Eye Detection in Facial Image by Genetic Algorithm Driven Deformable Template Matching

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Summary

As face recognition and facial feature based human computer interaction have become the subjects of intense focus in recent decades, facial feature extraction has emerged as a challenging task in the field of computer vision. Eye is said to be the most salient feature on face because of its versatility of appearance and expression variety. Various eye detection schemes are proposed in the literature but most of them require massive mathematical processing which is a barrier against real-time implementation. A novel approach for eye detection is proposed in this paper which exploits the flexibility of deformable template and uses genetic algorithm to match the template for eye detection. Implementation of genetic algorithm reduces the time required for template matching than conventional template matching algorithm. Moreover the method does not require any prior knowledge about eye geometry or potential eye location tags on facial image. Experimental results show that the proposed scheme can easily be implemented in real-time as it can detect eye in few genetic epochs. The method was tested on ORL face image database which contains 400 images grouped into 40 persons having 10 different expressions each. The detection accuracy was 87.2%.

Key words:
Cross Correlation Co-efficient, Deformable Template, Genetic Algorithm, Pattern Recognition, Template Matching.

1. Introduction

Facial feature extraction is a challenging task in the field of image analysis and computer vision. Various facial features of human face convey very useful information for Human Computer Interaction (HCI) and face recognition technologies. Automatic facial feature extractor, facial expression recognizer, gaze or motion tracker can substitute various input devices like mouse, keyboard, joystick etc. These tools can also aid the handicap people to a greater extent. So facial feature extraction and facial expression recognition have become very important research topics during last few decades.

Before continuing to facial feature extraction or face recognition, first a system needs to extract the facial region from a complex natural image. Various face detection techniques have been proposed in recent years for this purpose. Some of the methods of face detection can be found in [1, 2, 3, 4]. Among other objects on a facial image, "eye" is the most important one because of its versatility of appearance and expression variety. A novel eye detection technique is proposed in this paper. Although various eye detection schemes are available in the literature, the proposed method is unique with its own features. Most of the techniques so far proposed in the literature are based on template matching which requires massive calculation time or based on very complex mathematical calculations. The proposed technique in this paper is based on genetic algorithm based deformable template matching. Genetic algorithm is applied to avoid exhaustive blind search as template matching techniques do. The eye may be at different scale than the template and may be rotated to certain angle. To achieve scale and rotation invariance, deformable template is used. Experimental results show that the proposed method can detect eye in less amount of iteration than the worst case complexity of conventional template matching. This feature makes the method capable for practical implementation. The system is tested on ORL face image database [5] which contains 400 facial images grouped in 40 persons having 10 different expressions each.

The paper is organized as: in the next section some previous works on eye detection are discussed. Section 3 is devoted to explain template matching and deformable template. Genetic algorithm is discussed in Section 4. Experimental results are presented in Section 5 and finally conclusion is drawn in Section 6. Some useful references are placed in the section that follows.

2. Literature Review

In [6] exhaustive template matching was avoided and approximate eye position was estimated by means of head contour geometry and wavelet subband projection. The problem of crafting visual routines for detection tasks was

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addressed in [7] by using the framework of hybrid genetic architecture. Their theory was applied to eye detection. Use of fractal dimensions was introduced in [8] for eye detection. In that scheme possible eye candidates were identified by valley field detection. After that, local properties of eye were matched by roughness and orientation represented by fractal dimensions. Artificial neural networks and support vector machines were investigated for eye detection in [9, 10, 11]. Some new projection functions were proposed in [12] for eye detection. In [13] color cues were used along with projection function. Some mathematical tool like curve fitting and Hough transform were utilized for eye detection and eye contour extraction in [3, 14].
Most of the schemes in literature for eye detection were more or less effective but their efficiency was greatly limited by either time or real-time implementability. Most of those techniques also use prior heuristics about eye geometry and some of them really based on very complex mathematical calculations which are almost not possible for real-time implementation. The scheme proposed in this paper does not require any prior knowledge about the eye but it just uses an eye template. This scheme can also be implemented in real-time.

