Iris and eye corner detection by processing internal webcam images

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Abstract: In this study, the aim is to extract the attributes of the eye regions of laptop users. To achieve this, the iris and eye corners are detected by processing the images captured by the standard internal webcam of a laptop. In addition, an artificial neural network (ANN) is used for determining the eye region. Hereby, the iris and eye corners can be detected in the determined eye region. In the study, 107 user images are captured by using a laptop's internal camera under different light intensities, environments, viewpoints, and positions. These images are used for the training of the ANN. Two different methods are used for the iris detection. In the first, circular Hough transform (CHT) is employed for iris detection in the determined eye region. In the second, the right and the left iris regions are determined by using two different ANNs respectively and then CHT is employed for the iris. Higher success rates are achieved by the second method. In the next stage of the study, two different methods, weighted variance projection (WVPF) function and lowest valued pixels (LVP), are used for the detection of the eye corners. It is demonstrated that the second method has a higher performance than the first.

Key words: Eye region detection, eye corner detection, iris detection, webcam images

1. Introduction

Today, developments in computer technologies make it possible to process digital data faster while studies in digital signal processing have been expanding continuously. Digital image processing is also among the areas on which researchers have been focusing. Image processing is extensively used in image improvement, image compression, subject detection, subject tracking, processing radar images, processing biomedical images, and processing geographical images. In subject detection and tracking inside an image, studies on human faces are included. Detecting the face region in an image helps to gather data on face and eye regions.

Some data relating to the eye region are collected for different aims in various applications, such as (primarily) health [1], security systems, and person identification [2–5]. Recently, with the aim of applying reference inputs to control systems via gazes, many more studies have been conducted for the purpose of collecting data from the eye region [6–10].

As a challenging problem, it is clear that one of the main aims is to accurately obtain as many attributes as possible, for example detecting the iris, eyebrow, nose, and eye corners, by using simpler equipment such as webcams in place of infrared cameras.

Although characteristics of the system to be controlled (cursor on the computer screen, encoding system

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on the virtual keyboard, text editor, mechanical robotic arm or robot) and the purpose of control are supposed to influence the hardware to be used, it is obvious that a camera will be used to take pictures and these images will be processed.

In this study, the aim is to extract eye region attributes by processing the image obtained by an internal webcam. For this purpose, eye and iris regions are found by employing an artificial neural network (ANN) in webcam images. Methods such as circular Hough transform (CHT), weighted variance projection function (WVPF), and lowest valued pixels (LVP) are utilized to determine the iris center and eye corners in these regions.

Gaze coordinates can be estimated by means of the obtained attributes and then used in various research areas. For instance, gazes can be used to enter passwords from a virtual keyboard without using its keys, to apply reference inputs to control systems, to move a cursor without using a mouse, and to meet some objectives in 3D games and private applications.

2. Literature review

Studies interested in processing images containing the human face differ from each other depending on the processing method and the purpose of the study. For example, some are concerned with eye disease diagnosis, while others are related to biometric recognition systems or tracking eye movements.

The purpose of this study is to extract eye regions from the images of people captured by a webcam from the front. For this process, the ANN is used and then the results obtained with the ANN are compared to some other effective methods. For images captured under different lighting conditions, the proposed method with the ANN is found to have more effective results [11]. Similarly, the eye region is detected by using wavelet transform and a support vector machine (SVM)-based classifier [12]. Principal component analysis (PCA) is used in order to determine the iris region in the eye region [8].

CHT is one of the most common methods for detecting iris edges. It is especially preferred due to its robustness against noise [1]. The iris is extracted from the image using a discrete approximation of an integro-differential operator (IDO) to define personal iris properties [4]. In another study [3], an IDO was used to find the iris and it was stated that an IDO can be regarded as an advanced variant of the Hough transform.

The WVPF, proposed in [13], is one of the most promising methods and is used for finding the corners of eyes. In this method, first of all, the corner of the eye in the image is determined, the row and column variances of pixel values are calculated, and then the resulting calculations are multiplied by a weighting factor to determine the weighted variance values. The maximum values of weighting variances on the rows and columns that represent the coordinates of the corner of the eye in the image are found [13].

In some studies, the aim is to find corners of eyes based on determining the upper and lower eyelid curves. In these methods, the intersection points of eyelid curves indicate the eye corners [8,14].

