the quality of scanned images may be lower compared to the high resolution digital face images. Further, device issues such as printing and scanning of the document photographs may introduce irregularities and noise, which sometimes can distort the facial features. Unlike traditional face recognition, here we have to contend with two important covariates in face recognition: *image quality* and *facial aging*. Fig. 1 shows an example of the scanned and digital images of an individual, with variations in image quality and age. As shown in this example, differences between scanned and digital images may often lead to misclassification.

Automatic matching of digital to scanned face photographs is an important research problem but has received little attention in the literature [1], [2]. Starovoitov *et al.* [1] proposed an algorithm for video to photo matching using eye localization, preprocessing, and edge map matching.

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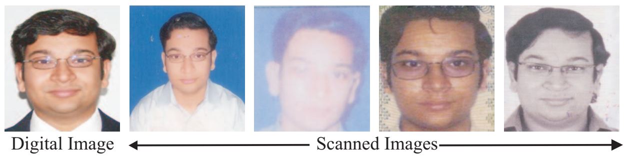

Fig. 1. Digital and scanned face images with image quality and aging variations. First image is high quality digital image at age 29 years, second image is a scanned photo from driver license card at age 20, third image is a scanned photo from passport at age 21 years, fourth image is a visa photograph at age 23 and fifth image is a visa photograph at age 28.

Recently, Bourlai *et al.* [2] proposed a preprocessing algorithm to address the challenges due to *image quality*. The algorithm starts with photometric and geometric normalization followed by denoising and classification. Though both the algorithms attempt to minimize the quality difference between the gallery and probe images, they do not handle aging variations which is also an important aspect of the problem. For example, if we try to match a high quality probe image of an individual at 29 years (as shown in Fig. 1) and the scanned gallery image of the same person at 21 years age, the algorithms may not yield correct results.

In this paper, a preprocessing framework for face recognition is proposed that can be applied in forensic and law enforcement applications. As illustrated in Fig. 2, the proposed framework is divided into the following three steps:

1) In the first step, the irregularities due to illumination variations present in the scanned gallery (database) and digital probe (query) images are removed. The proposed quality enhancement algorithm uses discrete wavelet transform (DWT) for synergistically enhancing the local regions and removing the irregularities present.
2) In the second step, differences between the quality of enhanced scanned face image and enhanced digital face image are minimized. Even after enhancement, the quality of scanned image is lower because of the scanning effect. Since the quality of the scanned image cannot be improved beyond a certain extent, Eigentransformation algorithm is applied to degrade the quality of the digital image. This process transforms the digital image so that both the scanned and digital images are in the same quality domain.
3) The third step minimizes the age difference between two face images by using the registration based age transformation algorithm. Unlike the conventional method, gallery face image is registered with respect to the probe image. The registration algorithm uses

mutual information to minimize the entropy difference between two face images. The algorithm also minimizes minor variations due to pose and expression.

Once the gallery and probe face images are preprocessed, existing approaches for feature extraction and matching are applied. The proposed framework is evaluated on a frontal face database that contains scanned and digital images pertaining to 310 subjects. The next section presents the proposed algorithm for preprocessing the digital and scanned face images. Section III describes the existing face recognition algorithms and database protocol used for evaluation. Experimental results and analysis are summarized in Section III-C.

II. Preprocessing Digital and Scanned Face Image

The proposed preprocessing algorithm normalizes the digital and scanned face images. Face is detected from the input image using Adaboost based face detection algorithm [3]. The detected face image is then preprocessed using the quality enhancement, eigen-transformation, and age transformation algorithms.

A. Image Quality Enhancement using DWT Fusion

To improve the quality of both scanned and digital face images, we propose an image quality enhancement algorithm using DWT. In the proposed quality enhancement algorithm, red channel (from RGB color mode) and luma channel (i.e. Y channel from YCbCr color mode) are processed by applying multiscale retinex enhancement [4], wavelet denoising [5] and Wiener filtering [6]. In the watermarking literature, it is well established that red and luma channels are less sensitive to the visible (as well as perceptually invisible) watermarks. Since most of the document photographs have some form of watermarks, we, therefore select these two channels for enhancement. The output of these global enhancement algorithms are then fused using DWT. The proposed DWT algorithm identifies the good quality regions from each of the globally enhanced images and synergistically combines these enhanced quality regions to form a single composite image. This composite image contains feature-rich enhanced regions that are useful in face recognition. Details of the algorithm are as follows:

- Let f be the color face image to be enhanced. Let f^r and f^y be the red and luma channels respectively. These two channels are processed using multi-scale Retinex (MSR) algorithm [4], [7]. MSR is a modified form of the single scale retinex (SSR) that provides good dynamic range compression, color independence from the spectral distribution of the scene illumination, and color and lightness rendition. MSR is applied on both red and luma channels to obtain f^{rm} and f^{ym}.
- Next step in the proposed quality enhancement algorithm is denoising of f^{rm} and f^{ym}. In this research, wavelet based adaptive soft thresholding scheme [5] is used for image denoising. The algorithm starts with computing generalized Gaussian distribution based soft threshold which is then used in wavelet based denoising. After denoising f^{rm} and f^{ym}, we obtain $f^{rm'}$ and $f^{ym'}$ respectively.
- After noise removal, genuine information that are useful in face recognition are blurred and therefore, it is important to apply a filter to deblur those edges. Experiments show that Wiener filter can restore the genuine facial edges. Applying Wiener filter on $f^{rm'}$ and $f^{ym'}$ produces f^1 and f^2.
- After computing the globally enhanced red and luma channels, DWT fusion algorithm is applied on f^1 and f^2 to compute a feature rich enhanced face image, F. Single level DWT is applied on f^1 and f^2 to obtain the detail and approximation wavelet bands for these images. Let f^j_{LL}, f^j_{LH}, f^j_{HL}, and f^j_{HH} be the four bands from face images and $j = 1, 2$. To preserve the features of both the channels, coefficients from the approximation band of f^1 and f^2 are averaged.

$$f^e_{LL} = mean(f^1_{LL}, f^2_{LL}) \quad (1)$$

where f^e_{LL} is the approximation band of the enhanced image. All the three detailed subbands are divided into windows of size 3×3 and the sum of absolute pixels in each window is calculated. For the i^{th} window in the HL subband of the two images, we select the window with the maximum absolute value and use it for f^e_{HL}. Similarly, we obtain f^e_{LH} and f^e_{HH}. Finally, inverse DWT is applied on the four fused subbands to generate a high quality face image.

$$F = IDWT(f^e_{LL}, f^e_{LH}, f^e_{HL}, f^e_{HH}) \quad (2)$$

This DWT fusion algorithm is applied on both scanned and digital face images. Fig. 3 shows examples of the enhanced face images.

B. Digital Image to Scanned Image Transformation

It was observed that, even after enhancement, the difference between a digital and scanned image of the same person is greater than the digital images of two different persons. To overcome this difference, we propose a transformation algorithm that transforms the digital face image into a scanned like face image. An eigen space is generated using the scanned face image and the digital face image is projected into this Eigen space for transformation [8]. The algorithm is described as follows:

1) Let $\mathbf{F}_D = \left[\overrightarrow{F}_{D_1}, \overrightarrow{F}_{D_2}, ..., \overrightarrow{F}_{D_n}\right]$ be the enhanced digital training images and $\mathbf{F}_S = \left[\overrightarrow{F}_{S_1}, \overrightarrow{F}_{S_2}, ..., \overrightarrow{F}_{S_n},\right]$ be the enhanced scanned photo images, where n is the number of training images.
2) Average digital face image $\overrightarrow{a_D}$ and average photo face image $\overrightarrow{a_S}$ are computed for the digital and the photo training set respectively.
3) Eigenvector matrix E_D is computed from the digital training set.

