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Diagnosis Oculomotor Dysfunction with Eye Tracking Technology

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Abstract

We proposes a computer aided diagnosis system(CADx) for tracking and analyzing the movement of the eye ,which has many applications in medicine including diagnosis of oculomotor dysfunction. this process should be done in an environment with proper lighting with a laptop and a webcam. The architecture of the proposed system consists of two phases. In the first phase, pupil of the eye is tracked and its position is saved into a database.

in the second phase prediction the oculomotor dysfunction. is done by The neural network which is trained based on 112 data which includes 57 patient with normal condition and 55 patient with oculomotor dysfunction. Also 100 data have been used to evaluate the precision of the system. Precision in diagnosis of the tested samples as if they are healthy or unhealthy is evaluated as 84%. proposed system can be used as a supplement of physician’s suggestion to improve the diagnosis in clinical environment.

Keywords: *eye tracking, image processing technology, iris detection, oculomotor dysfunction, neural network, diagnose with computer.*

1. Introduction

Nowadays the influence of the eye tracking technology in different aspects of human life such as: medical scope, security, advertising and marketing and automobile industry have been caused to generation of some data. analysis of such data has resulted to some changes including the establishing interactional systems which can help disable persons, diagnosis of the attention level in drivers, more precision diagnosis of some illnesses like neural based diseases and etc. [1],[2],[3].

Oculomotor dysfunction is a disease that happens because each muscle around the eye are not properly coordinated and the patient can not follow the lines whilst he/she is reading [4].

Diagnosis of this disease can be done by the observation made by the physician, in such a way that the object is moved directly and the patient have to follow the object by his eye, which in this method you should refer to the physician. The recommended system due to not requiring the special equipments has this capability that the patient can be inspected remotely and without need to visit the physician. Also the experiment by the observations can have some errors in some intervals for detection of the movement of the pupil. The recommended system with simulating by the physician can be implements and recording the center of the eye pupil of the patient can inspect and search the following of the object by the eye of the patient in all of the time intervals. The above mentioned system as a computerized diagnosis system can be used as a complementary tool for opinion made by the physician in the clinical environments or it can be used online.

In the following the next 5 sections, Literature Review, Methodology, Results, Discussion and Conclusion and Recommendations are provided.

2. Literature review

In the present section of the paper based on the main parts and components of the system including: face detection, eye detection, eye tracking, the related works and literature and different researches related to each of these fields will be discussed and studies separately.

2.1. Eye tracking methods

Eye tracking structurally can be conducted in two ways: 1. Remote 2. Head-mounted. Remote tracking is similar to the recommended non-interventional method and without using from the special equipments applied by a physician and it is done by a camera like a webcam in order to find and detect the clear features and specifications of the eye.

In contrast the Attached to Head method is similar to [5], [6], [7], [8], [9], and [10] in which a camera will be placed with a special equipment in front of the patient eye and detect the patient eye pupil directly. Although the accuracy of the latter method is higher, but the first method (Remote Tracking) because it does not need any complicated equipments, can be used by different devices such as portable laptops, mobile or tablets. The Eye tracking methods according to [11] can be categorized to 4 main methods: 1. Search circle / Contact Lenses for the White region of the Eye. 2. Electrical Eye-Graph 3. Video or projective eye-graph. 4. Combination of the light reflection from the cornea and pupil based on the video. The Search Circle method is conducted with placing a contact lens on the sclera of the eye which has an Aluminum rod in which due to movement of the eye, it moves [12]. The electrical Eye-Graph method is conducted by determining the potential difference of the skin around the eye and used from this feature to track the eye, but these two methods because in them the physical contact is required, are not desired by the users [13]. Also the forth method similar to [14] which can be done with a light source, tracks the eye with the light reflection and movement of the pupil of the eye. The third method which is the selected method to be used in the recommended system needs no special equipments or tools and it has no physical contact with the user, and by recording the video images and processing the video frames can track the eye movements.

2.2. Face detection methods

The face detection methods according to [15] can be dividend to 2 main methods: 1) Based on the feature, 2) Based on the image. The feature based method can detect the face in the image by using from the details and specifications of the face; while the image-based method can detect face similar to [16] and by using from the image itself as the input of the system. The feature-based method has 3 different methods itself: 1. Low level Analysis, 2. Feature Analysis, 3. Using from the active form models. In low level analysis method by using from the features if the pixels such as grey surfaces, colors and edges, which are affected by the changes in the light, the face can be detected [17]. The methodology used in this method uses from the feature analysis method in which a set of the Haar specifications and features which are not affected by the light, are used for detecting the face [18]. Active shape model can detect the oval shape of the face by detecting the convex objects, and in case there are any other oval shapes in the image, this method will have some problems. face detection methods based on the image includes: 1. Under the linear space method. 2. Neural network 3. Statistical methods by using from the positive and negative classes (The images including or not including the face), and system learning for detecting the face. Albeit the learning process is a long one and these methods have large amount of the process tasks.