In some other studies, eye corners can also be used in order to detect eye regions. In these kinds of studies, after the face region is described by applying a skin filter to a gray-level image, eye corners are determined with the help of linear filters and then the eye region is found. According to Sirohey and Rosenfeld [15], it is possible that the problems in these methods can be overcome by employing a nonlinear filter, which achieves better results with regards to the determination of the eye region. In Sirohey and Rosenfeld's study, a nonlinear filter is designed accordingly to determine eye corners and hence eye region in colored images.

In Batista's study [7], the following algorithm was proposed to find the corners of eye:

"If the eyes are closed;

1. Convert from coloured into greyscale image and apply a contrast stretching to increase contrast

2. Apply a vertical gradient mask to sharpen the horizontal edges and the coloured image is changed into a black-white counterpart by thresholding

3. Obtain the skeleton of the eye region by using the pruning operator

4. Select the end-points of the skeleton as the eye corners" [7].

"If the eyes are opened;

1. Convert from coloured into greyscale image and apply a contrast stretching to increase contrast

2. Taking the previously segmented iris, obtain the VPF values on the horizontal vicinity of the iris; these values will encode the grey level variability that exists between the dark regions of the eyelids and the bright area of the sclera

3. Obtain an estimate for the location of the eye corners by thresholding the VPF values

4. Threshold the image in order to enhance the iris and upper eyelid areas, and remove the pixels that belong to the previously segmented area of the iris

5. Obtain the skeleton of the remaining region and fit a polynomial function to the skeleton

6. The end-points of the skeleton polynomial function are used to locate the eye corners

7. Combine the information supplied by both approaches" [7].

3. Material

A laptop computer that has a 2.13 GHz dual core processor, 1.3 megapixel internal webcam, and 2 GB RAM is used in this study.

For training the ANN, the database set is prepared by capturing 107 images of the user ($480 \times 640 \times 3$) via the laptop's internal webcam with different light intensities, environments, perspectives, and positions. In addition, the testing database set is also prepared by capturing 20 images ($480 \times 640 \times 3$) of the same user with similar processing as above. Although the capture distances (40–80 cm) are different from one another, the average of all is 50 cm.

MATLAB is used for the process of image processing and the following MATLAB toolboxes and functions are utilized:

○ Neural Network Toolbox,

○ Image Processing Toolbox,

○ Wavelet Toolbox,

○ CHT functions (circle_hough, circle_houghpeaks, circlepoints) developed by Young [16],

○ MATLAB functions developed by the researchers.

4. Method

While the user looks at different coordinates on the laptop screen, it is intended that attributes of the user's eye region, effective ones in identifying the coordinates of the iris and eye corners, are accurately determined. For this purpose, the location of the iris center, radius of the iris, location of eye corners, distance between the iris centers, and distance between eye corners and iris center can be determined by identifying the iris and eye corners in the captured image. The iris radius and the distance between iris centers are thought to include the user's distance to screen, and the eye region starting coordinates, as well as the distance of eye corners between each other and the iris center, is thought to include the viewpoint angle knowledge. The aim of this study is to determine these attributes of the user's eye region by processing the image. The flow chart prepared for this purpose is given in Figure 1.
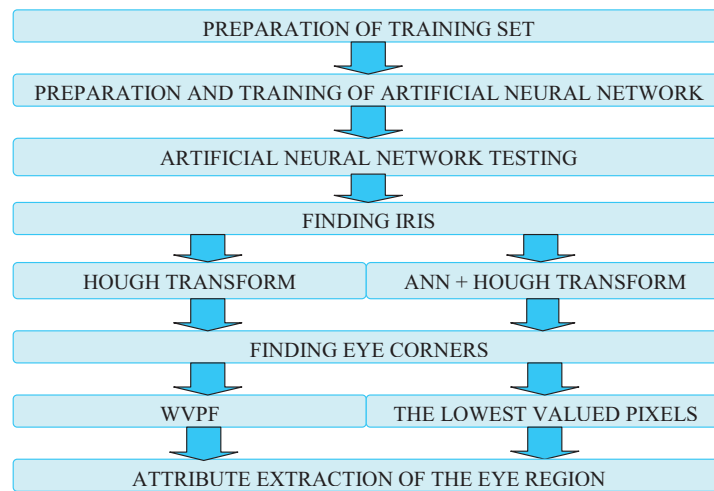

Figure 1. Flow diagram used in this study.

