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A Survey on Facial Features Detection

Jacek Naruniec

***Abstract*—In this article chosen approaches to the facial features detection have been gathered and described. In the conclusion author discusses advantages and disadvantages of the presented algorithms.**

***Keywords*—Object detection, image processing, face recognition.**

I. Introduction

FACE detection is an important preprocessing task in biometric systems based on facial images. The result of the detection derives the localisation parameters and it could be required in various forms (Figure 1), for instance:

- a rectangle covering the central part of face,
- a larger rectangle including forehead and chin,
- irregular mask of the face area,
- eyes centres,
- multiple face fiducial points,
- contours of the face parts.

While from human point of view the area parameters are more convincing, for face recognition system, fiducial points are more important since they allow to perform facial image normalisation – the crucial task before facial features extraction and face matching.

In the facial fiducial point detection problem, taken assumptions are of crucial importance. The simplest case occurs, when the number and the position of all of the faces is known and usually given by one of the popular face detectors (for example AdaBoost based [48]). In this situation the area of probable location of the facial features can be strongly reduced. In the classical localisation we assume that the face is present, but its position is not known. Another case is when the fact of the face existence in the image is not known, but there can be at most one. The most difficult situation appears when the position and the number of faces is not known.

Methods of facial features localisation can be divided into groups dependent on the information used [6], [3]:

- appearance-based,
- geometry-based,
- knowledge-based,
- 3D Vision-based.

Most of the algorithm existing in the literature combines features of more than one of the given methods and they are usually easy to distinguish.

II. Appearance-based Approach

In this approach values of luminance or gradients in the given area are analysed. Object model is usually formed by reducing the image data dimensionality and improving separability between facial and non-facial patterns.

A. Principal Components Analysis (PCA)

One of the most popular and simplest image analysis method is Principal Components Analysis [40], [21]. In this algorithm mean vector μ and the covariance matrix of the training set are computed. For the covariance matrix eigenvectors sorted by the corresponding eigenvalues are extracted. Eigenvectors associated with the highest eigenvalues carry most of the object energy. Matrix $\mathbf{A}$ is created by choosing k first eigenvectors. Data x representation in the new space is defined by the formula:

$$\mathbf{x}' = \mathbf{A}^t(\mathbf{x} - \boldsymbol{\mu}), \tag{1}$$

The process leads to the dimensionality reduction without loosing most relevant information. Matrix $\mathbf{A}$ can be also easily computed by the SVD decomposition and choosing eigenvectors corresponding to the highest variances.

PCA is usually used as an preprocessing technique, not necessarily working directly on the luminance values. It often applies not only to the appearance models, but also to the 3D-based methods [44].

Example of the dimensionality reduction for the facial features detection can be found in the works of Antonini [1] (reduction 1024-elements vector to 50 elements) or Celiktutan [6] (reduction 768 to 100 elements vector). Matas [36] applied PCA for the detection of 10 fiducial face points by analysing pixels in the closest neighbourhood of the Harris corner detector responses. He also suggested, that probably better results could be achieved by using more sophisticated methods like neuron networks or SVM. This work was continued by Hamouz [25], who achieved better results by replacing PCA with the Gabor filters. Cootes, in his work on Active Appearance Models (AAM) [9] applied PCA to create face appearance model, derive face shape parameters and combine these two approaches.

B. Linear Discriminant Analysis (LDA)

The goal of the PCA is to find principle directions of the data samples without any consideration of the data separability. Extension of this method is Linear Discriminant Analysis (LDA), lineary converting data to maximise criterion defined as the ratio of between- and within-class variance [20], [22]. Classification is performed by computing distances of the vector in the new space to the mean vectors of all categories and as the result the class with the lowest value is given. LDA is used mostly in face recognition, but articles about facial features representation can also be found. Kim [32] proposed LDA for computing the descriptor of the face components. He

J. Naruniec is with the Institute of Radioelectronics, Warsaw University of Technology, Nowowiejska 15/19, 00-665 Warsaw, Poland (e-mail: J.Naruniec@ire.pw.edu.pl).

divided face into 14 overlapping rectangular regions and used LDA to distinguish them.