3. Template Matching and Deformable Template

Template matching is a popular method for pattern recognition. Detail description of this method can be found in [14, 15, 16, 17]. In this section this method is discussed briefly.

3.1. Template Matching

Definition 1: Let I be an image of dimension $m\times n$ and T be another image of dimension $p\times q$ such that $p<m$ and $q<n$ then template matching is defined as a search method which finds out the portion in I of size $p\times q$ where T has the maximum cross correlation coefficient with it.

3.1.1. Cross-correlation Coefficient

The normalized cross correlation coefficient [16] is defined as:

$$\gamma(x,y)=\frac{\sum_s\sum_t \delta_{I(x+s,y+t)}\delta_{T(s,t)}}{\sum_s\sum_t \delta^2_{I(x+s,y+t)}\sum_s\sum_t \delta^2_{T(s,t)}} \qquad (1)$$

where,

$$\delta_{I(x+s,y+t)}=I(x+s,y+t)-\bar{I}(\text{x},\text{y}),\quad \delta_{T(s,t)}=T(s,t)-\bar{T}$$

$s\ \varepsilon\ \{1, 2, 3, \ldots, p\}$, $t\ \varepsilon\ \{1, 2, 3, \ldots, q\}$,

$x\ \varepsilon\ \{1, 2, 3, \ldots, m-p+1\}$, $y\ \varepsilon\ \{1, 2, 3, \ldots, n-q+1\}$

$$\bar{I}(x,y)=\frac{1}{pq}\sum_s\sum_t I(x+s,y+t)$$

$$\bar{T}=\frac{1}{pq}\sum_s\sum_t T(s,t)$$

The value of cross-correlation coefficient γ ranges in *[-1, +1]*. A value of *+1* indicates that T is completely matched with *I(x, y)* and *-1* indicates complete disagreement. For template matching the template, T slides over I and γ is calculated for each coordinate *(x, y)*. After completing this calculation, the point which exhibits maximum γ is referred to as the match point.

3.1.2. Template Matching Algorithm

The template matching procedure is summarized in the following algorithm.

Algorithm 1:

```
For y := 1 To n – q + 1 Do
    For x := 1 To m – p +1 Do
            Calculate γ(x, y) using (1)
    Loop
Loop
max := -∞
mx := 1
my := 1
For y := 1 To n – q + 1 Do
    For x := 1 To m – p + 1 Do
            If max < γ(x, y) Then Do
            max := γ x, y)
            mx := x
            my := y
            End If
    Loop
Loop
Return (mx, my)
```

3.2. Deformable Algorithm

The matching procedure discussed above matches a template of fixed size in a predefined orientation, but it is not always desirable. In an image the matched region may not always have the same size as of template, for this reason the template size must be adjusted according to the matched region. Moreover the matched region may be rotated to certain angle with respect to template axes. So template must be rotated to that angle in order to match. By thinking these cases a new template comes in mind and that is deformable template. Details of these types of templates for pattern recognition are investigated in [18, 19, 20]. In our eye detection case we need to find out what will be the degrees of freedom of the eye template. Two degrees of freedom are the adjustable parameter of the template. For template matching algorithm discussed above, the degree of freedom is 2 for x and y coordinates of template's origin. For deformable template another degrees of freedom are scaling factor and rotation angle, because when a person rotates the head, eyes are also rotated and due to zooming difference the eye size in image may vary.

3.3. Complexity of Deformable Template Matching Algorithm

The worst case complexity of deformable template matching can be defined by the following lemma.

Lemma 1: If the deformable template has N degrees of freedom with variation ranges $\{R_1, R_2, R_3, \ldots, R_N\}$*, an image of size* $m \times n$ *posses a worst case complexity of* $O(R_1 R_2 R_3 \ldots R_N mn)$ *for template matching.*

Proof: It is apparent from Algorithm 1 that calculation of γ over the entire image, requires time of $O(mn)$. In that algorithm the variation range of x and y were 1 and 1 respectively since x and y were not changed while calculating $\gamma(x,y)$ at a particular point (x, y). So worst case complexity for fixed size template matching is $O(1 \times 1 \times mn)$. But if each degree of freedom varies in a range 0 to R_i then $\gamma(x, y)$ at point (x, y) will be calculated $O(R_1 R_2 R_3 \ldots R_N)$ times. So the worst case complexity for deformable template matching is $O(R_1 R_2 R_3 \ldots R_N mn)$. ■

This time is huge for real-time implementation. That's why a new template matching algorithm is formulated in this paper which is based on genetic algorithm.