4.1. Preparation of training set

At this stage, the eye region [48 × 160] is manually found by converting colored images captured from the webcam into gray-level images. A total of six images, one correct and five wrong, are acquired from each image representing the eye region. A three-degree wavelet transform is applied to these images, data are turned into a vector of size 1 × 120, and the training set is constituted. User images used in the preparation of the training set and the eye region that is obtained manually from these images are represented in Figure 2.
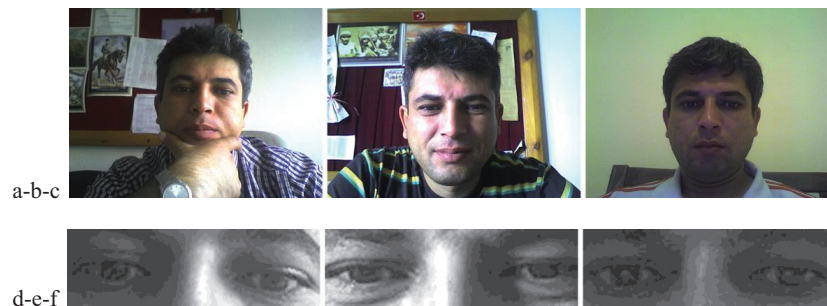

Figure 2. a, b, c) Laptop user images captured by webcam; d, e, f) obtained eye regions from webcam images for ANN training set.

4.2. The preparation and training process of the artificial neural network

In the study, a feedforward backpropagation network model is used. The input matrix (642 × 120) with the target matrix (642 × 1, 1 for correct entries and –1 for wrong entries) is applied to the ANN. The ANN parameters are updated according to the results obtained from test data. The ANN was constituted as given in Table 1 after many attempts.

Table 1. ANN parameters used for the eye region's presence.

Set of inputs	107 true, 535 false images' data used in generating the input vectors
Network model	Feedforward backpropagation
Number of layers	1 middle layer, 1 output layer
Number of neurons	Middle layer 150 neurons, output layer 1 neuron
Activation function	Middle layer logarithmic sigmoid; output layer tangent sigmoid
Learning algorithm	trainscg
Learning coefficient	0.6
Momentum coefficient	0.8

The generated ANN is trained many times, and it is observed that the number of intervals is in the range of 300–350 and the necessary time interval for training is in the range of 25–35 s.

4.3. The testing process of ANN

After the ANN was trained, it was applied to the test set and achieved 100% success rate. The ANN training was repeated for all sets of samples and success rates were observed in the range of 90%–100% for different training processes. This success rate has been defined according to number of finding the eye region (true or false) in total test images. The ANN that provides a 100% success rate is preferred in the study. Some images obtained by the application of the ANN to the test set are given in Figure 3.

Figure 3. a, b, c, d) Eye region examples found by the ANN.

4.4. The process of finding the iris

Determination of geometric shapes in images finds many application fields. Some of them can be listed as object identification, iris detection, and plate detection. For example, Hough transform is used to determine straight lines in black and white images. In addition, it is used in the determination of nonlinear curves.

CHT is widely used to find circular shapes. It works according to the voting method [17]. The possibility of being the center of each pixel in threshold images is evaluated, and hence the pixel with the highest vote is accepted as the center [1]. When it is assumed that (a, b) are the coordinates of the circle center and r is the radius of the circle, the center of the circle can be found using the following equation for radius values in the specified range:

$$\begin{aligned}
r^2 &= (x-a)^2 + (y-b)^2 \\
x &= a + r \times \sin(\theta) \\
y &= b + r \times \cos(\theta)
\end{aligned} \tag{1}$$

Two different methods are used for finding the iris in the eye region. First, after the separation of the right and left eye regions, prefiltering, Canny edge detection algorithm, and CHT processes are applied to try to determine the iris in the image. In this study, initially, minimum and maximum radiuses are determined according to possible iris size as the CHT is applied to the image in which the iris is sought. Then the white points that are as distant as the radius around each point within the black and white image are counted and the pixel coordinate with the largest number of white points is determined as the center of the iris. In this method, the success rate, which has been defined according to overlap of the iris in test images and the circle obtained by CHT, is not high despite the fact that it is repeated by making different repeated prefiltrations.

