Performance Evaluation of Geometric-Based Hybrid Approach for Facial Feature Localization

Sourav Dey Roy, Priya Saha, Mrinal Kanti Bhowmik and Debanjana Debnath

Abstract Nowadays, facial recognition technology (FRT) has come into focus because of its various applications in security and non-security perspective. It provides a secure solution for identification and verification of person identity. Accurate localization of facial features plays a significant role for many facial analysis applications including biometrics and emotion recognition. There are several factors that make facial feature localization a challenging problem. Facial expression is one of the influential factors of FRT. The paper proposes a new geometric-based hybrid technique for automatic localization of facial features in frontal and near-frontal neutral and expressive face images. A graphical user interface (GUI) is designed that could automatically localize 16 landmark points around eyes, nose, and mouth that are mostly affected by the changes in facial muscles. The proposed system has been tested on widely used JAFFE and Bosphorous database. Also, the system is tested on DeitY-TU face database. The performance of the proposed method has been done in terms of error measures and accuracy. The detection rate of the proposed method is 96.03 % on JAFFE database, 94.06 % on DeitY-TU database, and 94.21 % on Bosphorous database.

Keywords Biometrics · Face recognition technology (FRT) · Facial feature localization · Image processing

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1 Introduction

Facial feature localization is defined as the detection and localization of certain characteristic points that play a distinctive role on the face graph. Accurate localization of facial features plays a significant role in many face image analyses such as face recognition, facial expression understanding, animation, face tracking, etc. [1]. Among the successful applications of image analyses, face recognition technology (FRT) has been largely investigated for the past two decades. In the perspective of law and non-law enforcement, FRT is more convenient than other techniques like passwords, fingerprints, and others because of its individuality and noncontactness. The face recognition can be broadly classified into two different categories: holistic and feature-based approach [2]. The holistic-based approach of face recognition uses the whole image and considers the global patterns of the face. Whereas in feature-based approach of face recognition, the system works on some extracted features of the face instead of the whole face. Automatic localization of facial features is a difficult task, which faces all the difficulties of face recognition, such as occlusion, illumination, expression, pose, and camera resolution [3]. Some important landmark points that are mostly affected by the activity of muscles in human faces are eye corners, eyebrow corners, and mouth points. These landmark points are significant to identify the face that may provide applications for surveillance in criminal identification and also for finding missing peoples in public places.

The paper proposes a newly framed hybrid approach for facial feature localization. The proposed work is a combination of methods, which decreases the computational burden and also advances the accuracy by making the method flexible to changes in expression. Also graphical user interface (GUI)-based software is designed that could automatically localize 16 landmark points on the face. The strength of the system is assessed by testing on JAFFE database, DeitY-TU database, and Bosphorous database. This paper also explores a rigorous literature survey and comparison of our method with various techniques proposed by various researchers.

The whole paper is organized as; Sect. 2 describes the literature survey on facial landmark detection. Section 3 gives a brief description of the database used for the experiment. Section 4 explains the proposed methodology of automatic facial feature localization. In Sect. 5, a performance evaluation measure has been illustrated. Section 6 reports the experimental results with discussion of the proposed methodology. Section 7 describes the comparison of the proposed methodology with other techniques developed by various researchers. Section 8 gives an overview of graphical user interface (GUI) design of the proposed landmark methodology. And finally, Sect. 9 concludes the paper.