2.3. Eye detection methods

Eye detection methods according to [19] can be categorized to 2 main methods: active and inactive. The active methods use from a light source such as Infrared Light source in order to detect the dark or bright pupil of the eye and by using from that can detect the eye [20]. Presence of light or lack of that in the environment can have effects on the size of the eye pupil which leads to errors in this method [1]. According to [21] the inactive method can be categorized to three sections: 1. shape based [22], 2. Feature based [23] 3. Appearance based [24] and the hybrid method [25]. The shape based method can detect the eye with the geometrical features such as line, circle. One of the disadvantages of this method is requiring high amounts of the calculations and images with high contrast. The methods used in the recommended system are the feature-based method in which the eye can be detected with the features of the eye. These specifications and features are the Haar features which are not affected by the light. The appearance-based method can detect the eye with learning the positive and negative classes which includes high volume of calculations. Finally the Hybrid method is a combination of the active methods for detection of the eye.

3. Research method

The presented system includes two main phases: 1) Eye tracking and 2) Analysis by using the neural network. The structure of he presented system is a hierarchical structure in order to confine and limit the search regions and increase the rate of the process [19] ,[26], [27]. With regard to two available eye tracking methods namely remote method and Head-attached method, [11] and with considering less dependency of the system to the special tools and equipments in order to use them without visiting physician, the remote eye tracking method was used and determined as the selected method. The operation of the system according to Fig.1 is as follow: The moving object is presented directly and the person under test should follow it by his eyes; then some images are captured by the camera positioned in front of the person immediately.

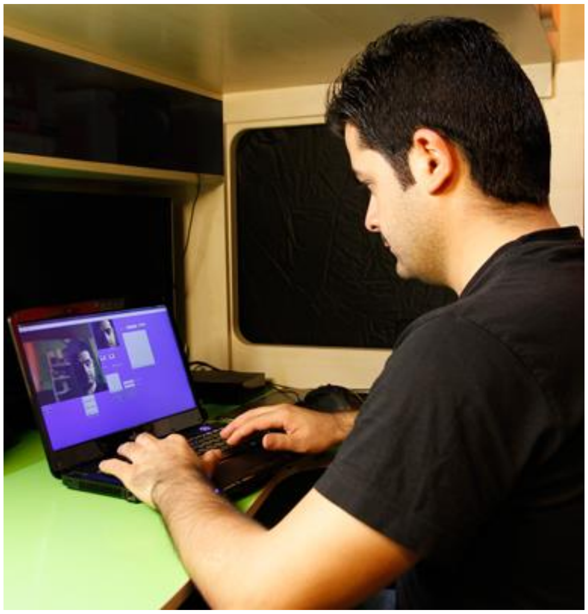

Fig. 1 Test a person with webcam and laptop

Some processes are done on each of the frames in order to standardize the images and then the face is detected and separated from the remaining of the image. After that the eye on the selected region should be detected, and by detecting eye and separating that from the remaining region, with doing the required processes on the image, the center of the pupil will be detected. Finally the coordination of the pupil of the user during this experiment will be recorded in the database. final video frame has shown in Fig.2.

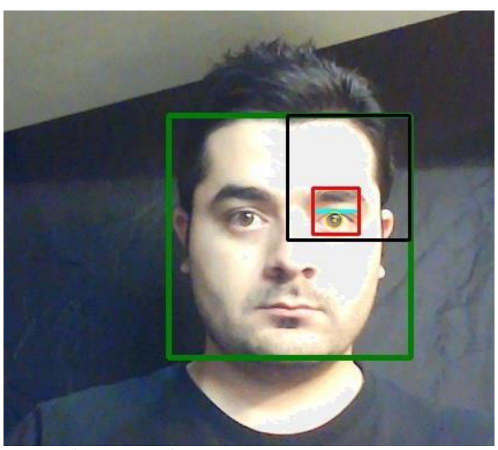

Fig. 2 final video frame processed by proposed system

The second phase of formation of the neural network consists of three steps generally: 1. Formation of the data resource. 2. Formation of the wave from the data resource. 3. Modeling. Finally by using from the recorded data in the first phase which are resulted from conducting this experiment on different people with known situations in terms of their health (Normal / Abnormal) and also using from the neural network, the situation of the new patient can be predicted. The recommended system by using from Eye Tracking Technology wants to study the movements of the pupil, and by this system we can diagnose some of the disabilities of the eye such as movement disability disease. In Fig.3 a schematic of the structure of the system in the operational environment is shown; when an object is moving and the person under the experiment should follow it with his eyes.

