Multi-Scale Gabor Feature Based Eye Localization

Sanghoon Kim, Sun-Tae Chung, Souhwan Jung, Dusik Oh, Jaemin Kim, and Seongwon Cho

***Abstract*—**Eye localization is necessary for face recognition and related application areas. Most of eye localization algorithms reported so far still need to be improved about precision and computational time for successful applications. In this paper, we propose an eye location method based on multi-scale Gabor feature vectors, which is more robust with respect to initial points. The eye localization based on Gabor feature vectors first needs to constructs an Eye Model Bunch for each eye (left or right eye) which consists of n Gabor jets and average eye coordinates of each eyes obtained from n model face images, and then tries to localize eyes in an incoming face image by utilizing the fact that the true eye coordinates is most likely to be very close to the position where the Gabor jet will have the best Gabor jet similarity matching with a Gabor jet in the Eye Model Bunch. Similar ideas have been already proposed in such as EBGM (Elastic Bunch Graph Matching). However, the method used in EBGM is known to be not robust with respect to initial values and may need extensive search range for achieving the required performance, but extensive search ranges will cause much more computational burden. In this paper, we propose a multi-scale approach with a little increased computational burden where one first tries to localize eyes based on Gabor feature vectors in a coarse face image obtained from down sampling of the original face image, and then localize eyes based on Gabor feature vectors in the original resolution face image by using the eye coordinates localized in the coarse scaled image as initial points. Several experiments and comparisons with other eye localization methods reported in the other papers show the efficiency of our proposed method.

***Keywords*—**Eye Localization, Gabor features, Multi-scale, Gabor wavelets.

I. INTRODUCTION

EYE localization is necessary for face recognition and related application areas. In face recognition systems, size normalization of incoming face images is necessary. Since eyes are one of the most prominent facial feature points which can be successfully used for face size normalization, eye localization is very important process before normalization [1]. It is well known that precision of eye localization affects face recognition success rate [2]. A lot of research efforts have been done on eye localization [3,4,5,6,7,8]. Kawaguchi et al. [3] proposed an algorithm to detect the irises of eyes using separability filter and Hough transform. Jesorsky et al. [4] used a model-based, coarse-to-fine approach adopting Hausdorff distance. In coarse phase, AOI (Area Of Interest) is segmented, binarized, and localized by searching the best match between model and the binarized edge image according to the Hausdorff distance. Then, in refinement phase, the found positions are refined by applying MLP (Multi-layer Perception) trained with pupil centered images. Zhou and Geng [5] devised generalized projection function to detect eye. Ma et al. [6] proposed an eye location algorithm based on probabilistic framework, and Campadelli et al. [7] presented an eye localization algorithm using two support vector machines trained on properly selected Haar wavelet coefficient. Niu et al. [8] presented an eye localization algorithm using a 2D cascaded Adaboost classifier.

The facial feature point localization method based on Gabor feature vectors are used to extract eye coordinates and other facial feature points of the face in a face recognition algorithm such as EBGM (Elastic Bunch Graph Matching) [9]. Gabor feature vectors are well known to be relatively robust with respect to distortion, rotation, scaling and illumination [10]. In the eye localization algorithm based on Gabor feature vectors, eye coordinates are localized by utilizing correlation between Gabor feature vectors of trained models and Gabor feature vectors around initial points in incoming images. In EBGM, initial values for eye coordinates are set by an average of eye coordinates in n model images. Performance of feature point localization method based on Gabor feature vectors are greatly affected by initial points and search ranges [9].

If one extends the search range in order to enhance the precision rate of eye localization, that will cause highly increased computational burden.

In this paper, we propose an improved eye localization method based on Multi-scale Gabor feature vectors, which produces more precise localization without widened search range but does not incur much computational burden.

The rest of the paper is organized as follows. Section 2 introduces eye localization method based on Gabor feature vectors, and Section 3 presents our proposed algorithm. Experiments are given in Section 4, and finally Conclusion comes in Section 5.

II. EYE LOCALIZATION BASED ON GABOR FEATURE VECTORS

A. Gabor Wavelet, Gabor Jet, and Gabor Similarity

The Gabor feature vectors at eye coordinates used in this paper are the ones obtained by convolving Gabor wavelet

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kernels with the intensity of the pixel at eye coordinates of face images.