2 Related Work

Many approaches to facial analysis rely on robust and automatic facial landmarking to correctly function. But the localization of facial landmark is still an open and difficult problem. In the recent years, the research communities have sparked off thunder in their research for automatic localization of facial features that immensely varies with the changes in facial expressions. Table I shows some recent landmarking approaches in the literature. In [4], Li et al. proposed a multitask sparse representation-based fine-grained matching algorithm, which accounts for the average reconstruction error of probe face descriptors sparsely represented by a large dictionary of gallery descriptors in identification. In [5], Dibeklioglu et al. proposed a statistical method for automatic localization of facial landmark. The landmarking uses a Gabor wavelet features on the coarse scale is complemented with a structure analysis shape and fine tuning shape. In [6], Huang et al. used 2D Gabor filter to extract the features from a given face image. Next, face mapping is carried out using weighted warping procedure. Finally, proposed an improved ASM method to capture the features and locate the frontal face image in order to efficiently advance the convergence performance and accurately locate feature points. In [7], Valstar et al. developed a graph-based feature point detection system for detection of 22 landmark points. The method used support vector regression of Haar-like features and Markov random fields where the search space is constrained. The algorithm was tested on visual face images of FERET, MMI, and BioID database and obtained 94.75 % accuracy. Liu et al. [8] proposed an adaptive algorithm that uses generic active appearance model (AAM) and subject- specific appearance model together for detecting 72 facial feature points. Zhao et al. [9] used Gabor feature to align 13 control points on the face and further 83 points are generated by constrained profile and flexible shape models. In [10], Sohail et al. proposed a method for detection of 18 landmark points in the face based on Anthropometric Face Model. The method obtained success rate of 90.44 % on JAFFE database. Gizatdinova et al. [11] proposed a method for feature-based landmarking on extracting oriented edges and constructing edge maps at two resolution level. In [12], Vukadinovic et al. proposed a method that uses Gabor feature-based boosted classifiers. In this approach, the detected face is divided into region of interest (ROI). Then based on grayscale texture information and Gabor wavelet features individual GentleBoost templates are used to detect landmarks within the relevant ROI independently.

3 Database Description

In order to develop a system for automatic facial feature localization, a database is required which is full of facial images under various lightning conditions and camera positions. For this experiment, we used frontal images of two most widely used databases, i.e., JAFFE database and Bosphorous database. Also the experiment was conducted on DeitY-TU face database which was created in Biometrics Laboratory of Tripura University. The brief description of these three databases are given below.

3.1 DeitY-TU Face Database

The DeitY-TU face database is a visual face image database [13]. The database was created in Biometrics Laboratory of Computer Science and Engineering Department, Tripura University (A Central University), India. The database contains the face images of different tribal and nontribal people of Seven North Eastern states of India. These face images are taken under strictly control conditions. The database contains total 96,995 images of 524 subjects. The database contains a total of eight expressions; including neutral expression, closed eye, and six basic expressions; four different types of illumination variations and images with glasses; and each of these variations are being clicked concurrently from five different angles to provide pose variations. The face images collected from different states and from different communities illustrate the existence of facial structural differences.

3.2 Japanese Female Facial Expression (JAFFE) Database

The Japanese Female Expression (JAFFE) Database [14] is also a visual face image database. The JAFFE database was designed at the Department of Psychology in Kyushu University. The database was released in the year 1998. The database contains totally 213 images of 10 Japanese females. These face images are also taken under strictly controlled conditions. The resolution of each image is 256 × 256. The database contains six basic facial expressions + 1 neutral of each subject. And all the images are in TIFF (Tagged Image File Format) format and frontal.

3.3 Bosphorous Database

The Bosphorous database [15] consists of 3D faces and corresponding texture images, specially collected for expression analysis purpose. The database was designed by Yale University, United States in the year 2001. The subject variation in this database comprises not only various expressions and poses but also realistic occlusion. The database consists of total 4666 face images of 105 subjects. The size of each image is 1128 × 1368 and all the images are in PNG format.

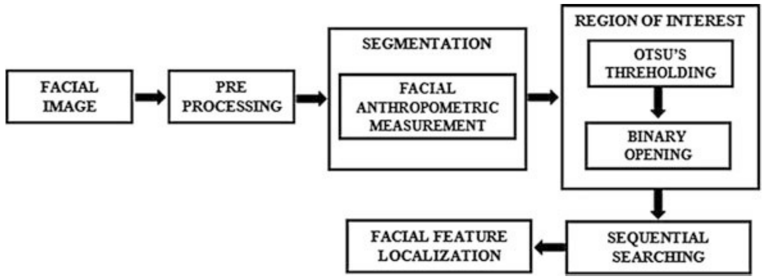

Fig. 1 Block-diagram of proposed facial feature localization method

4 Methodology

The proposed method has been illustrated in Fig. 1 through the block diagram. The theoretical details have been described below in different stages.