In spite of CHT's common usage in the process of finding the iris and the achievement of higher success rates, the success rate appears lower than expected in this study. This result depends on two possible reasons: the first is the fact that the image is captured closely and the second is the use of an infrared camera in those studies with a high success rate. It is observed that the first has a positive effect on finding the iris accurately, and the second also has a positive effect on the sensitivity of the circle drawn around of the iris.

For this reason, the second method is preferred for this study. Using this method, the aim is to narrow the region where the CHT searches for the center of the iris with the aid of two different ANNs. Accordingly, two different ANNs are developed for this purpose and are prepared to find the iris regions in the eye regions. By ignoring low sensitivity caused by light intensities, the success rate of finding the iris can be increased with the second method. In this method, regions inclusive of the iris region in the size of 24×24 are determined within the right and left eye region, and matrixes in the size of 6×6 are obtained by applying wavelet transform. These matrixes are applied to the ANN by turning them into a 1×36 vector and the target matrix as 1 for each correct entry and –1 for each wrong entry. The ANN parameters are updated according to the results obtained from test data. The features of the ANN that is developed to find the left iris region are given in Table 2. Features of the ANN developed to find the right iris region are given in Table 3.

Table 2. ANN parameters used for the left iris region's presence.

Set of input	107 true, 535 false images' data used in creating the input vectors
Network model	Feedforward backpropagation
Number of layers	1 middle layer, 1 output layer
Number of neurons	Middle layer 150 neurons, output layer 1 neuron
Activation function	Middle layer radial basis; output layer tangent sigmoid
Learning algorithm	trainscg
Learning coefficient	0.7
Momentum coefficient	0.8

Table 3. ANN parameters used for the right iris region's presence.

Set of input	107 true, 535 false images' data used in creating the input vectors
Network model	Feedforward backpropagation
Number of layers	1 middle layer, 1 output layer
Number of neurons	Middle layer 100 neurons, output layer 1 neuron
Activation function	Middle layer radial basis; output layer tangent sigmoid
Learning algorithm	trainscg
Learning coefficient	0.7
Momentum coefficient	0.8

Eye region images that are used in the preparation of the training set and the iris region that is obtained manually from these images are represented in Figure 4.
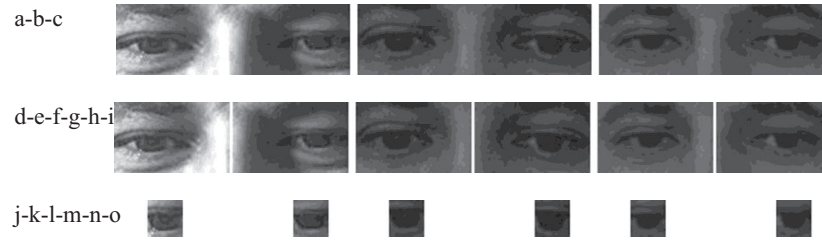
Figure 4. a, b, c) Eye regions; d, f, h) left eye regions; g, h, i) right eye region; j, k, l) obtained left iris regions from eye regions for ANN training set; m, n, o) obtained right iris regions from eye regions for ANN training set.

It is clear that the success rate of finding the iris is increased thanks to the fact that CHT is applied to the right and left iris regions found by using these ANNs. Samples obtained by employing both the ANN and CHT together (in the iris region) and only CHT (in the eye region) are given in Figure 5.
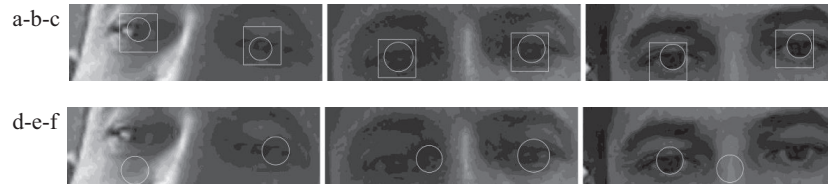

Figure 5. a, b, c) Samples of iris detection by ANN and CHT together (in the iris region); d, e, f) samples of iris detection by CHT alone (in the eye region).

4.5. The process of finding eye corners

Two different methods are used to find the eye corners. The first of these is WVPF. The other is originally proposed in this study and is based on the principle of the detection of LVP. Eye corners are found by using both methods, and in this context, the obtained results are compared with each other.