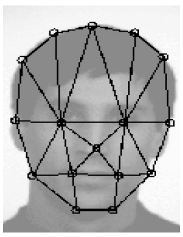
Particular aspect of Linear Discriminant Analysis is two class problem - ”fiducial face point” and ”non-fiducial face point”. Hotta noticed [26], that in this case it is more efficient to treat every sample of ”non-object” as a separate class. This is caused by the fact that for the ”face” samples mean and variation can be easily computed, while the ”non-face” statistics are less reliable. Efficiency of this method has been also proven by the author of this article [38].

C. *Support Vector Machine (SVM)*

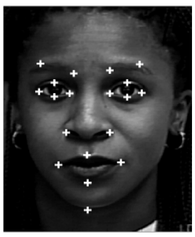
Separation measure used in LDA often appears unsatisfactory, especially when the samples are not lineary separable. Alternative to this method is Support Vector Machine (SVM) [12]. For the linear classification of the lineary separable data SVM maximises margin between two half-spaces given by the equations:

$$\begin{aligned} H_1 &: \mathbf{x}_i\mathbf{w} + \mathbf{b} \geq +1 \text{ for } y_i = +1 \\ H_2 &: \mathbf{x}_i\mathbf{w} + \mathbf{b} \leq -1 \text{ for } y_i = -1 \end{aligned}, \tag{2}$$

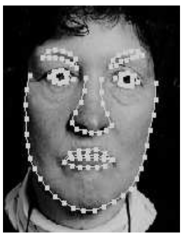
where $\mathbf{w}$ and $\mathbf{b}$ are the parameters of the hyperplane parallel to and fitted in the middle of the halfspaces H_1 and H_2. $\mathbf{x}_i$ corresponds to the i-th support vector and y_i corresponds to its class: $+1$ or -1. Margin between hyperplanes is equal $m = \frac{2}{||w||}$. The name of the method is taken from the fact, that H_1 and H_2 lean on some of the data samples - support vectors. Usually dual version of the equation 2 is used. In this approach the hyperplane is dependant on the model coefficients and the product of pairs of vectors $\mathbf{x}_i\mathbf{x}_j$ [5]. In consequence the classification can be performed in non-linear space while the process of defining new subspace remains unchanged (it is called ”kernel trick”). When the classes are not separable, which is the usual case, *soft margin* allowing error penalty is added to the equations.



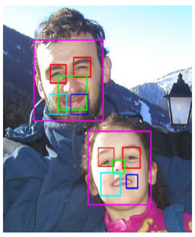
face graph [50]



set of the face fiducial points [49]



set of face fiducial points placed on face parts contours [9]



rectangles covering face parts and the face itself [17]

Fig. 1. Different methods of representing face fiducial points and face parts.

Jee [30] applied SVM with RBF kernel for eyes detection. 200-elements descriptor was extracted from the 20×10 analysis window. Training set consisted of 400 images of eyes and non-eyes. After choosing candidates, SVM verified combinations of eye pairs, rejecting impossible sets. Similarly Hamouz [25] applied SVM for verifying face candidates localised by its fiducial points. Zhu [53] have taken assumption, that in the IR light image, eyes are brighter than in the image taken in the visible light spectrum. From the difference of these two images he chose only the ones with the highest difference values and verified them by SVM with gaussian kernel. Antonini [1] used SVM to classify 50 elements vector obtained by ICA and PCA to one of the 10 fiducial face points classes. Other interesting remark was made by Ngyuen [39]. On the base of SVM analysis he discovered, that for the eyes analysis only few of the pixels in the window of analysis are important to the detection process. He managed to reduce the number of processed pixels to 13% without loosing localisation accuracy.

D. *Independent Components Analysis (ICA)*

Other method of data analysis used in facial features detection is Independent Components Analysis (ICA) [8], [15]. It’s functionality can be described on the blind source separation. Assuming, that there are n independent scalar sources of the signal $x_i(t)$ for $i = 1..n$, where t stands for the time index $1 \leq t \leq T$. For k-dimensional data vector derived from the sensor in the time index, following equation can be given:

$$s(t) = \mathbf{A}\mathbf{x}(t), \tag{3}$$

where $\mathbf{A}$ is a $k \times n$ matrix. The goal of the ICA is to find d independent components derived from the observation s. In the pattern classification problem we don’t know how many sources exists, so this value is mostly set to the number of categories. ICA is usually used as a preprocessing technique before classification methods, for example by bayesian classifier or SVM. In most cases achieved results are better than obtained by PCA. This is caused by the fact, that the higher order statistics are taken into account, not only the covariance matrix. On the other hand separation of the signals is not always possible, for example if the signal probability distribution is gaussian.