The Gabor wavelet kernels used in this paper are as follows.

$$W(x,y,\theta,\lambda,\sigma) = e^{-\frac{1}{2\sigma^2}(\vec{x}\bullet\vec{x})} e^{i\vec{k}\bullet\vec{x}} \tag{1}$$

where wave vector $\vec{k}$ is given as $\vec{k} = \left(\frac{2\pi\cos\theta}{\lambda}, \frac{2\pi\sin\theta}{\lambda}\right)^t$, and θ represents wavelet direction, λ represents wave length , σ in (1) represents the size of Gaussian, and is proportional to λ. In this paper, we consider 40 Gabor wavelet kernels obtained by $\theta \in \{0,\frac{\pi}{8},\frac{2\pi}{8},\frac{3\pi}{8},\frac{4\pi}{8},\frac{5\pi}{8},\frac{6\pi}{8},\frac{7\pi}{8}\}$, $\lambda \in \{4,4\sqrt{2},8,8\sqrt{2},16\}$ and $\sigma = \lambda$ in (1).

Let us denote the Gabor wavelet coefficient (Gabor feature vector) obtained by convolving j-th one among the above 40 Gabor wavelet kernels with $I(x,y)$ (intensity of image at (x,y)) as $J_j(x,y)$. Then, Gabor jet $J(x,y)$ at a pixel point (x,y) of an image is defined to be the set $J = \{J_i; j = 1,...,40\}$.

Each Gabor wavelet coefficient J_j can be represented as $J_j = a_j e^{i\phi_j}$ (magnitude a_j, phase ϕ_j).

Suppose $J_j^0 = a_j^0 e^{i\phi_j^0}$ is the j-th Gabor wavelet coefficient at (x_0, y_0), and the Gabor jet at (x_0, y_0) as $J^0(x_0, y_0) = \{J_j^0; j = 1,...,40\}$. Then, Gabor jet similarity $S_\phi(J, J^0)$ between J and J^0 is defined [9] as

$$S_\phi(J, J^0) \equiv \frac{\sum_{j=1}^{40} a_j a_j^0 \cos(\phi_j - \phi_j^0)}{\sqrt{\sum_{j=1}^{40} a_j^2 \sum_{j=1}^{40} (a_j^0)^2}} \tag{2}$$

B. Eye Model Bunch

For n model face images, one detects face, render the detected face upright (if necessary) and normalize the size of faces. For those n normalized model face images, one can locate the eye coordinates manually and calculate Gabor jet at each manually located eye position. Then, we call {n Gabor jets, 'average eye coordinates'} for each eye (left eye or right eye) as Eye Model Bunch of each eye. This 'Eye Model Bunch' is similar to 'Model Bunch Graph' in EBGM [9] where 'Model Bunch Graph' is defined as the collection of n Gabor jets at facial feature points, n coordinates of feature points, and average coordinates of each facial feature points in n model face images.

The model images should be randomly selected to reflect well various poses, expressions (including closed eyes and glassed eyes, and etc.), and illuminations so as for eye localization to work well on testing.

C. Eye Localization Based on Gabor Jet Similarity

Eye localization based on Gabor jet similarity is processed as follows. For a normalized new incoming face image, one first calculates Gabor jets at all positions around left and right eye's initial estimated eye coordinates. The initial estimated coordinates of left and right eyes are usually set by the average eye coordinates in Eye Model Bunch of each eye. Next, one try to find one of positions around initial eye coordinates of each eye where Gabor jet has the maximal Gabor jet similarity with a Gabor jet in Eye Model Bunch of each eye. Then the position is decided as the eye coordinates. In order to enhance the precision rate of this eye localization method, one may need to calculate Gabor jets at a larger neighborhood around each eye's initial coordinates. Calculating Gabor jets at all positions around the initial estimated eye coordinates takes lots of computation time and thus localization of eye coordinates by finding the maximal Gabor jet similarity between Gabor jets in Eye Model Bunch and all Gabor jets around the initial points is not appropriate for real-time processing . Thus, [9] proposed a faster computation method as follows.

Suppose we know Gabor jet $J^0(x_0, y_0)$ at (x_0, y_0). Then, the Gabor jet similarity between the Gabor jet $J'(x_0 + dx, y_0 + dy)$ at $(x_0 + dx, y_0 + dy)$, which is sufficiently near (x_0, y_0), and Gabor jet J^m can be approximately calculated without direct computation of Gabor jet $J'(x_0 + dx, y_0 + dy)$ at $(x_0 + dx, y_0 + dy)$ as

$$S_\phi(J^m, J') \cong \frac{\sum_{j=1}^{40} a_j^m a_j^0 \cos(\phi_j^m - (\phi_j^0 + \vec{d}\bullet\vec{k}_j))}{\sqrt{\sum_{j=1}^{40} (a_j^m)^2 \sum_{j=1}^{40} (a_j^0)^2}} \tag{3}$$

where $\vec{d} = (dx, dy)^t$, $J_j^m = a_j^m e^{i\phi_j^m}$, $J^m = \{J_j^m; j = 1,...,40\}$