4. Genetic Algorithm

Genetic Algorithm (GA) is an unorthodox search or optimization problem inspired by natural genetic evolution of genes. GA is not new in pattern analysis and classification. Detail study and application of genetic algorithm can be found in [3, 21, 22, 23, 24, 25, 26]. To perform search by genetic algorithm at first the problems solutions are to be encoded as chromosomes [25, 26]. Each chromosome indicates a potential solution to the given problem. The chromosomes are sequence of genes or symbols. The symbols may come from any alphabet. Initially the chromosomes are chosen randomly and then the algorithm follows a set of steps to generate next generation of chromosomes. The set of chromosomes is called the population. The size of the population is kept constant during evolution. The following steps are followed to produce new generation.

4.1. Evaluating Fitness of Chromosomes

Each chromosome is evaluated according to its fitness. Fitness means the performance of the chromosome to be a good solution. Fitness of the chromosome is defined by a fitness function [25, 26].

4.2. Selection

After evaluating each chromosome, selection takes place. According to Darwinian Theory, the chromosome with higher fitness will survive. There are various methods for selection. We have used the most common Roulette-wheel Selection [26]. The probability of survival of i^{th} chromosome is defined as,

$$p_i = \frac{F_i}{\sum_{j=1}^{n} F_j} \qquad (2)$$

where,
F_i *= fitness of* i^{th} *chromosome*
n *= size of the population*
Detail description of Roulette-wheel selection is presented in [26].

4.3. Cross-over

Cross-over is a genetic operator which produces new chromosome by taking some parts of the chromosome from chromosome A and other parts from chromosome B. Chromosomes A and B are termed as parents and the new chromosome is child. Cross-over takes place with a certain probability, P_C which ranges from 0.5 to 1.0. There are several types of cross-over namely single point, two point, uniform cross-over etc. Two point cross-over [26] is depicted in Figure 1.

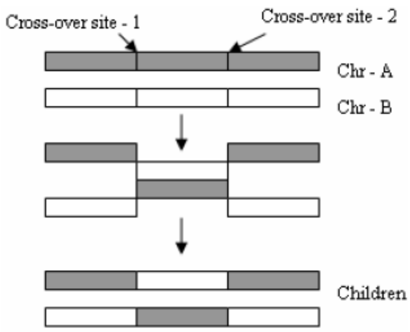


Figure 1: Two point cross-over.

4.4. Mutation

Mutation is another genetic operator which changes one or more genes in a chromosome. Mutation is also takes place with a certain probability, P_M. An example mutation is described in Figure 2.

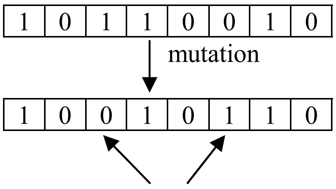


Figure 2: Mutation

4.5. GA Pseudo code

GA is summarized in Algorithm 2 and the flow chart for this is given in Figure 3.

Algorithm 2

```
1. Initialize the population.
2. Evaluate fitness of each chromosome.
3. If the fitness of the chromosomes
   have reached to desired level then
   go to step 8 else proceed to next
   step.
4. Select chromosomes in order to
   their survival probability.
5. Perform cross-over.
6. Perform mutation.
7. Go to step 2.
8. Stop.
```

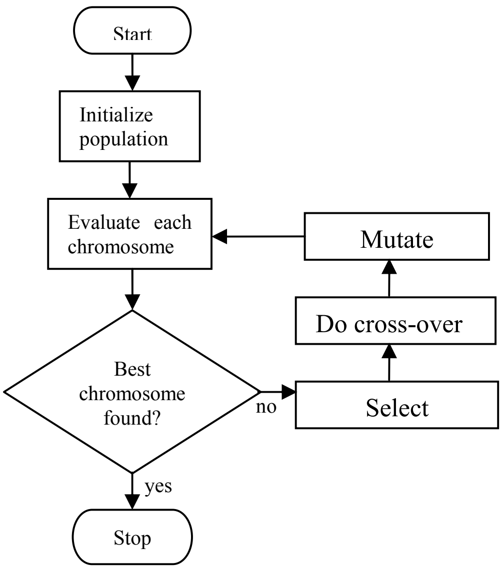


Figure 3: Flow chart for genetic algorithm.