4.1 Preprocessing Using Elliptical Mask

The input image is considered as a two-dimensional array, that is, with X × Y size. In the preprocessing stage, the facial images are cropped with an elliptical mask by taking the nose as the centre and cropped to a standard resolution. It is applied over the image to remove all the unnecessary parts of the face image except the central face region. Then the preprocessed image has been taken for segmentation that has been described in the next section.

4.2 Segmentation

Segmentation is the method of partitioning an image into several segments having a significant effect of easier analysis. For region-based segmentation, we have taken two ideas, i.e., ideal facial proportions and the facial anthropometry.

4.2.1 Facial Anthropometric Measurement

Facial anthropometric measurement includes different distance measurements of facial landmarks. It begins with the identification of landmark points on the face. Farkas [16] proposed a system, where a large amount of anthropometric data is available for describing a face using 47 landmark points. The landmarks, which are used here, are as follows: tr for trichion (hairline), n for nasion, sn for subnasale,

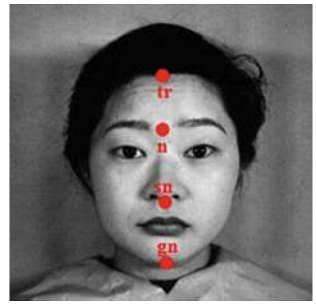

Fig. 2 Anthropometric landmarks

and gn for gnathion (the lowest point on the chin). It has been observed during the distance measurements of these landmarks on face images of JAFFE database, DeitY-TU database, and Bosphorous database, facial measures slightly differ between subjects. Based on the anthropological measurements, the preprocessed image is segmented into horizontal thirds, [17] i.e., the upper third contains only eyebrows; the middle third contains eyes and nose and the lower third contains lips. Figure 2 represents the face image containing four landmark points.

4.2.2 Region of Interest Formation

According to the previous measurement, it is now easier to move forward to detect the region of interest (ROI) for facial feature localization. For ROI formation we have taken two ideas, i.e., Otsu's thresholding and morphological opening. Same strategy has been maintained for three different facial proportions, i.e., the upper third, the middle third, and the lower third. Thresholding is a very important technique for converting a grayscale or color image into binary image based on the threshold criterion T. A threshold using Otsu's method [18] has been chosen on the resultant face images so that only the feature of interest remains.

After binarizing the three regions using Otsu's method, we can see that there are some background pixels in the foreground region of interest. To overcome this problem, binary opening is used to remove small objects from the foreground of the image and placing them in the background. If we deeply see the shape of the eyebrow, eye, and lip, it will be clearly seen that they all contain a disk-shaped structure. A disk-shaped binary mask has been created and using a mask; at first erosion was done and then expanded or dilated the three thirds separately based on anthropometric statistics [4, 19].

4.3 Sequential Searching and Facial Feature Localization

The sequential search considers the first element in the list and then examines each sequential element in the list until a match is found. Forward and reverse iterative sequential search procedures have been applied to the binarized thresholded facial parts.

4.3.1 Localization in Eyebrow Region

To detect the eyebrow region, four landmark points need to be localized, i.e., two inner and two outer eyebrow corners. Localization of eyebrow corners has been done using the reverse sequential search. To detect the inner corner of the left eyebrow, the search starts from the middle of the last row of the upper facial part to the landmark point (i.e., bottom to top). The search proceeds iteratively in the left direction of the facial part and carries on until a black pixel is found. In this way, left inner eyebrow corner is localized. Likewise right inner eyebrow corner is localized using iterative sequential searching in the right direction of the facial part. Then the algorithm proceeded to detect the outer corner of left and right eyebrow. Two search processes have been performed from the first and last of the upper facial part. And finally the four detected landmark points of the eyebrow are localized in the original image. Figure 3a–c shows the inner and outer eyebrow corners points in face image of JAFFE, DeitY-TU and Bosphorous database, respectively.

