BBL 588E
ADVANCE TOPICS IN COMPUTER VISION
TERM PROJECT

Face Detection System With Cascades of Boosted Classifiers

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CONTENTS:

A- Introduction

In this documentation CD, I prepared a comprehensive and critical survey for face detection algorithms. By the development of the technology and new technological applications, face detection became useful and necessary first step for a wide range of applications like face authentication[46],face tracking[47], facial expression recognition[48], indexing of images and video databases, and intelligent human-computer interfaces. Because of wide range application area, face detection became important process in the digital image processing world.

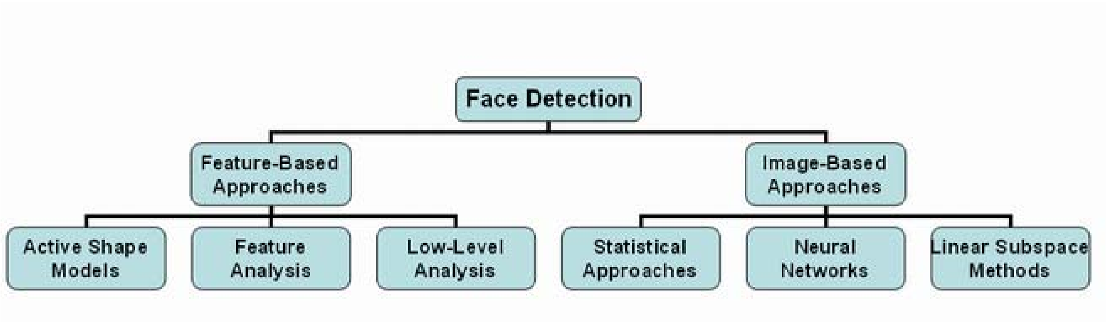
The goal of face detection is simply to determine whether or not there are any faces in the any given image and,if present, return the image location and extent of each face. But this task is not always very simple. Following reasons make difficult face detection process:

- Pose direction: Face images dramatically change according to pose direction of camera, and some features can partially or wholly disappear.
- Presence or absence of structural components: Facial features like beards, mustaches, and glasses may or may not be present. Because of this reason, there is big variability due to the prensence or absence of these components.
- Occlusion: Sometimes, faces can be partially occluded by other object. This reason makes difficult to detect face.
- Size and Orientation: Face images can be anywhere in image with any size.
- Imaging Conditions: When the image is formed, environmental conditions like lighting, and camera characteristic affect the appearance of the face.

B- Literature Survey of Face Detection

1- Face Detection : An Overview

From the early research at the beginning of the 1970s, a lot of face detection methods were developed. According to their main image processing techniques, we can classify face detection methods into two main approaches: Features-based approaches and Image-based approaches. Also, these two approaches have several sub face detection methods. Following figure show main two approaches and their sub-methods.



2- Feature-Based Face Detection Approaches

Feature-based face detection approache is divided into three areas. These are low-level analysis, feature analysis, and active shape models. These sub-approaches are methods to find some facial features. To design robust face detection system, instead of using just one approache, using hybrids of these approaches gives us more success. Here, there is more information about sub-approaches of Feature-Based face detection.

a- Low Level Analysis

Low-level analysis deals with the segmentation of basic visiual features by using pixel properties like intensity levels, edges, and color properties.

* Edges

Edge representation is one of the earliest methods in face detection by Sakai et al. [49]. Sakai's method was based on analyzing line drawings of faces to locate facial features. Craw et al. [50] designed hierarchical method to trace human head outline based on Sakai's work. More recent examples of edge based techniques can be found in [51, 52, 53] for facial feature extraction and in [12, 54, 55] for face detection. In edge detection based face detection, simply, edges are labeled and matched with face models to detect face.

* Gray Levels

Gray levels in face can be used as features. Facial features like eyebrows, pupils, and lips are usually darker than their surrounding regions. By this property, we can differentiate various facial parts. Several face detection algorithm were developed based on this differentiation.

* Color

While gray level information gives us basic features about face representation, color information can provide us more face features by extra dimensions of pixel representation. For example, same features in intensity space can be very different in color space. On the other hand, skin color estimations can help us about finding possible face regions in the image. Actually, this is complex task when faces of different races are considered [56, 57, 62].