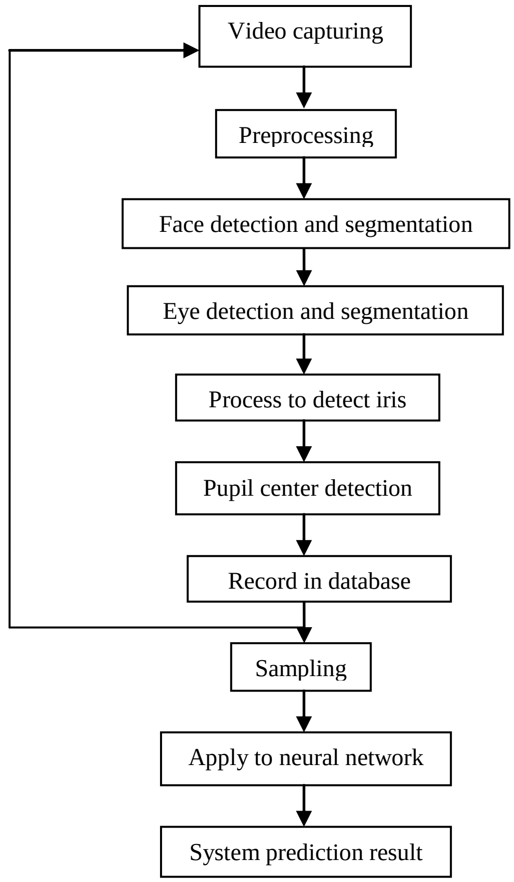

Fig. 3 Architecture of proposed system

3.1. Video capturing and preprocessing

The video captures real time from the person under the tests by a webcam, and some pre-processing operations are conducted in order to standardize the images. In order to do this standardization, after transforming the color images to the grey-scale images, the Equalization Histogram Algorithm is used in order to improve the contrast, and sensitivity of the face detection to the light changes is removed. This algorithm will lead to improve the contrast in images with the intensity distribution[28]. In other words according to Eq.1 we need to calculate the probability mass function(PMF) ,and cumulative distribution function(CDF) according to Eq.2, afterwards by Eq.3 normalizing the CDF.

$$\text{PMF(x)}=\frac{number\ of\ pixels\ with\ color\ x}{total\ number\ of\ pixels} \quad (1)$$

$$\text{CDF(x)}=\sum_{i=0}^{x} PMF(i) \quad (2)$$

$$\text{scaled CFD(x)}=\frac{CDF(x)-CDF(min)}{CDF(max)-CDF(min)} * 255 = CDF(x) * 255 \quad (3)$$

3.2. Face detection

Face detection is done with the Viola- Jones algorithm. This algorithm will conduct the face detection operation with 4 main key concepts: 1. Haar features. 2. Integrated image. 3. Learning algorithm. 4. Cascade classifier.

Haar features concept as seen in the Fig.4 is a set formed from the dark and bright pixels which can form some rectangles. The advantages of these specifications in comparison to the specifications of the pixels (Grey surfaces, edges and …) is not being sensitive to the light, and with having the scalability it can detect the objects in different sizes[29],[30],[31].

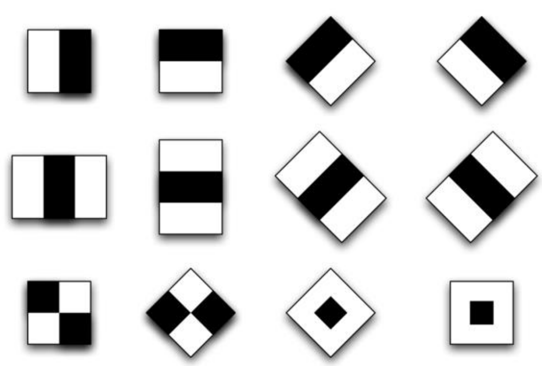

Fig. 4 Haar Features

The used algorithm in order to detect the face by using from a set of the Haar features, can detect the face of the user, and with regard to this fact that findings many of these specifications and features is a time-consuming task, then in order to decrease the volume of the calculations, a concept named an integrated image is used. In order to obtain an integrated image, the value of each pixel (dot) of the image is equal to the values of all of the dots which are located on the upper and left sides of that dot.

The third concept which is being used is the Learning Algorithm, which is used by using from the Haar specification and features and negative and positives classes (Images including and not including the faces) in order to learn the algorithm for face detection task, which its output is a classifier in order to detect the Haar specifications and features. In order to increase the rate of the Haar specifications detection in the above mentioned algorithm, a set from different classifier is used, in order to remove the parts of the images which probably do not contain any face, and in this way the search region will be less.

3.3. Eye detection

After detecting the face correctly, the eye search in that region will begin, in which a system for eye detection is using from the Haar features. With sectoring the face region to 4 sections as seen in Fig. 5 for searching the left eye, in the section 2 this task will be done. This will lead to not detecting other components of the face such as mouth or right eye instead of the left eye. Also it is clear that in order to detect the right eye, the section 1 can be used.