VPF is one of the most highly used methods for finding the iris region in the eye region [18,19]. The WVPF, which is developed based on VPF, is used to find the eye corners. First of all, the regions that have the probability of being eye corners are detected and then the pixels in the image are weighted according to the probability of being a corner by the Harris Corner Detector. Lastly, eye corners are found by processing the weighted values via VPF [4]. Horizontal and vertical WVPF equations are shown below.

Vertical WVPF:

$$\delta_{wv}^2(x) = \frac{1}{x_2 - x_1} \sum_{x_i=x_2}^{x_2} R(x, y_i) * [I(x, y_i) - H_m(x)]^2 \tag{2}$$

Horizontal WVPF:

$$\delta_{wh}^2(y) = \frac{1}{y_2 - y_1} \sum_{y_i=y_2}^{y_2} R(x_i, y) * [I(x_i, y) - H_m(y)]^2 \tag{3}$$

As shown in the vertical and horizontal WVPF equations, the weighting factor (R) located for each pixel is used in the calculation of the variance. Maximum values of the row and column variances give the coordinates of the corner point.

Finding the lowest value [20–22] is used as a simple strategy [23] in many studies. LVP, which is developed for eye corner detection in this study, is used to find the eye corners. First, the regions that have the probability

of being an eye corner are determined by the proposed method. Then prefiltration processes are applied to the determined regions. Eventually the location of the lowest valued pixels in the related region is determined and thus eye corners are accurately detected.

Samples belonging to eye corner regions and eye corner detection are given in Figure 6.
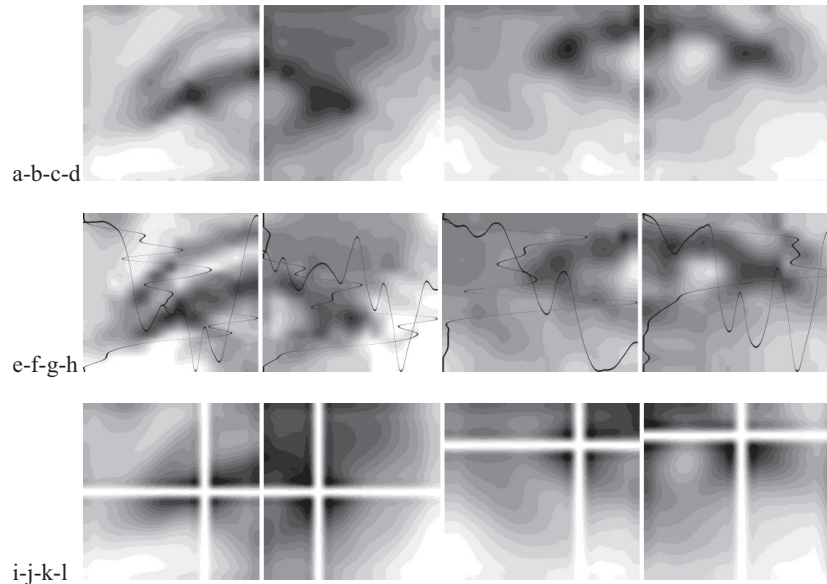

a-b-c-d

e-f-g-h

i-j-k-l

Figure 6. a) Outer corner region of the left eye; b) inner corner region of the left eye; c) inner corner region of the right eye; d) outer corner region of the right eye; e, f, g, h) finding eye corner by WVPF; i, j, k, l) finding eye corner by LVP.

The sample images with either correct or false results produced by WVPF are given in Figures 7a–7f. Since the left iris region in Figure 7d and the right iris region in Figure 7e are not determined correctly by the ANN, accordingly the determination of irises and eye corners is not correct normally.
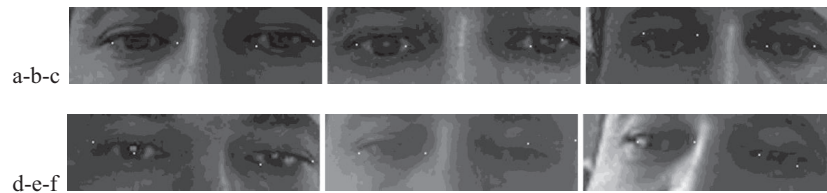

a-b-c

d-e-f

Figure 7. The results obtained by WVPF.