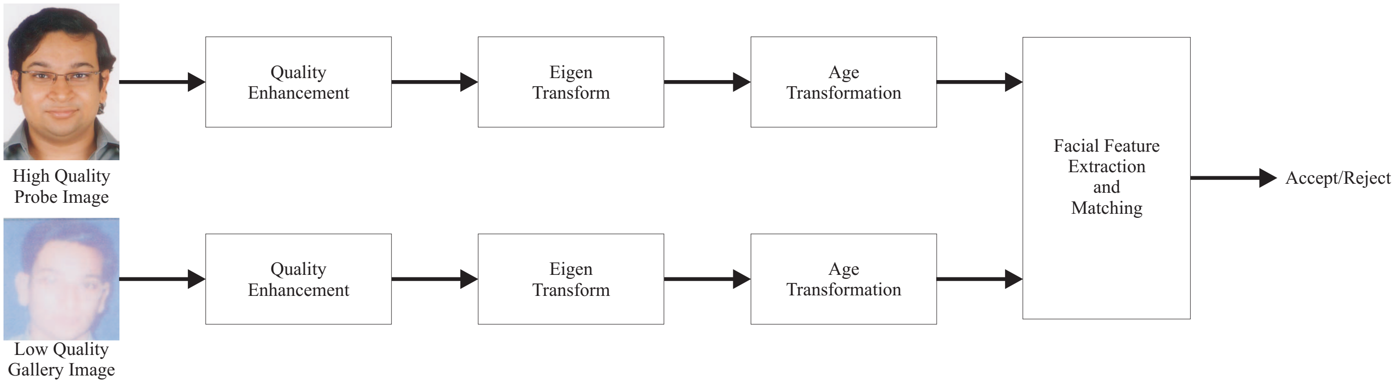

Fig. 2. Block diagram illustrating the steps involved in the proposed preprocessing framework.

4) For transforming the probe image, average digital face $\overrightarrow{a_D}$ is subtracted from the input digital face image $\overrightarrow{F}_{D_t}$,

$$\overrightarrow{F}_{D_{t'}} = \overrightarrow{F}_{D_t} - \overrightarrow{a}_D. \tag{3}$$

5) $\overrightarrow{F}_{D_{t'}}$ is projected in the Eigen space of $\overrightarrow{E}_D$ to compute the weight vector $\overrightarrow{w}_D$.
6) Digital face image is then reconstructed using the following equation,

$$\overrightarrow{F}^R_D = F_S V_D D_D^{-\frac{1}{2}} \times \overrightarrow{w}_D \tag{4}$$

where V_D represents the eigenvector matrix of digital face image training set and D_D represents the diagonal eigen value matrix.
7) Average photo face $\overrightarrow{a}_S$ is added to the reconstructed digital face image to obtain the transformed face image $\overrightarrow{F}^T_D$,

$$\overrightarrow{F}^T_D = \overrightarrow{F}^R_D + \overrightarrow{a}_S. \tag{5}$$

The proposed eigen-transformation algorithm therefore transforms input digital face image $F^{t'}_D$ to scanned face like image F^t_D. As shown in Fig. 2, the quality of the reconstructed transformed digital face image is close to the scanned face image.

C. Age Transformation using Mutual Information Registration

Once the face images are preprocessed and quality of the images is normalized, we minimize the age difference between gallery and probe face images. One way to address the challenge of facial aging is to regularly update the database with recent images or templates. However, this method is not feasible for applications such as border control and homeland security, missing persons and criminal investigations. To address this challenge, researchers have proposed several age simulation and modeling techniques. These techniques model the facial growth that occurs over a period of time to minimize the difference between probe and gallery images.

Unlike the conventional modeling approach, we proposed mutual information registration based age transformation algorithm to minimize the age difference between gallery and probe images. Mutual information is a concept from information theory in which statistical dependence is measured between two random variables [9], [10]. Researchers in medical imaging have used mutual information based registration algorithms to effectively fuse images from different modalities such as CT and MRI [9], [10]. We have used this algorithm because there may be variations in the quality of preprocessed scanned and digital face images, and the registration algorithm should contend with these variations. Age difference minimization using registration of gallery and probe face images is described as follows:
Let F_G and F_P be the detected and quality enhanced gallery and probe face images to be matched. Mutual information between two face images can be represented as,

$$M(F_G, F_P) = H(F_G) + H(F_P) - H(F_G, F_P) \tag{6}$$

where, $H(\cdot)$ is the entropy of the image and $H(F_G, F_P)$ is the joint entropy. Registering F_G with respect to F_P requires maximization of mutual information between F_G and F_P, thus maximizing the entropy $H(F_G)$ and $H(F_P)$, and minimizing the joint entropy $H(F_G, F_P)$. Mutual information based registration algorithms are sensitive to changes that occur in the distributions as a result of difference in overlap regions. To address this issue, Hill *et al.* [9] proposed normalized mutual information that can be represented as,

$$NM(F_G, F_P) = \frac{H(F_G) + H(F_P)}{H(F_G, F_P)}. \tag{7}$$

The registration is performed on the transformation space, T, such that

$$T = \begin{bmatrix} a & b & 0 \\ c & d & 0 \\ e & f & 1 \end{bmatrix} \tag{8}$$

where, a, b, c, d are shear, scale, and rotation parameters, and e, f are the translation parameters. Using the normalized mutual information and exploring the search space, T, we define a search strategy to find the transformation parameters, T^*.

$$T^* = arg\ max\ \{NM(F_P,\ T(F_G))\} \tag{9}$$

Fig. 3. Examples of enhanced scanned and digital face images obtained using the proposed DWT fusion algorithm.