The most common color model is RGB representation in which colors are defined by combinations of red, green, blue color components. Lighting conditions can dramatically change RGB variations of images. Because of this reason, normalized RGB values are preferred in color-based feature detection [47, 56 , 58 , 63, 62 , 64]. Normalized colors can calculate by following equations:

$$r = R / (R + G + B)$$

$$b = B / (R + G + B)$$

$$g = G / (R + G + B)$$

In this color representation space, sum of r, g, and b values are always 1. And also, it shows high invariance for lighting conditions.

On the other hand, other color representation models are used for face detection like HSI [59, 57, 60, 61], HSV [4, 54, 65], YES [66], YUV [75], YCrCb [4, 67].

Color based face detection is usually performed by using skin color thresholds according to pre-calculated skin color models [58, 61]. More complex methods use statistical measures of large training sets (adaptive learning). These methods' implementations can be improved by new face examples, and they become more robust against environmental factors' changes like illumination conditions, camera characteristics [47, 56, 57, 62, 68].

* Motion

When use of video sequence is available, motion information can be used to locate moving objects. Moving silhouettes like face and body parts can be extracted by simply thresholding accumulated frame differences [69]. Besides face regions, facial features can be located by frame differences [47, 53].

b- Feature Analysis

Low-level analysis features are not very effective and robust. By these features, possible face regions can be found, but also false regions are found. For example, in skin color model face detection, background objects of similar color can be also detected as a face region. To solve this problem, higher level feature analysis can be used. In feature analysis, visual features are orginized due to global concept of face by using face geometry information. Feature analysis approache is divided into two sub-appraoches. These are feature searching and constellation analysis. Feature searching strategies are based on relative positions of simple facial features. Constellation strategies use flexible features of various face models.

* Feature Searching

In the feature searching strategies, firstly important facial features are determined. These features are generally biometrics measurements like eyebrows' lines, eyes' circles, etc. In the literature, most commonly used facial feature is distinct side by side appearance of a pair of eyes [47]. Also, main face axis [50], outline (top of the head) [49, 50], and body (below the head) are searched to detect face regions. After determining features which we focus on, these features are searched. According to found features' orientations and geometric their geometric ratios, face regions are detected.

* Constellation Analysis
Feature models of low-level analysis and feature searching strategies are more rigid. Because of this reason, locating faces of various poses in complex backgrounds can fail. To solve this problem, feature constellation analysis strategies are developed [70, 71, 72]. In these face-like constellation strategies, more robust modeling methods like statistical analysis are used. Our face detection project method is an example of constellation analysis. Focused features are haar-like features, and also adaptive boosting method is used to train system.

c- Active Shape Models
Active shape models focus on complex non-rigid features like actual physical and higher level apperance of features. Active shape models use local features (edges, brightness) to find shape of feature models. Active shape models are divided into three groups: These are snakes, deformable templates, and point distribution models.

* Snakes
In this approach, active contours (snakes) are used to locate head boundary [73, 219]. Also features' boundaries can be found by these contours.

* Deformable Templates
Locating facial features' boundaries by using active contours is not easy task. Finding and locating facial edges is difficult. Sometimes there can be edge detection problems because of bad lighting or bad contrast of image. So, we need more flexible methods. Deformable templates approaches are developed to solve this problem. Deformation is based on local valley, edge, peak, and brightness [74].

* Point Distribution Models
These models are compact parameterized descriptions of the shapes based on statistics [76]. By using principal components analysis, variations of features in the training set develop point distribution models. So, PDM become linear flexible models.

3- Image-Based Face Detection Approaches
In feature-based face detection approaches, feature models have troubles with unpredictablity of face appearance and environmental conditions. Some of feature based methods are improved against unpredictabilty, but there is still needs for improvments against unpredictabilty. Image-based face detection approaches are deleveloped for this needs. In image based approaches, window scanning techniques are applied to original images. According to premodeled and trained face information, multiple face are detected. Image-based face detection approaches can be divided into three main sub-approaches. These are linear subspace methods, neural network approaches, and statistical approaches.

a- Linear Subspace Methods
Human face images lie in a subspace of overall image space. By using this subpsace concept, several analysis methods are developed. In image processing world, the most

important three methods are principal component analysis (PCA), linear discriminant analysis, and factor analysis (FA).

Principal component analysis (PCA) involves a mathematical procedure that transforms a number of (possibly) correlated variables into a (smaller) number of uncorrelated variables called *principal components*. The first principal component accounts for as much of the variability in the data as possible, and each succeeding component accounts for as much of the remaining variability as possible. According to this analysis method, firstly principal components are expressed. In face detection examples, eigenvectors of face images can be used. Each individual face in the face set can be approximately represented by a linear combination of largest eigenvectors (eigenfaces). PCA method is used in a lot of face detection methods [19,27].