5. The Proposed Method

In this section the proposed method is discussed in detail.

5.1. Deformable Eye Template

In the proposed method a template of size 25×12 was used. This template is constructed by manually cropping the eye region from 20 images. Then the average image is calculated which is the final template. The template is shown in Figure 4.

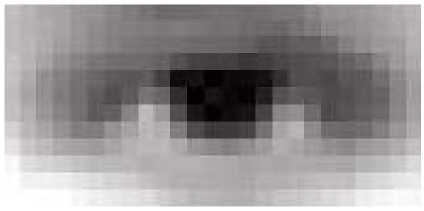


Figure 4: Template used in the experiment.

This template is deformed by changing its scale and rotation angle. The deformation mechanism is depicted in Figure 5. The transformation matrix [27] for scaling and rotation are as follows,

$$\begin{bmatrix} x' \\ y' \end{bmatrix} = \begin{bmatrix} s & 0 \\ 0 & s \end{bmatrix} \begin{bmatrix} x \\ y \end{bmatrix} \quad (3)$$

where, s is the scaling factor

$$\begin{bmatrix} x' \\ y' \end{bmatrix} = \begin{bmatrix} \cos\theta & -\sin\theta \\ \sin\theta & \cos\theta \end{bmatrix} \begin{bmatrix} x \\ y \end{bmatrix} \quad (4)$$

where, θ is the rotation angle

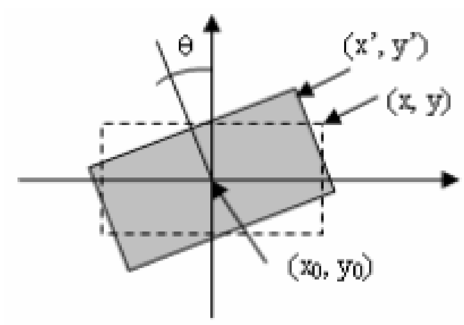


Figure 5: Deformation mechanism.

5.2. Chromosome Structure

The deformable template and its location on the face image are encoded into chromosome. The chromosome consists of the coordinate (x_0, y_0) of the template location, scaling factor, *s* and rotation angle, θ. All the values are encoded in binary form. The ORL image size is 92×112 so the values of x_0 and y_0 may vary in the range [0, 92] and [0, 112] respectively. For this reason the *x* and *y* coordinate can be encoded by 7 bits. Rotation angle is confined in the range [- 32, +31] and thus 6 bits are required for θ. Scaling factor *s* is taken from the set {0.5, 0.75, 1, 1.25, 1.5, 1.75, 2, 2.25} and 3 bits are needed to select any one value from this set. So the total length of chromosome is 7 + 7 + 6 + 3 = 23. The structure of the chromosome is presented in Figure 6.

x0:7 bits	y0: 7 bits	s : 3 bits	θ : 6 bits

Figure 6: Chromosome structure.