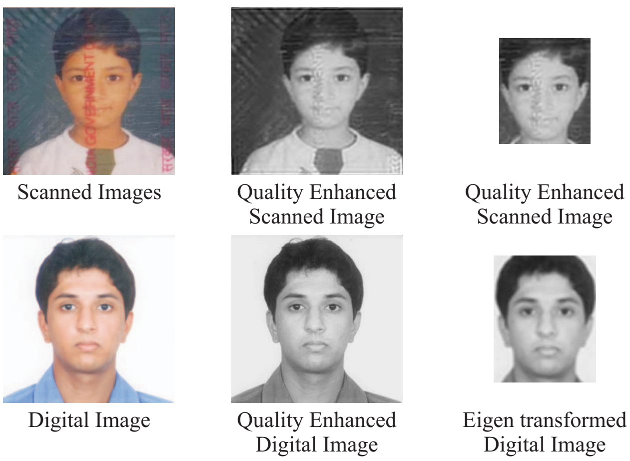

Fig. 4. Scanned face image and transformed digital face image

Fig. 5. Results of the age transformation algorithm.

Gallery and probe face images (F_G and F_P) are thus registered using the transformation parameters T^*. This registration algorithm is linear in nature. To accommodate non-linear variations in faces, multiresolution image pyramid scheme is applied which starts with building the Gaussian pyramid of both the gallery and probe images. Registration parameters are estimated at the coarsest level and used to warp the face image in the next level of the pyramid. The process is iteratively repeated through each level of the pyramid and a final transformed gallery face image is obtained at the finest pyramid level. In this manner, the global variations at the coarsest resolution level and local non-linear variations at the finest resolution level are addressed. Fig. 5 shows examples of the gallery face image, probe face image, and the age difference minimized gallery face image. Once the age difference between the gallery and probe face image is minimized, face recognition algorithm can be efficiently applied to verify the identity of the probe image.

III. Performance Evaluation

Performance of the proposed face recognition framework is evaluated on a scanned-digital face database. In this section, we first briefly describe the characteristics of the database and algorithms used for evaluation followed by the results.

A. *Characteristics of Database*

The proposed preprocessing algorithm is evaluated on a frontal face database of 310 individuals containing 1550 scanned and digital images that are collected by the authors. For each individual, there is one scanned and four digital face images. The scanned and digital images are captured with variations in facial expression, illumination, and camera properties. The age difference among the scanned and digital face images varies between 0.5 to 6 years. One scanned and two digital face images are used to train the Eigen-transformation and face recognition algorithms. Furthermore, for the gallery-probe matching, one scanned face image is used as gallery and the remaining two digital images are used

TABLE I

DETAILS OF THE FACE DATABASE USED FOR VALIDATION

Age group	Number of class	Average age difference in years
1-15 years	37	4.2
15-30 years	201	5.9
30-45 years	48	5.1
Beyond 45 years	24	4.6

as probe (digital images used for training are not used for probe). The face database is divided into four age groups: (1) 1-15 years, (2) 15-30 years, (3) 30-45 years, and (4) beyond 45 years. This division criteria is inspired by the observation that facial development depends on the age. For example, development in muscles and bone structure cause significant changes in the face during the age of 1-15 years. From 15-30 years, the growth rate is comparatively lower, whereas after 45 years, wrinkles and skin loosening may be the major changes that occur in facial features and appearance. It is thus very difficult to accurately model an individual's face for large age variations such as from age 10 to 60. Considering these factors, we divided the database into four age groups. Details of the images in these four age groups are provided in Table I.

B. Face Recognition Algorithms used for Evaluation

To evaluate the performance of the proposed preprocessing framework, the following three existing face recognition algorithms are used.

- Principal Component Analysis (PCA) [11]
- Local Binary Patterns (LBP) [12]
- Modified C2 features with SVM classification [13].