4.3.2 Localization in Eye Region

To detect the eye region, eight landmark points need to be localized, i.e., two inner eye corners, two outer eye corners, two upper eyelids, and two lower eyelids. Like the eyebrow corner localization, four eye corners have been localized using reverse sequential searching. Then the search proceeded to detect the upper and lower eyelid of left and right eye. The central point of the eye can be located using inner and outer corner of the eye. From the middle of the first and last row of the two eye

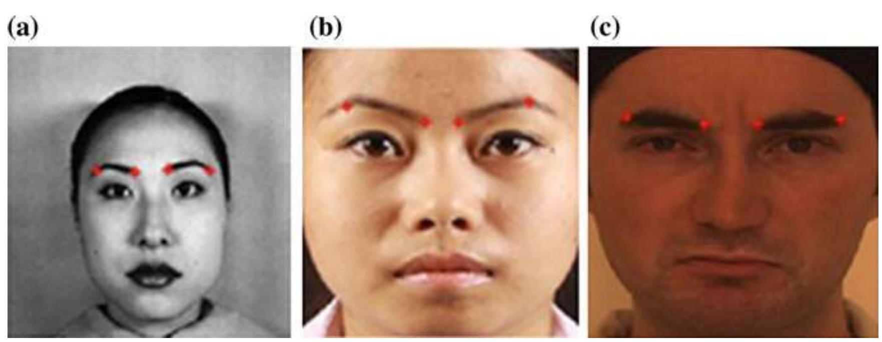

Fig. 3 Eyebrow corners localization **a** JAFFE database, **b** DeitY-TU database, **c** Bosphorous Database

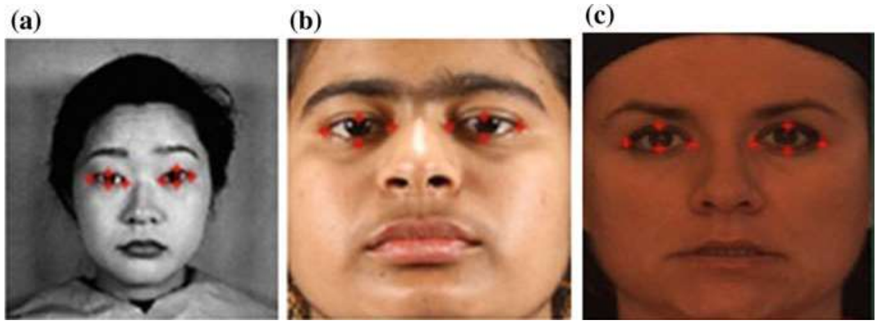

Fig. 4 Eye corners localization **a** JAFFE database, **b** DeitY-TU database, **c** Bosphorous Database

corner, iterative sequential searching (i.e., top to bottom for upper eyelid and bottom to top for lower eyelid) has been performed so that the upper and lower eyelid can be determined. The same process has been performed on both the eyes to detect the four landmark points. Thus eight detected landmark points of the eye are localized in the original image as shown in Fig. 4a–c.

4.3.3 Localization in Mouth Region

To detect the mouth region, we have to localize four facial feature points of the mouth, i.e., two lip corners, upper lip, and lower lip. Using forward and reverse sequential search in the lower facial part, two lip corners can be easily detected. The central point of the lip also can be located using two lip corners. From the middle of the first and last row of the two lip corners, iterative sequential searching has been performed so that the upper and lower lip point can be determined. That is to locate the lower and upper lip middle point, bottom-top and top-bottom search has been applied on lower facial part respectively. And finally the four detected landmark points of lip are localized in the original image. Figure 5a–c localize the mouth points in face image of JAFFE, DeitY-TU, and Bosphorous database, respectively.

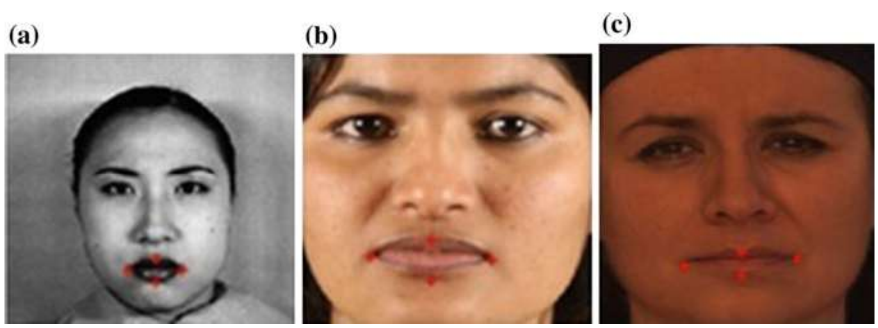

Fig. 5 Lip corners localization **a** JAFFE database, **b** DeitY-TU database, **c** Bosphorous database