Also, (dx, dy) which maximizes (3), can be approximately calculated as in the below equation (4).

$$\begin{aligned}
&\begin{pmatrix} dx \\ dy \end{pmatrix} \cong \frac{1}{\Gamma_{xx}\Gamma_{yy} - \Gamma_{xy}\Gamma_{xy}} \begin{pmatrix} \Gamma_{yy} & -\Gamma_{yx} \\ \Gamma_{xy} & \Gamma_{xx} \end{pmatrix} \begin{pmatrix} \Phi_x \\ \Phi_y \end{pmatrix} \\
&\Phi_x = \sum_j a_j^m a_j^0 k_{jx}(\phi_j^m - \phi_j^0), \Phi_y = \sum_j a_j^m a_j^0 k_{jy}(\phi_j^m - \phi_j^0) \\
&\Gamma_{xx} = \sum_j a_j^m a_j^0 k_{jx} k_{jx}, \Gamma_{yy} = \sum_j a_j^m a_j^0 k_{jy} k_{jy} \\
&\Gamma_{xy} = \sum_j a_j^m a_j^0 k_{jx} k_{jy}, \Gamma_{yx} = \sum_j a_j^m a_j^0 k_{jy} k_{jx}
\end{aligned} \tag{4}$$

Thus, one can calculate the positional variation (dx^m, dy^m) from the initial estimated eye coordinates (x_0, y_0) which maximizes Gabor jet similarity between the Gabor jets around at (x_0, y_0) and Gabor jet $J^m (m = 1,..., n)$ in Eye Model Bunch. Then one can decide the final eye localization as

$$(\hat{x}, \hat{y}) \cong (x_0, y_0) + (dx^{\hat{m}}, dy^{\hat{m}}) \tag{5}$$

where $(dx^{\hat{m}}, dy^{\hat{m}})$ is the positional variation which maximizes the Gabor jet similarity among the positional variation (dx^{m}, dy^{m}) for all $(m = 1,...,n)$.

Equations (3), (4) and (5) hold well only for small variation, so that the precision of the eye localization based on (3), (4) and (5) decreases as the initial eye coordinates (x_0, y_0) go away from the true eye coordinates.

III. Multi-Scale Gabor Feature Based Eye Localization

A. Outline of our Proposed Method

The multi-scale Gabor feature based eye localization proposed in this paper consists of two stages; Construction of Eye Model Bunch and Localization of eye coordinates. Construction of Eye Model Bunch is done in 3 scales: 256×256, 128×128, and 64×64. First, Eye Model Bunch of each eye is constructed from all normalized model face images of 256×256 size, and second Eye Model Bunch is constructed from the model face images of 128×128 size down sampled from 256×256 model face images. Also third Eye Model Bunch about 64×64 size model face images is constructed in the same way.

Localization of eye coordinates proceeds in 3 steps: 1) face detection, 2) face normalization, 3) multi-scale eye localization.

We use Ada-Boosting algorithm [11] to detect face in a new incoming image. The faces detected by Ada-Boosting methods do not have regular size since the incoming images can be taken in different positions from the camera. Therefore, normalization process where face poses are rendered to be upright and face sizes are regularized is necessary for fair and efficient feature extraction. After we estimate tilt angle of face rotation in an image by using information about valleys and edges [3], we rotate the original image by the reverse tilt angle and render the face image upright. For the upright images, we detect faces and normalize the faces into size 256×256.

B. Multi-Scale Eye Localization

For an upright and 256×256 normalized face image, we first obtain down sampled 128×128 face image and 64×64 face image. Afterwards, we localize eye coordinates in 64×64 face image based on Gabor jet similarity as stated in Section 2.3 by taking the average eye coordinates in 64×64 face image obtained from down sampling from average eye coordinates in 256×256 Eye model bunch as the initial eye coordinates. Next, the localized eye coordinates are up sampled into 128×128 size face image and are used as the initial eye coordinates for Gabor similarity-based eye localization for 128×128. Then we localize eye coordinates in 128×128 face image based on Gabor jet similarity again. Likewise, the eye coordinates localized in 128×128 face image are up sampled into 256×256 size face image and are used again as the initial eye coordinates for Gabor feature based eye localization for the original 256×256 face image. Finally, we localize the eye coordinates in the original 256×256 face image based on Gabor jet similarity.

Fig. 1 Some face images of the IMM face database

IV. Experiments

A. Experiment Environments

In order to see the efficiency of our proposed eye localization method, we have done two experiments. First experiment compares our proposed method with the previous basic Gabor feature based eye localization method. Second experiment compares our proposed method with other eye localization methods reported in the other papers [4,5,6,7,8].