In linear discriminant analysis method, dimensionality reduction techniques are used like PCA method, but LDA produce transformation matrix which maximize between class variance, and minimize within class variance. This analysis method is not common like PDA, but it is used in a lot of face detection system.

b- Neural Networks

Neural networks can be applied successfully in face detection systems. The advantage of using neural networks for face detection is the feasibility of training a system to capture the complex class conditional density of face images. However, one drawback is that the network architecture has to be extensively tuned (number of layers, number of nodes, learning rates, etc.) to get exceptional performance. Several Neural network models are used in face detection projects [3, 6, 8, 9, 10, 11,17,21,22,31].

c- Statistical Approaches

Apart from linear subspace methods and neural networks, there are several other statistical approaches to face detection like systems based on information theory, a support vector machine, and Bayes' decision rule.

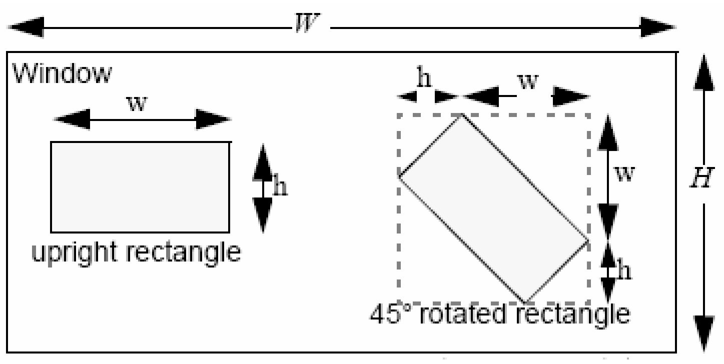
C- Implemented Method: Cascades of Boosted Classifiers for Rapid Face Detection

Recently, Viola et al.[1] have designed a machine learning approach for face detection which is capable of processing images extremly rapidly and achieving high detection rates. Their face detection method is based on boosted cascades of simple feature classifiers. Their method has three key concept. Firstly, they have introduced new image representation concept called "Integral Image" for quickly feature computation. The second concept is a learning algorithm based on adaptive boosting, which selects small number of features from a larger set to produce extremly efficient classifiers. The third is classifier cascading concept, which can eliminate non-face patterns very rapidly. In Lienhart et al.[2]'s work, this method is extended by two ways. Firstly, a novel set of rotated haar-like features is introduced. These novel features significantly enrich the simple features and can also be calculated efficiently. Secondly, they present a through analysis of different boosting algorithms (namely Discrete, Real and Gentle Adaboost) and weak classifiers on the detection performance and computational complexity.

In my project, I implemented face detection method by using cascades of boosted classifiers based on Viola et al. and Lienhart at al.'s works. I design my face detection system in OpenCV environment by using C programming language.

1- Features

The main reason to use features instead of raw image data for learning algorithm is to reduce in-class variance, and to increase out-of-class variance. So, classification becomes easier. Features usually hide knowledge about domain, which is difficult to learn from raw data. In my project, I used haar-like features to detect faces. Also, to compute quantitive feature values, I used sumation of pixel values, namely integrating image concept.
Assume that test window for face detection is WxH pixels. A rectangle is specified by the tuple r = (x,y,w,h,α) with $0 < x, x+w < W$, $0<y, y+h < H$, $x,y,w,h>0$, and α is between 0 and 45 degrees. Sum of rectangle is specified by RecSum(r). Two rectangle examples are in following figure.

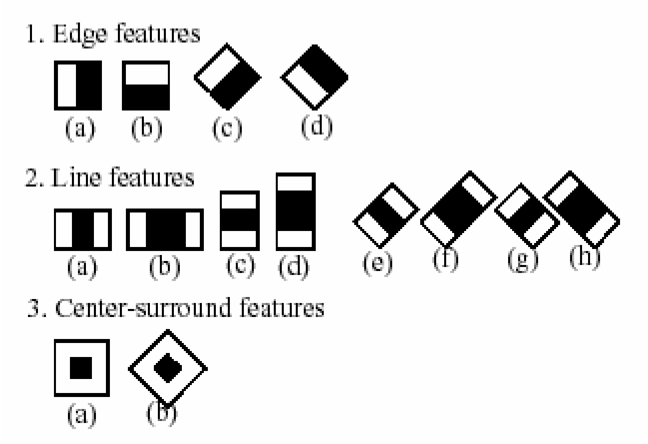


Pre-feature set is all possible features of following equation where the weigth w_i € R, rectangle r_i, and Nare arbitrarly chosen.

$$feature_I = \sum_{i \in I=\{1,\ldots,N\}} \omega_i \cdot RecSum(r_i)$$

Because of infinetly possible large set, we need to reduce size of set. According to following three rules, we reduce size of set, and we gain small effective set.
1- Only sum of two rectangle with their weights is used.
2- Weights are chosen according to compansetion of two non over lapping rectangles.($-w_0$*Area(r_0)=w_1*Area(r_1))
3- The features mimic haar-like features and early features of the human visual pathway such as center-surround and directional responses.