5 Performance Evaluation Measures

The performance evaluation of facial feature localization methods proposed in the literature has been given either visual inspection of the detection result or error measure. The localization error can be measured using the distance between manually annotated and automatically detected feature points. The distance is calculated in terms of Euclidean pixel distance. According to Dibeklioglu [5], an error measure is calculated using interocular (d_{io}) distance, which is the distance between the left and right eye centers. A landmark location is correctly detected if the distance to the manually annotated area is less than a percentage of the interocular distance. This threshold was set at 10 % of the interocular distance. The error measure is mathematically represented as

$$\text{Error Measure} = \frac{\|\text{M} - \text{A}\|}{d_{\text{io}}} \tag{1}$$

The average detection rate of each landmark points is computed as

$$\text{Detection Rate} = \frac{\text{TP} \times 100}{\text{TN}} \tag{2}$$

where,

TP Number of images correctly detected
TN Total number of images
M Manually detected landmark points
A Automatically detected landmark points
d_{io} = Interocular distance.

6 Experimental Results and Discussions

In this section, performance analysis of our proposed landmark detection algorithm is made in terms of error measure and accuracy. For measuring the performance of the proposed algorithm, 75 individuals of DeitY-TU face database including both tribe and non tribe with variable image sizes, 100 images of JAFFE database and 300 images of Bosphorous database including male and female are used. The average success rates of the system on DeitY-TU face database, JAFFE database, and Bosphorous database are 94.06, 96.03, and 94.21 % respectively. The localization error and detection rate of the proposed method on these three databases are listed in Table 1.

The proposed methodology has 100 % detection rate of 4 corners of left and right eye. Whereas the average detection rate of all 16 landmark points for JAFFE

Table 1 Localization error and detection rate of the proposed landmark method on various databases

Landmarks	Mean error (% of IOD)			Detection rate (%)		
	JAFFE database (%)	DeitY-TU database (%)	Bosphorous database (%)	JAFFE database (%)	DeitY-TU database (%)	Bosphorous database (%)
Left inner eye corner	3	6	8	100	100	100
Left outer eye corner	2	8	6	100	100	100
Right inner eye corner	2	6	3	100	100	100
Right outer eye corner	3	5	4	100	100	100
Left inner eyebrow	3	7	9	96	95	91.5
Left outer eyebrow	13	15	17	78	75	83.3
Right inner eyebrow	2	7	2	94	92.5	95
Right outer eyebrow	9	11	15	80	80	82.5
Left upper eyelid	2	11	1	100	97.5	95
Left lower eyelid	3	7	2	100	95	100
Right upper eyelid	3	2	3	100	95	95
Right lower eyelid	2	5	6	100	92.5	95
Left lip corner	2	8	5	98	97.5	90
Right lip corner	3	5	2	100	95	95
Upper middle lip	3	2	5	94	95	95
Lower middle lip	1	5	8	96.5	95	90

database is more compared to DeitY-TU face database and Bosphorous database. Also in case of JAFFE database 100 % detection rate for left inner eye corner, left outer eye corner, right inner eye corner, right outer corner, left and right upper, and lower eyelid was achieved which justifies that the proposed work is effective in the three face databases. Experimental results on the face dataset demonstrate that the system works well for all fully frontal face images. The localization error rate for right and left outer eyebrow is more serious than other 14 detected landmark points. This amount of error happens mostly due to the shadow effects around the outer eyebrow corner.

7 Comparative Study

Most researches in facial feature localization have been performed based on error measure. In [20], S. Arca et al. reported the 95.1 % localization accuracy for 22 landmarks on JAFFE database. Sohail et al. [10] and Huang et al. [6] have also made their comparative study based on point error measure. So, by comparing success rate of our proposed method with techniques developed by other researchers as shown in Table 2, we can say that our proposed landmark detection method generates noticeable results on JAFFE face images.