The sample images with either correct or false results produced by LVP are given in Figures 8a–8f.
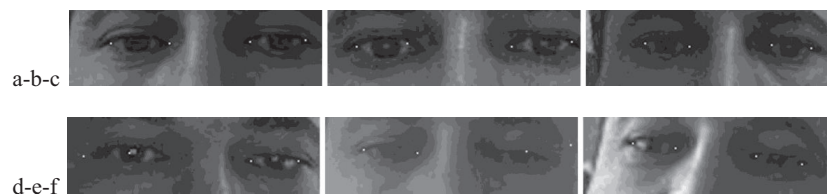

a-b-c

d-e-f

Figure 8. The results obtained by LVP.

Owing to the fact that the left iris region in Figure 8d and the right iris region in Figure 8e are not determined correctly by the ANN, the determination of irises and eye corners are not correct normally. The

other samples examined are found more accurate for the eye corners by LVP. LVP has higher success rates than WVPF.

4.6. The extraction process of attributes

As a result of determination of the iris and eye corners in the image, the attributes that can be extracted are given below.

1. The initial coordinates of the eye region.

2. The radius of the iris region.

3. The coordinates of the iris center.

4. The coordinates of eye corners.

5. The distance between the eye corners and the eye center.

6. The distance between the left and right eye centers.

7. The distance between the corners of the same eye.

These extracted attributes can be used as the input data of an ANN that was developed with a view to determining the gaze coordinates of anyone who looks at a point of the laptop screen, but a training set that determines gaze coordinates must be prepared for this purpose nonetheless.

5. Results

In this study, an algorithm for extracting some attributes of the eye regions of laptop users is developed. The laptop users' images captured by an internal webcam are used to detect the iris and eye corners in order to achieve this.

By virtue of the ANN that is developed in order to find the eye region, applied to 20 test images, 100% success rate is achieved.

In the second stage, CHT is applied to the eye region in order to detect the iris, but a lower success rate is obtained than expected. In order to increase the success rate, the iris is sought in a narrowed region obtained with the aid of two different ANNs. First of all, two different ANNs are developed for finding the narrowed left and right iris regions. Then the CHT is applied to these regions. In the context of the proposed method, the achieved success rates for the detection of the iris are given in Table 4.

Table 4. The results obtained using two different methods for detecting the iris.

After separating the left and right eye regions			
CHT		ANN + CHT	
The success rate of detection of left iris in left eye region by CHT	The success rate of detection of right iris in right eye region by CHT	The success rate of left iris region detection by ANN	The success rate of right iris region detection by ANN
		95%	90%
75%	65%	The success rate of detection of left iris in left iris region by CHT	The success rate of detection of right iris in right iris region by CHT
		100%	100%

These values given in Table 4 contain the obtained results of finding the iris. Sensitivity of the drawn circle is not taken into account. When Table 4 is examined, it is clear that the success rate of the left and right iris detection is 100%, except for the images where the iris region is incorrectly found by ANNs. On the contrary, the correct detection rate of the left iris is 95% and the right iris is 90% respectively when all the images are considered. As seen from the table, according to the first method, the success rate is increased to 26.66% for finding the left iris, and it is increased to 38.46% for finding the right iris by using the second method.

In the next stage of this study, the aim is to detect eye corners. First, WVPF is used for this purpose, but it does not provide the desired success rate. For this reason, an attempt is made to develop a different proposed method. In this proposed method, first the eye corner region is found and then subjected to prefiltration. In this way, the eye corners are determined by finding the location of the lowest valued pixels in the eye corner region. The second method increases the success rate as expected. The success rates obtained here are presented in Table 5.

Table 5. The results obtained using two different methods for detecting the eye corners.

After determination of the inner and outer corner regions for the left and right eyes		WVPF	LVP
Left eye	Outer corner	60%	90%
	Inner corner	40%	80%
Right eye	Outer corner	40%	80%
	Inner corner	70%	85%

As demonstrated in Table 5, the success rates obtained using WVPF are not high, notwithstanding the use of different prefiltering methods. However, higher success rates are achieved by the proposed method, which is referred to as the second method. The obtained ratios consist of all the images of the iris that include incorrect results produced by ANNs. As seen from the table, according to the first method the success rate increases to 50% for finding the left eye outer corner, 100% for finding the left eye inner corner, 100% for finding the right eye inner corner, and 21.43% for finding the right eye outer corner by using the proposed method. The obtained ratios are reached by including the images in which irises are found incorrectly.