In mentioned before work of Antonini [1] ICA was used after PCA. Classification was performed using Support Vector Machines. Celiktutan [6] also applied ICA and SVM to classify the vector to one of the 12 facial features, but no prior PCA have been applied. He also compared this method to other feature extractors - DCT, Gabor wavelets and non-negative matrix factorisation. According to his work it appears, that the latter methods are more suitable for classification. He also proved efficiency of the fusion of all of these methods.

E. *Neuron Networks (NN)*

Neuron Network is a multi-element structure processing the data using neurons. Neurons are connected with defined weight given in the training process. Between input and output elements "hidden layers" can also exist. Number of neurons, topography and connections can be different for every solution. Classical NN lead to the linear classification.

Most of the NN literature concerns face detection [31], [43], nevertheless algorithms on face fiducial points detection are also present. Reinders [41] applied NN for localising 4 facial features in a video sequence. The search was performed in the closest neighbourhood of the feature position in the previous frame. Detected points were verified by the geometric model. In order to handle light variations, the analysis was performed in two images - edge direction and gradient. Ryu [45] described eyes and mouth detection using NN. He had proven, that processing of the eigenvectors can lead to the successful classification. Duffner [16] proposed a 6-layer architecture of the facial features detection network. Three of the layers computed convolution of the points map with defined kernel, while the remaining layers gathered basic neurons.

F. Windows Contrasts and AdaBoost

In 2001 Viola and Jones presented their reliable and fast face detection algorithm [48]. It was based on combining many "weak" classifiers, working by simple thresholding region contrasts, into one "strong", reliable classifier using AdaBoost. Real-time processing became possible by using integral image, allowing fast region pixels summation, and the cascade of the classifiers. In the subsequent years the algorithm was extensively developed by enlarging extractors set, substituting AdaBoost by the GentleBoost algorithm [35] or using asymmetric samples weighting in the training process [47]. Basic implementation is freely available within popular OpenCV library.

Viola and Jones algorithm isn't limited to face detection and can be applied to various objects. Cristinacce [13] proposed two-step analysis based on AdaBoost detectors. Firstly all the faces in the image were localised and afterwards search of the eyes and mouth corners in the region of these faces was continued. In order to validate found features, shape statistics have also been used. Vukadinovic [49] proposed applying GentelBoost to improve analysis of the Gabor filter responses for fiducial points classification. Algorithm of facial features detection using AdaBoost and contrast features was proposed by Erukhimov [17]. After initial defining possible position of the face parts, their validation was performed based on geometric model.

Above all of the cited algorithms AdaBoost detector is most often used as a preprocessing technique to define possible face candidates for more sophisticated localisation.

G. Gabor Filters

Gabor filters [23] are one of the most popular facial features extractors. It was proven (for example in [14]), that they are more efficient than PCA, LDA or Local Feature Analysis (LFA). Response of the Gabor filter $g(x, y)$ can be expressed as:

$$g(x, y) = car(x, y)env(x, y), \tag{4}$$

where $car(x, y)$ stands for complex 2D sinusoidal signal (carrier) and $env(x, y)$ is a 2D modulating gaussian function

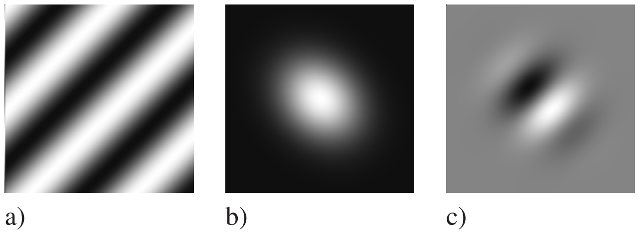


Fig. 2. Gabor filter construction. Real part of a) sinusoidal carrier, b) gaussian modulating function, c) Gabor filter created by multiplying a) and b).

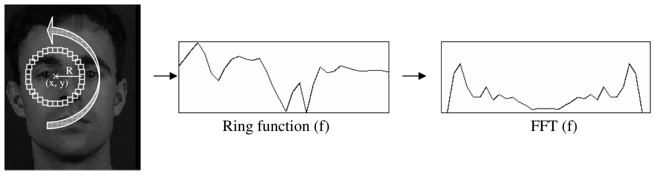


Fig. 3. Discrete approximation of the Gabor filters - discrete Gabor Jets [38]. Every ring square represent mean luminance value.