According to these rules, we choose 14 feature prototypes. These are four edge features, eight line features, and two center-surround features. These feature prototypes are shown in following figure.



Features can be computed very fast in constant time for any size by means of two auxiliary images. These auxiliary images Summed Area Table SAT(x, y) and Rotated Summed Area Table RSAT(x, y). SAT(x, y) is defined by following equation.

$$SAT(x,y)=\sum_{x'\leq x,y'\leq y} I(x',y') .$$

SAT(x, y) is summation of pixels of the upright rectangle ranging from the left corner (0, 0) to bottom corner (x, y). It can be iteratively calculated by neighborhood SAT pixels and original image's pixel intensity. Following two equations summarize this iterative calculation.

$$SAT(x,y)=SAT(x,y-1)+SAT(x-1,y)+I(x,y)-SAT(x-1,y-1)$$
$$SAT(-1,y)=SAT(x,-1)=SAT(-1,-1)=0$$

By using Summed Area Table, we can easily calculate summation of upright rectangle r = (x, y, w, h, 0) with following equation.

$$\begin{aligned}RecSum(r)=&SAT(x-1,y-1)+SAT(x+w-1,y+h-1)\\&-SAT(x-1,y+h-1)-SAT(x+w-1,y-1)\end{aligned}$$

Rotated Summed Area Table RSAT(x, y) is a little different than SAT. RSAT is designed for summation of rotated rectangles. RSAT(x, y) is summation of the pixels with 45 degree rotated rectangle with bottom corner (x, y).

$$RSAT(x,y)=\sum_{y'\leq y,y'\leq y-|x-x'|} I(x',y') .$$

It can be iteratively calculated also in one pass from left to right and top to bottom over all pixels by following equations:

$$RSAT(x,y)=RSAT(x-1,y-1)+RSAT(x+1,y-1)-RSAT(x,y-2)$$
$$+I(x,y)+I(x,y-1)$$

$$RSAT(-1,y)=RSAT(x,-1)=RSAT(x,-2)=0$$
$$RSAT(-1,-1)=RSAT(-1,-2)=0$$

Summation of 45 degree rotated rectangles can be easily computed by help of RSAT by following equation.

$$RecSum(r)=RSAT(x-h+w,y+w+h-1)+RSAT(x,y-1)$$
$$-RSAT(x-h,y+h-1)-RSAT(x+w,y+w-1)$$

2- Learning Process by Boosting

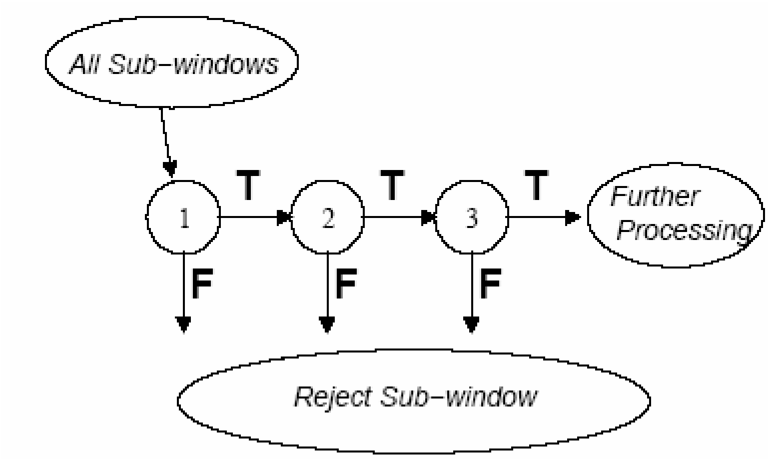
Learning is based on *N* training examples (x_1, y1), (x_N, and yN). Each component encodes a feature relevant for the learning task at hand. The desired two-class output is encoded as –1 and +1. In the case of face detection, the input component x_i is one haar-like feature. An output of +1 and -1 indicates whether the input pattern does contain a complete instance of the face class. In our system learning process is based on discrete adaptive boosting [40, 41, 42, and 43]. By following algorithm, classifiers are produced and improved.