For our experiments, we used 4 face databases: IMM, FERET, BioID and JAFFE.

Fig. 2 Some face images of the FERET face database

The first face database is the IMM face database [12] which consists of 240 images of 40 different human faces with 6 different poses or expression or illumination. Each image is JPEG with 640×480, and some face images of IMM database are shown in Fig. 1.

The second face database is FERET (Face Recognition Technology) [13] which consists of 8525 gray-level images of 884 persons. Each image is gray-level 256×384 pixels. For our experiments, we use only 488 images of 'fa', which are all frontal-view, and some face images of FERET database are shown in Fig. 2.

Fig. 3 Some face images of the BioID face database

The third face database is BioID face database [14] which consists of 1521 gray-level frontal view images with a resolution of 384×286 pixels. The BioID face database features various illuminations, various face sizes, and complex backgrounds. Some images of them are shown in Fig. 3. The BioID face database is believed to more difficult than some commonly used head-and-shoulder face database without complex backgrounds [5].

Fig. 4 Some face images of the JAFFE face database

The fourth face database is JAFFE face database [15] which consists of 213 gray-level frontal view images with resolution of 256×256 pixels. The images in JAFFE have various facial expressions posed by Japanese females. Some images of them are shown in Fig. 4.

The eye localization error metrics for decision of success of eye localization is defined as follows [4].

$$d_{eye} \equiv \frac{\max(\| C_l - \widetilde{C}_l \|, \| C_r - \widetilde{C}_r \|)}{\| C_l - C_r \|} \qquad (6)$$

where C_l and C_r are manually marked left and right eye coordinates, and $\widetilde{C}_l$ and $\widetilde{C}_r$ are localized left and right eye coordinates by localization method. The measure (6) has been already adopted by some research works on feature localization [4,5,6,7,8].

TABLE I
COMPARISONS BETWEEN THE PROPOSED METHOD AND THE BASIC GABOR FEATURE BASED EYE LOCALIZATION

Face Database (success decision criterion)	Success rate for Basic method (%)	Success rate for Proposed One (%)
IMM (d_{eye} <0.07)	84.8	93.8
FERET (d_{eye} <0.07)	81.0	91.8
BioID (d_{eye} <0.07)	74.3	93.8
JAFFE (d_{eye} <0.07)	92.4	100

TABLE II
COMPARISONS BETWEEN THE PROPOSED METHOD AND THE OTHER METHODS REPORTED IN THE PAPERS [5,6,7,8]

Methods (success decision criterion)	Success rate for BioID (%)	Success rate for JAFFE (%)
[4] (d_{eye} <0.25)	91.8	-
[5] (d_{eye} <0.25)	94.8	97.2
[6] (d_{eye} <0.1)	-	98.6
[7] (d_{eye} <0.25)	96.1	-
[8] (d_{eye} <0.1)	93.0	100
Proposed One (d_{eye} <0.25)	98.8	100
Proposed One (d_{eye} <0.1)	96.4	100
Proposed One (d_{eye} <0.07)	93.8	100

B. Experiment Results

Selection of appropriate model images is important in Gabor feature based eye localization. We randomly select 24 model images as for model image set of the first face database, 48 images for the second database, 70 images for the third face database, and 20 images for the fourth database. And we experiment 10 times for the remaining images excluding the model images for each face database; that is, 216 images for the first IMM database, 440 images for the second FERET database, 1451 images for the third BioID face database, and 193 images in the fourth JAFFE face database. Then, we calculate the average for each database. Table 1 shows the first experiment results which compares between our proposed method and the previous basic Gabor feature based eye localization method.

One can see that the proposed multi-scale Gabor feature based eye localization method performs much better than the conventional basic Gabor feature based eye localization method.

Table II shows the second experiment results which compares between our proposed method with the other eye localization methods reported in other papers [4,5,6,7,8]. The success rates of the other methods are ones reported from the papers. In the second experiments, the reason why we compare only for two face databases, BioID and JAFFE are only available face database for us among face databases which are used in the other papers [4,5,6,7].

One can see that our proposed multi-scale Gabor feature based eye localization method works well in comparisons with other eye location methods in the case of BioID face database and JAFFE face database.

V. Conclusion

In this paper, we proposed a multi-scale Gabor feature based eye localization method, and the efficiency of the proposed method is verified through experiments compared with other methods reported in the previous papers. In the future, we will test our proposed method for real-time eye localization as well as for the various face databases, and investigate how to construct an efficient Eye Model Bunch.

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