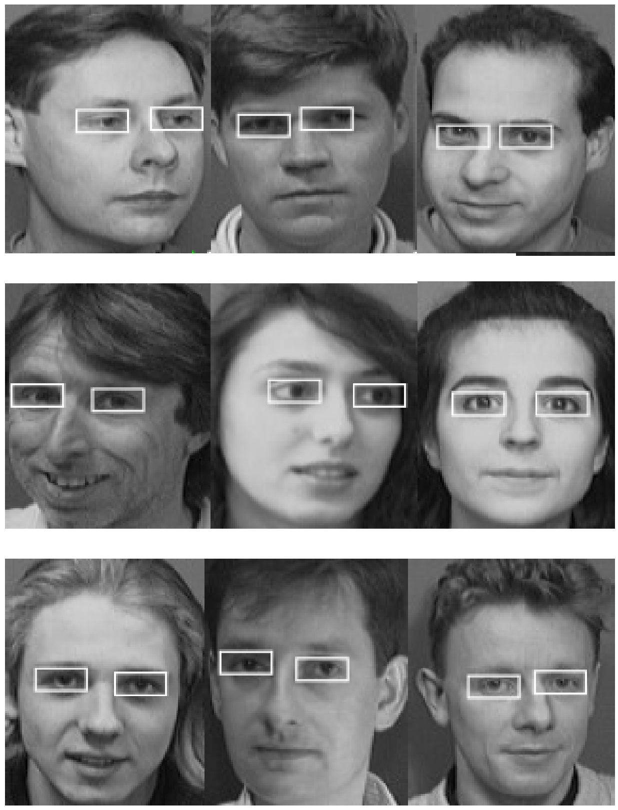
5.3. Template Matching by GA

Each time a new generation was created and average fitness of the chromosomes was calculated. If the average fitness is greater than 0.7 then eye detection was anticipated. Cross-over and mutation probability, population size, and maximum number of generations were varied to observe the performance of the method.

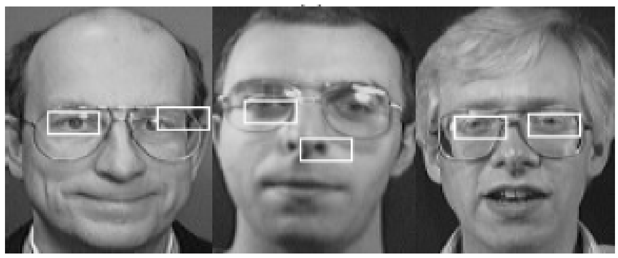
6. Experimental Results and Discussion

The proposed technique was implemented in Java programming language and run under Pentium-III (1GHz) machine with 256MB of RAM. 400 facial images from ORL database [5] were used to test the method. The accuracy of eye detection was 87.2%. Some true detection results are shown in Figure 7(a). Some false detection was seen due to strong reflection of spectacles which are shown in Figure 7(b). Some true detection was obtained for rotated eye presented in Figure 7(c).

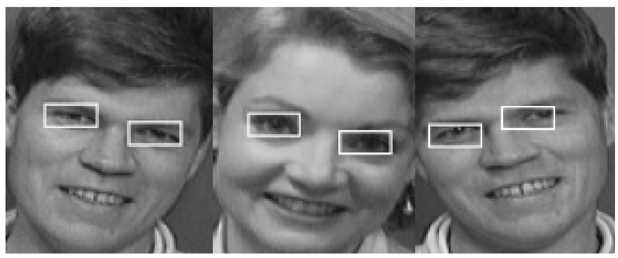
The average fitness vs. generation plot is given in Figure 8 for some test images. From these graphs it is clear that the desired cross-correlation value is attained after 20 generations, which is a great achievement over the existing techniques. It is obviously much less than the worst case complexity of conventional deformable template matching techniques.



(a)



(b)



(c)

Figure 7: Detection results: (a) True detection, (b) False detection, (c) Detection of rotated eye.