(envelope). Figure 2 presents a way of constructing such a filter.

In face fiducial points detection, usually set of 40 filter responses (Gabor jet) for 8 different orientations and 5 different frequencies is analysed. Lades proposed extraction of the face descriptors in the ties of the rectangular grid [33]. Models were formed on the base of many face images separately and the localisation in a new picture was performed by adjusting grid to give closest match to all of the trained models. One of the most important works on Gabor filters was written by Wiskott [50]. It was similar to the work of Lades, but the points were not chosen by the rectangular grid, but in the fiducial face points. For each of these points separate model consisting of Gabor jets for many different variations of this feature was trained. Classification of each point was performed by calculating the distance of actual object to all of the models and choosing the one with the lowest distance value. Jahanbin [29] proposed using Gabor jets in the detection of the face fiducial points in range and luminance images simultaneously. Faces were normalised by the tip of the nose so the problem was very simplified. Very good results have been achieved by Feris [19]. In his work point representation was given by the Gabor wavelet networks. Impact of the chosen Gabor jet responses set on the fiducial points detection was analysed by Fasel [18]. He had proven, that for various face parts, classical 40 elements vector is not the best solution. Because Gabor filters extraction is very computationally expensive, Naruniec and Skarbek [38] proposed discrete Gabor jets - an efficient approximation of the original filters (Figure 3).

III. Geometry-based Approach

Geometry-based methods assume some invariance in the spatial relationships of the face parts. These relations can be distances, angles etc. These dependencies are usually described by the graph.

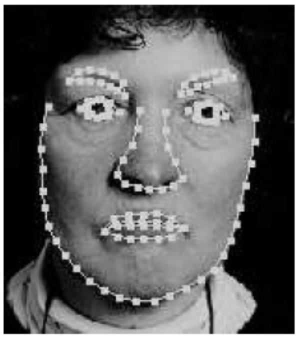


Fig. 4. Example of face image marked with 122 landmark points [9].

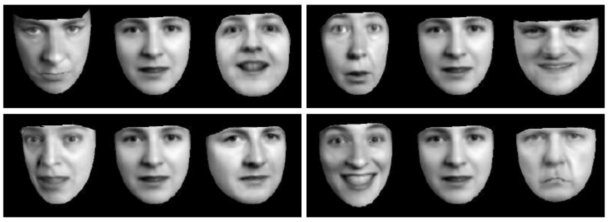


Fig. 5. Different appearance modes created by changing PCA parameters [9].

A. Active Shape Models (ASM)

Active Shape Models were proposed by Cootes in 1995 [10]. His work concerned medical images, but achieved results can be easily extended to face analysis. In this method model was formed on the base of defined object images set. At first for every sample pattern contour with marked fiducial points (always the same) was manually marked (Figure 4). These points were subsequently normalised by the rotation, scale and shift. In the next step PCA was used to decorelate points in order to get a few parameters controlling whole object variation. Moving each corner separately would lead to unreal patterns, but in this case only possible shapes can be adjusted. Cootes localisation was performed by placing initial shape on the image and adjusting it by the derived parameters to match the strong edges.

Modification of the algorithm allowing detection of about 80 face fiducial points was proposed by Milborrow [37]. For the localisation he used two models - one for a coarse detection and the second one to increase the accuracy of the found points. Zhenh [52] proposed creating separate model for every facial feature. Haj [24] applied skin colour detection for defining initial placement of the ASM.

In 1998 Cootes extended ASM to the Active Appearance Models (AAM) [9]. Grayscale image of the object was included in the PCA model to define also the appearance of the human face (see Figure 5) .

B. Elastic Bunch Graph Matching

This method, already mentioned in the appearance-based methods section, was proposed by Wiskott [50]. Author proposed graph consisting of face fiducial points (eyes centres, nose tip, mouth corners) and contour points. Connections were weighted by the distance between corresponding points. Elastic graph matching was performed by rough graph matching, and subsequent precising the results. Graphs ensure that no unrealistic set of points will be accepted. The proposed algorithm also has some limitations - face sizes must be similar on all of the images, the model is created for one face position, for example frontal or profile and only one face can be detected in an image.

IV. Knowledge-based Approach

Knowledge-based approach relies on our information about human face. It could concern colour, symmetry, edge direction, placement of the face parts or the proportions.