The graphs given below in Figure 9 are prepared to provide a better understanding of the results. While the horizontal axis represents each test image, the vertical axis is designed to represent the Euclidean distance between the manually determined real eye corners with situated eye corners by using the WVPF and LVP methods.

On the graphs, the real location of an eye corner is expressed with a red line. Euclidean distance between the location of the real eye corner and the location of the situated eye corner by LVP is expressed in the positive direction and with a blue line, and Euclidean distance between the location of a real eye corner and location of the situated eye corner by WVPF is expressed in the negative direction with a green line.

Upon analyzing the graphs, it can be clearly seen that the coordinates situated by the proposed method represent the eye corners more precisely than the coordinates situated by WVPF. In this respect, the values given in the graphs are similar to the values listed in the tables.

However, in the graphs, the success rate is relatively low. As seen in a few samples, Euclidean distances cannot represent points as acceptably as eye corners. In this study, in a few samples, although the coordinates determined by LVP and WVPF are different from the real coordinates, it is decided to represent the eye corner. The sample images regarding that are given in Figure 10. In the images, manually specified eye corner points
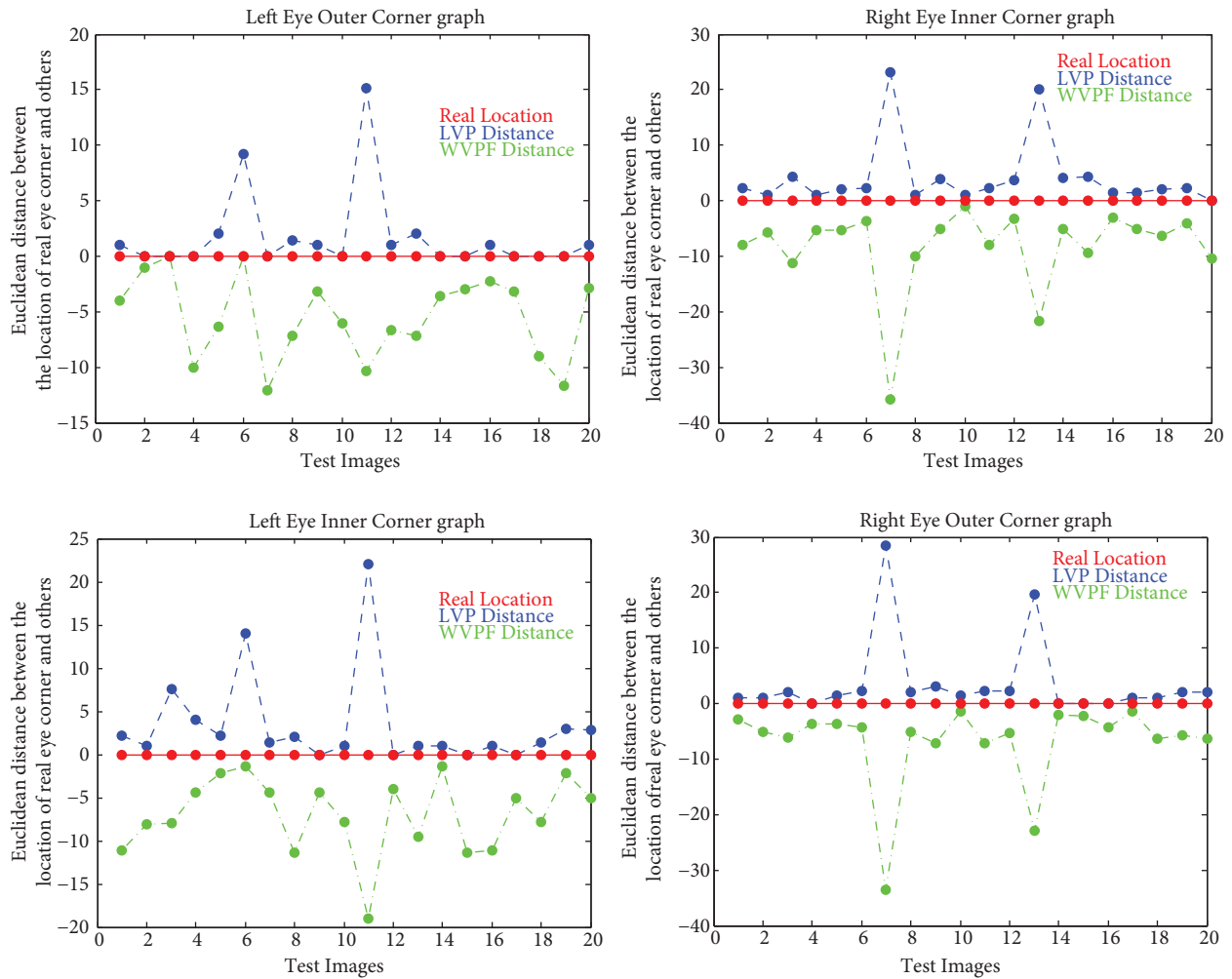
Figure 9. Euclidean distance between the location of real eye corners and others.