C. Experimental Results

For all the experiments, performance is computed in terms of verification accuracy at 0.1% False Accept Rate (FAR). To evaluate the performance of the proposed preprocessing algorithm, it is first applied on the gallery and probe images. Face recognition algorithms are then used to match the preprocessed gallery and probe face images. Experiments are performed with and without the preprocessing algorithm and verification accuracies are computed. Table II summarizes the verification performance for the four age groups. The key results and analysis are summarized below:

- The proposed preprocessing algorithm improves the face verification performance in the 7-10%. Since the proposed algorithms enhance the quality of face images and minimize the variations by registering gallery and probe images both locally and globally, the performance of face recognition is greatly enhanced.
- The performance improvement due to the individual steps of the preprocessing framework are also computed. For PCA, quality enhancement improves the accuracy by 3%, Eigen transform by 15%, and age transformation by 4%. Similarly, for LBP and C2 features, quality enhancement improves the accuracy by 3-3.5%, Eigen transform by 1-1.5% and age transformation by 3-5%. This experiment shows that each step in the framework is contributing towards improving the verification accuracy.

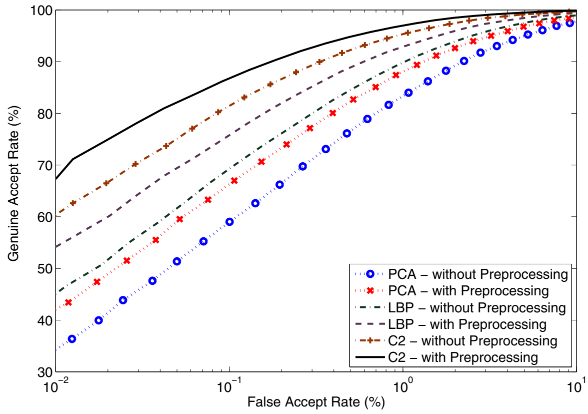

Fig. 6. ROC plot showing the performance of the proposed framework for different age groups

- The performance of the framework is evaluated for different age groups. For the age group of 1-15 years (with 37 subjects), all three face recognition algorithms yield verification accuracy in the range of 20-58%. After preprocessing, the accuracies improved by 5-7%. Similarly, other age groups also showed improvement when preprocessed images were used for matching. Higher accuracies were obtained for the age group of 30-45 years and beyond 45 years. This result is also intuitive because facial features change significantly during the 1-15 years age group compared to other age groups. For example, if the age difference between the gallery and probe image is two years, the rate of growth during 1-15 years is higher than 15-30 years or 30-45 years. Therefore, we can assert that due to feature stabilization, other age groups provide better verification performance.
- On a Duo Core Intel PC with 4GB RAM and Matlab programming environment, quality enhancement requires an average of 0.7 seconds whereas Eigen transform requires 0.2 seconds and age transformation requires 2 seconds. Therefore the computational cost is not very high.

IV. CONCLUSION

Generally, face recognition systems and algorithms are designed to recognize faces of cooperative individuals in controlled environment and a high level of performance has been achieved. However, it becomes a challenging problem when there is an age variation between the faces to be matched. Further, many law enforcement applications deal with scanned to digital face recognition. There is very limited research thrust addressing these critical issues that have important practical applications. This paper attempts to fill the gap and proposes a preprocessing framework to handle

TABLE II

VERIFICATION PERFORMANCE OF THE THREE FACE VERIFICATION ALGORITHMS WITH AND WITHOUT THE PROPOSED PREPROCESSING ALGORITHM. VERIFICATION PERFORMANCE IS EVALUATED AT 0.01% FALSE ACCEPT RATE.

Face Recognition Algorithm	Age group	Without preprocessing	With preprocessing
PCA	1-15 years	20.73	25.00
	15-30 years	38.19	45.01
	30-45 years	39.03	45.80
	Beyond 45 years	39.27	45.52
LBP	1-15 years	40.32	47.61
	15-30 years	45.11	54.87
	30-45 years	45.69	56.13
	Beyond 45 years	45.31	56.08
Modified C2	1-15 years	57.91	65.47
	15-30 years	60.16	67.80
	30-45 years	60.34	68.16
	Beyond 45 years	60.58	68.23

these challenges. A preprocessing algorithm is proposed which includes quality enhancement and age transformation. The quality enhancement algorithm first improves the quality of both scanned and digital images using DWT fusion and then minimizes the quality difference using the Eigen transformation technique. Further, a mutual information based age transformation algorithm is proposed to minimize the aging differences between the gallery and probe images. The performance of the framework is evaluated using three face recognition algorithms. Experimental results show significant improvement in verification performance when the preprocessing algorithms are applied. The results also suggest that the algorithm yields better performance for 15-30 years age group, 30-45 years age group, and beyond 45 years age group. However, further research is required to improve the recognition performance for 1-15 years age group. Also, additional research is required for addressing the issue of facial aging along with major variations in pose, expression, illumination, and disguise.

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