8 Graphical User Interface Design

It is a graphical user interface (GUI)-based prototype system for localization of facial feature from frontal view image. For performing all the required steps a total of 16 interfaces are designed. The first interface contains the database list, i.e., for which database we want to see the landmark points as shown in Fig. 6a. If we click the push button among the three database in the “Database Menu Page” then it will open the second interface, “Load Image.” The second interface is to load the face image and after loading the face image, from the list of popup menu we have to select whether we want to detect the landmark around eye, eyebrow, lip, or whether we want to see all the 16 landmark points at once. After selecting the appropriate

Table 2 Comparison of the proposed methodology with other methods

Author	Number of landmarks	Database	Accuracy (%)
Sohail et al. [10]	16	JAFFE database	93.04
Huang et al. [6]	–	JAFFE database	63.92
Li et al. [4]	20	Bosphorous database	91.14
Dibeklioglu et al. [5]	22	Bosphorous database	97.62
Arca et al. [20]	22	JAFFE database	95.1
Our method	16	JAFFE database	96.03
		DeitY-TU database	93.05
		Bosphorous database	94.21

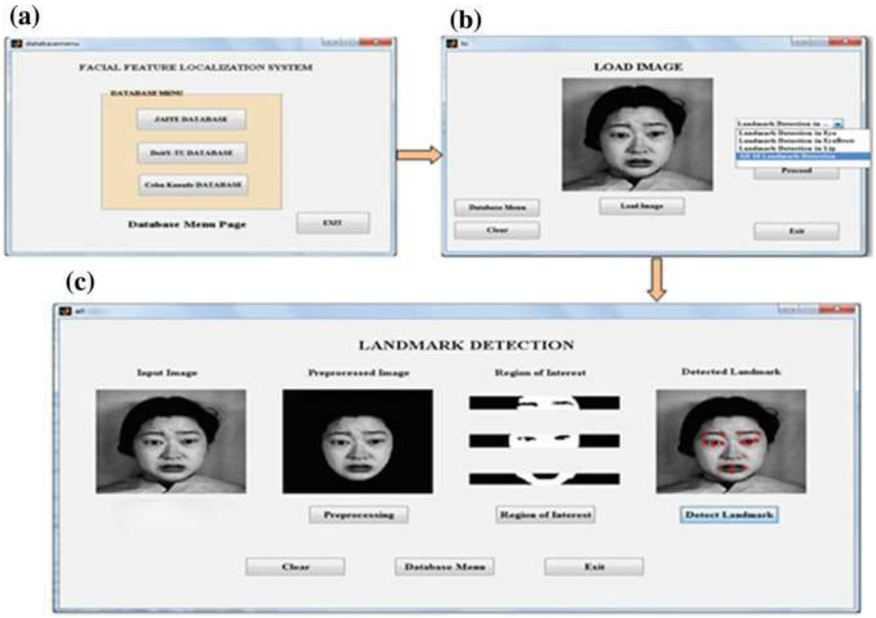

Fig. 6 Graphical user interface (GUI) based prototype system of the proposed method

choice from the popup menu we have to proceed for the landmark detection by clicking on “Proceed” button as shown in Fig. 6b. Then it will open the third interface based on the user’s choice selected in the previous interface. Then by clicking the respective buttons in the interface as shown in Fig. 6c we can see the outputs of all the intermediatary steps of the proposed system. And finally if we click on “Detect Landmark” button then it will localize the facial features around eye, eyebrow, and lip on the basis of user’s choice as selected in the second interface.

9 Conclusion

The paper presents an automatic facial feature localization method based on a geometric-based hybrid approach. A group of methods are integrated to develop an automatic system that detects 16 landmark points accurately. The experimental results also justify the proposed approach. The average success rate of the methodology is 94.78 % for three databases. The methodology contains some limitations in localization of outer eyebrows’ corners. We will try to improve this method in future. Although the present study only focuses on frontal faces, in future, faces with varying poses, occlusion, and illumination will be taken into consideration.

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