Discrete AdaBoost

1. Given N examples $(x_1,y_1),\ldots,(x_N,y_N)$ with $x\in\Re^k, y_i\in\{-1,1\}$
2. Start with weights $w_i = 1/N$, $i = 1, \ldots, N$.
3. Repeat for $m = 1, \ldots, M$
   (a) Fit the classifier $f_m(x)\in\{-1,1\}$ using weights w_i on the training data $(x_1,y_1),\ldots,(x_N,y_N)$
   (b) Compute $err_m=E_w[1_{(y\neq f_m(x))}]$, $c_m=\log((1-err_m)/err_m)$.
   (c) Set $w_i\leftarrow w_i\cdot\exp(c_m\cdot 1_{(y_i\neq f_m(x_i))})$, $i = 1, \ldots, N$, and renormalize weights so that $\sum_i w_i=1$.
4. Output the classifier $sign\left[\sum_{m=1}^{M} c_m\cdot f_m(x)\right]$

3- Cascade of Classifiers

To detect faces, input images are scanned by 20x20 over lapping sub windows. Classification stages are applied on input sub window. If sub window fail one of the classification stages, system decide that sub window is non-face area. So, other classification stages are not applied on sub window. If sub window can pass all stages, system decides that this is a face pattern. Following figure summarize decision tree of cascading of classification stages.

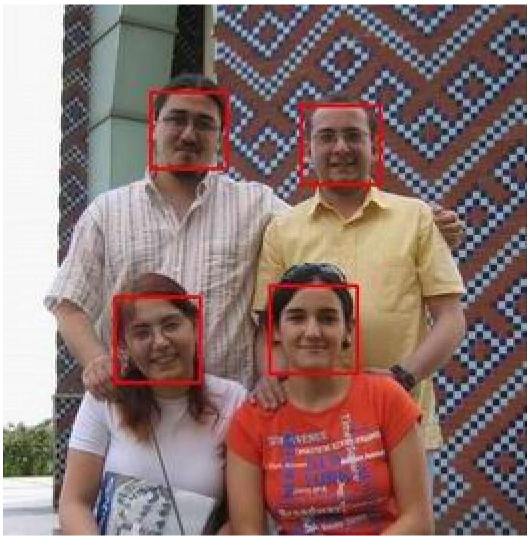


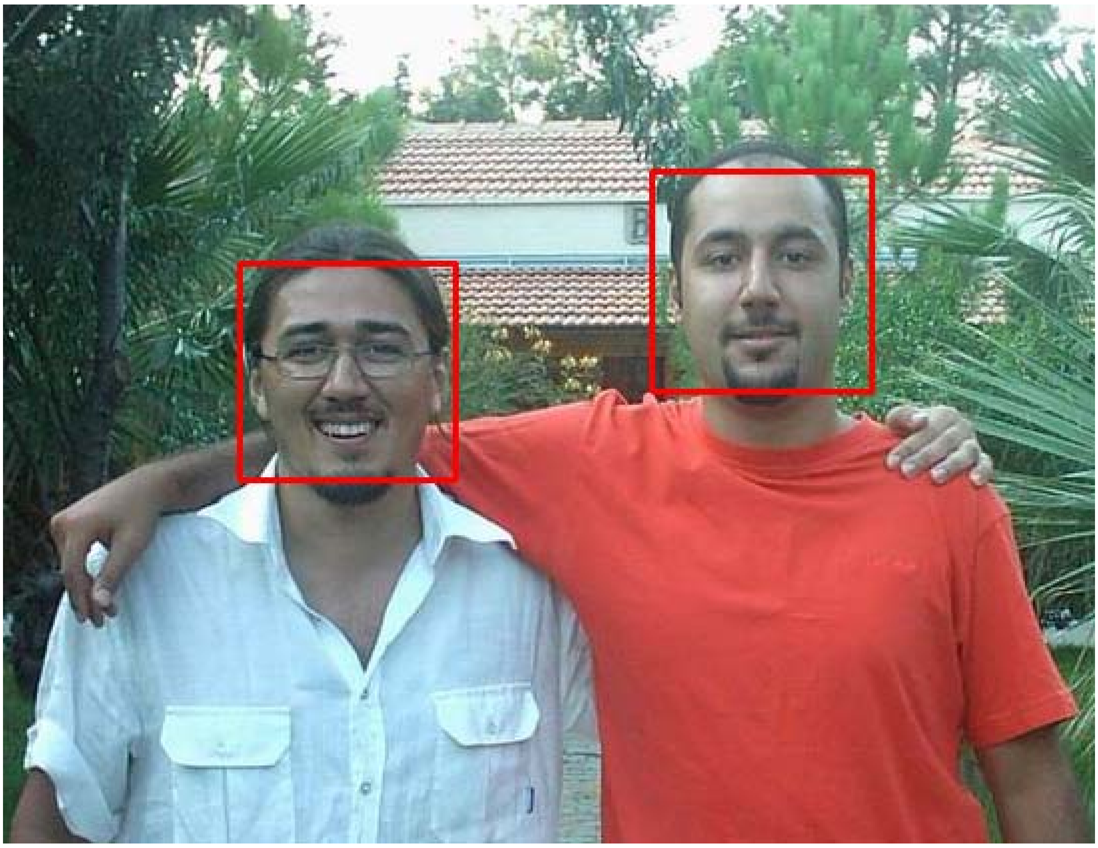
The best part of this method is those non-face patterns are detected very quickly. It is important because while scanning the input images, we need to process many sub windows. A big part of them don't contain any face pattern. By this method, we can quickly skip them while we focus on possible face pattern.