The simplest method of rejecting many false facial feature detection can be achieved by analysing their spatial distances. It can be easily verified if the left eye is on the left side of the right eye etc.

Face colour is usually applied as a preprocessing technique in order to define regions of interest or for verification of the detected faces. In some cases it is also used in direct localisation. Beigzadeh [2] formed the set of dependencies in the CbCr colour space describing eyes and mouth. Additional verification was performed by the edges and geometrical distances analysis. Hsu [27] suggested, that eyes neighbourhood is defined by pixels with high Cb and low Cr values, while mouth is characterised by high Cr values. He additionally stated, that eyes region usually consists of both dark and light pixels. This information along with simple geometric information was used for the facial features detector. In most publications colour is applied for defining initial face region in different colour spaces: HSV [46], RGB [24] or CbCr.

Algorithms applying symmetry information for face detection are also known. They usually assume, that the background is uniform and the face covers most of the image. Reisfeld proposed a method using edge image and symmetry for localising eyes and mouth [42].

Another interesting group of algorithms is based on so called experts. One of the most known works on this subject was proposed in 1992 by Craw [11]. He defined local and global experts. Local experts served as a set of rules for detecting facial features. For example eyes expert operated on the assumption, that they are placed in a dark region surrounded by lighter pixels.

Methods based on the knowledge are usually easy to implement and fast, but because of their low accuracy they are mostly used in combination with other techniques.

V. 3D Vision-based Approach

Currently the acquisition of the 3D models become very popular. In order to acquire 3D image various methods are used, for example:

- structural light [34],
- laser scans [28],
- multi-view cameras [4].

Availability of the 3D image gives more possibilities than 2D model. One of the most important issues, in the application of face recognition, is the possibility of estimating frontal face pose.

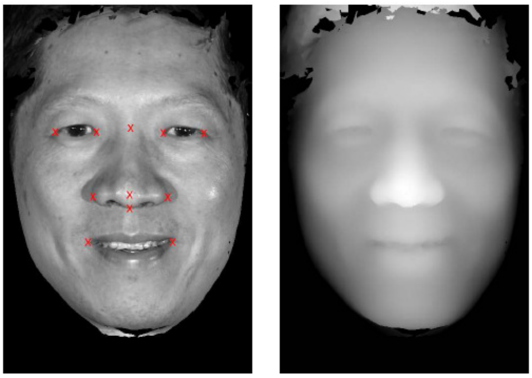


Fig. 6. Example of luminance (left) and depth (right) images [29].

Jahanbin [29] proposed system based on depth and luminance image normalised by the nose tip (Figure 6). It is usually simple to achieve due to the fact, that the nose is in most cases the closest point to the camera. In the probable facial features areas he classified points using Gabor jets (described earlier) for both luminance and depth image. As the result points with the lowest distance to the model were chosen. In order to reduce "spikes" of the 3D image Colbry [7] proposed smoothing operation before proper classification. Yuasa [51] presented geometric criteria validating localisation of any face fiducial points.

Methods based on the 3D-images, despite of delivering more information, cope with other problems. For acquisition expensive equipment of large sizes is often needed. Single scan usually takes some period of time (for example 1 second) demanding from the person to stand completely still in the time of the procedure. Simpler acquisition methods often give poor results with low resolution or high number of errors.

VI. CONCLUSION

Four groups of facial features detection algorithms have been described. Appearance-based methods are very general and can be used in multiple applications - most of them allow the detection of any patterns. It was proven, that they are very efficient in face fiducial points detection. Some of them can work in real-time what is very desirable in many systems. On the other hand it is usually very hard to find representative training set that describes whole variability of the human face. In the consequence features that are different than in the model (beard, glasses, etc.) can be missed in the image. In some cases (AdaBoost for instance) training process may last very long, even for weeks. Geometric models are often bound to one face profile. They usually allow localisation of only one face in the image. Their advantage is that in most of the solutions no unrealistic shapes can appear. Also large set of points can usually be detected what is hard to achieve for other groups of methods. Knowledge-based algorithms are simple and fast, but their efficiency is often worse than the others. 3D-Vision models deliver more information than 2D and therefore allow more efficient classification. They usually assume, that the tip of the nose is the closest point to the device. Acquisition often needs expensive and large equipment while the face scan is not as fast as using standard camera.

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