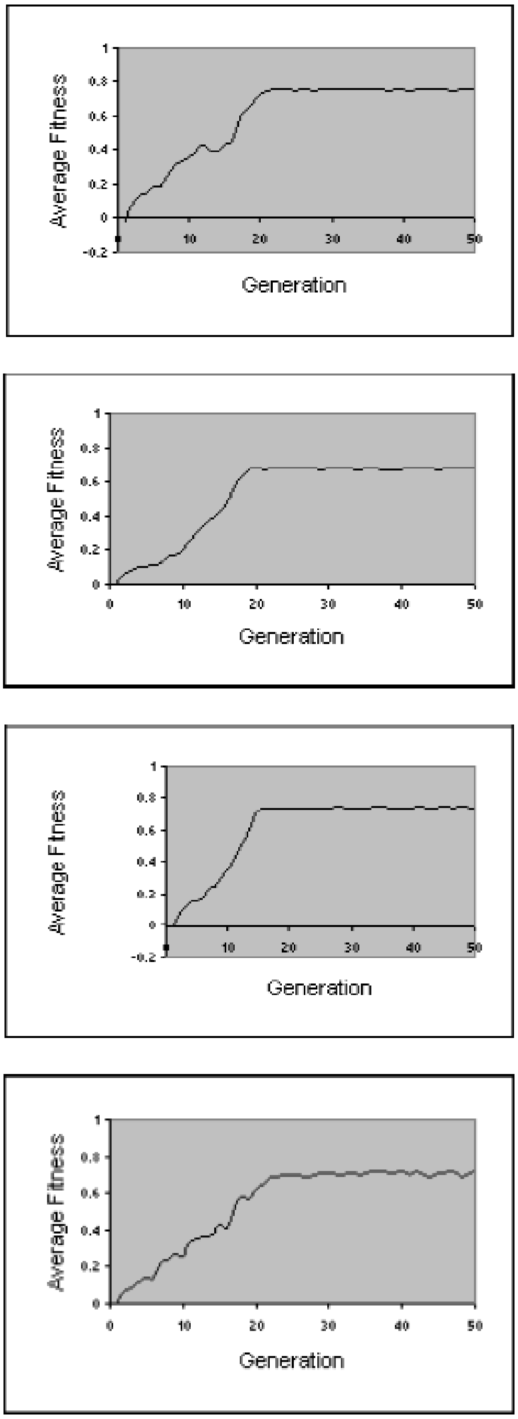
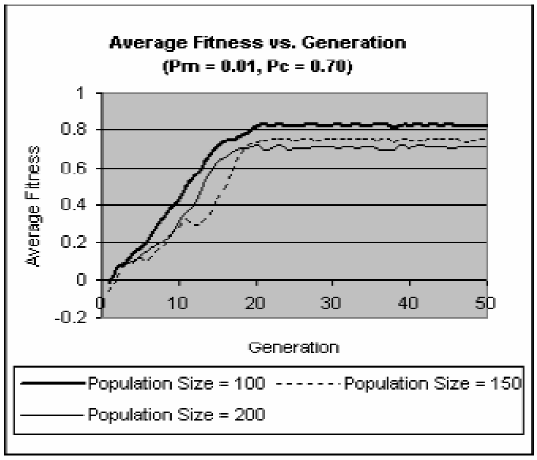
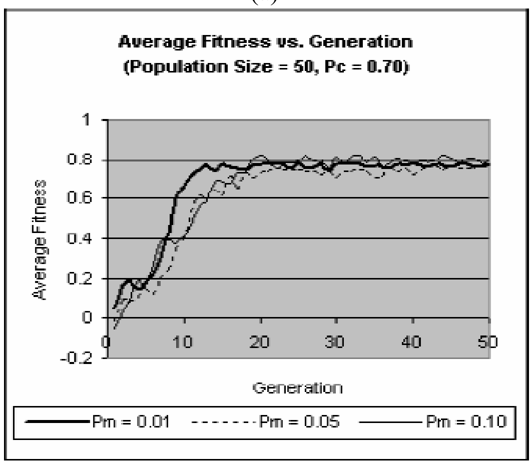


Figure 8: Average fitness vs. generation graph for some test images.

The probability of mutation and cross-over, and population size were changed and observed that changing in these parameters does not affect so much to the matching performance. Some results are shown in Figure 9.



(a)



(b)

Figure 9: Results of changing GA parameters: (a) Change in population size, (b) Change in mutation probability.

7. Conclusions

A novel eye detection scheme is proposed in this paper which relies on genetic algorithm based deformable template matching. The method does not require any sophisticated mathematical calculation and prior knowledge about eye geometry or potential eye location tags like head contour or nose position. It is shown that the GA based deformable template algorithm can find out eye location within only 20 generations for ORL facial images.

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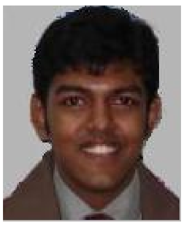

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