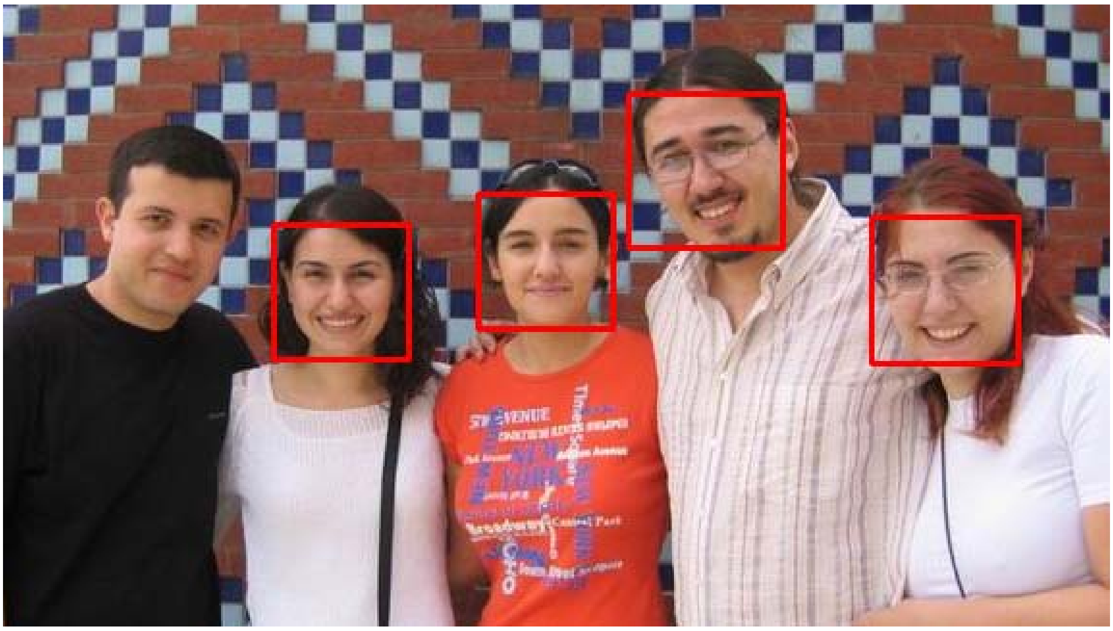
4- Results

After face detection system implementation in OpenCV environment by using C programming language, I became succesfull to detect faces. I formed small face image database with 15 images. These images are 19 frontal faces and 18 rotated faces. 18 of 19 frontal face are detected. But unforutanely, just 11 of 18 rotated images are detedted.

I also design real time face detection system with web cam, but real time system didn't work well. Following images are some of result images.







D- Conclusion

Finally, I can implement satisfactory face detection system. Frontal face patterns, which are bigger than 20x20 sizes are easily detected. But unfortunately, face patterns which have small size than 20x20 cannot be detected. Also, rotated faces cannot be detected too. Rotated face problem can be easily solved by system training with rotated face patterns.

In the future, I will improved this face detection system for rotated faces, and I will implement next step of this project, namely, face recognition.

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