(reference points) are expressed with a red point, the situated location of the eye corner by LVP is expressed with a green point, and the situated location of the eye corner by WVPF is expressed with a white point; when red and green are mixed in the image it has turned to yellow.

As seen in Figure 10, the reference points and the situated coordinates by LVP are seen to overlap while the left eye outer corner and right eye inner corner are determined, but the situated coordinates by WVPF are different and cannot be regarded as the eye corner. In addition, the reference points and situated coordinates with each of the two methods do not overlap while the left eye outer corner and right eye inner corner are determined. It can be seen that the situated coordinates by LVP may represent the eye corner, but the situated coordinates by WVPF do not.

Again in another example the image analyzed in Figure 11 is seen overlap between the reference points and the located points with LVP, but the located points for the left eye and right eye outer corners determined by WVPF are seen in a different place. Although the reference point can be considered as a Euclidean distance, the located point for the right eye outer corner is not been considered as an eye corner because it is not on the line formed by the combination of the eyelids. The located point for the left eye inner corner determined by LVP, which is similar to the Euclidian distance to the reference point, has been considered to be the eye corner

as the line mentioned above. In addition, the located point for the right eye inner corner has been considered as an eye corner because of being very close to the reference point.
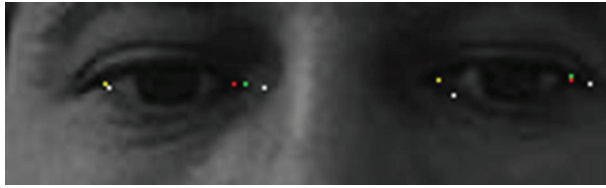

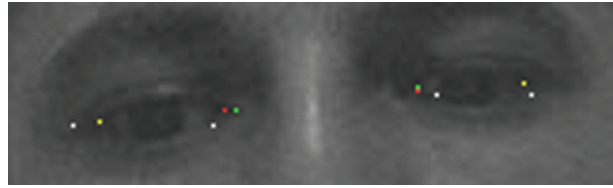**Figure 10.** Real eye corners and situated eye corners.

Figure 11. Real eye corners and situated eye corners.

6. Analyses of results

It is scarcely possible to find the iris or eye corners in large-sized images. Therefore, an ANN is developed to find the eye region in the image. This ANN has a 100% success rate. In addition, two ANNs are developed to find left and right iris regions within the eye region so that the search area of the iris is narrowed.

The development and training of an ANN is a preliminary study and done once; the testing stage does not create any burden on the run-time of the program. However, the fact that each test image is to be independent from the previous one and the eye regions are to be found by scanning the test images increases the program's running time. Nevertheless, since the sequential images in real-time studies are hardly independent of each other, the running time of the program can be reduced by developing an appropriate scanning algorithm.

In the next stage of the study, it is clear that the success rate of finding the iris is increased by using the ANN and the CHT together. The reason behind this increased success rate is that the region where the iris is sought in the images is narrowed by the ANNs. It is also evident that the sensitivity in finding the iris is important in order to achieve more accurate results in the attribute extraction.

Finally, eye corner regions are determined after the determination of the iris in the image. In these regions, the eye corners are sought using two different methods, WVPF and LVP. Higher success rates are reached by employing LVP.

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