Fig. 5 face divided in to 4 section to increase accuracy for eye detection

3.4. Process to detect iris and pupil center

Because the iris is more clear and obvious in comparison to the pupil, and by considering the center of that as the center of the pupil, we can detect the iris. In order to detect the iris, Half Circle Transform Algorithms are used. In order to apply these algorithms, according to Fig.6 first some processes should be done in order to sector the eye iris, in order to detect that more carefully. These processes includes: 1. Erosion, 2. Threshold to binary. 3. Opening. 4. Smoothing.

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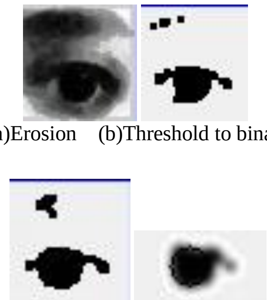

(a)Erosion (b)Threshold to binary

(c)Opening (d)Crop and smooth

Fig. 6 process to detect iris

According to [28] literature by using from the erosion operation, the dark regions will be darker, it means that the dark regions of the iris will be darker, and with the threshold to binary operator, the iris will be significant as a dark object in the bright background [32]. Therefore, in order to increase the coherence and consistency of the iris circle, the opening operator will be used in order to remove the white regions in the dark regions of the eye iris. Finally the noise of the image will be removed by the Gaussian filter, and by using from a Half Circle Transform Algorithm, similar to [33], the eye iris will be detected and its center will be considered as the center of the pupil. In order to remove the false detections of the circles as the iris region which probable be present in the eyebrow and sclera region, the eyebrow region is removed from the detected eye region, which is shown in Fig.7. Also in order to remove the false detections in the sclera region instead of the eye iris, the pixel value of the iris center was determined in order to check it with the true value and in case there is any inconsistency with the pixel value of the iris center, the false detection will be removed.

Fig. 5 Eyebrow region is cropped

3.5. Record in database

Finally the center of the detected pupil center will be saved and recorded in the data base. In the data base, all of the obtained coordination during the conducted tests will be recorded in order to identify the effect of the number of coordination in predictions related to the patient statues on the accuracy of the system.

3-6)apply to neural network and prediction result

By applying the coordination of the center of the eye pupil on the neural network of the desired person under the tests, the status of the person will be predicted. This status can be declared as normal or abnormal situation. topology of this system's neural network has shown in Fig.8.

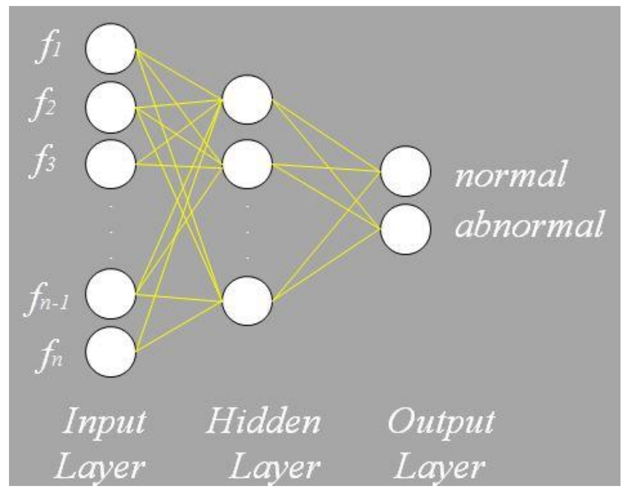

Fig. 6 neural network topology of proposed system

Formation of the neural network in order to analyze the data of the first phase includes 4 steps: 1. Defining the data source. 2. View definition. 3. Creating a mode. 4. Applying the input for the neural network, which these steps all will be done in the SQL Server Business Intelligence software. In the first step, the database of the system will be introduced as the data sources. Then in the next phase, the required specifications in order to teaching the system will be defined, these features and specifications includes the coordination of the center of the eye pupil of the patients' which their situations diagnosed by a physician through a clear-eye test. In the third step, after creating a model, the input and output of the neural network algorithm will be defined and the data and patterns will be provided for the algorithm then the algorithm by using from these patterns and data, will create new data. Finally by using the input (e.g. the coordination of the center of the eye pupil), for the neural network, the output (result: the status of the person under experiment) will be predicted [34].

4. Results

Fig 9 shows the results obtained from tracking the eye, in which finally the center of the eye pupil can be detected. In the green region the face has been detected and the search region for detecting the left eye is limited and confined to the black rectangle and in the red rectangle the left eye is detected.

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With removing the eyebrow region, the false detections inside the eyebrow region were removed and finally with detecting the eye iris which is shown with the yellow circle, its center is considered as the center of the eye pupil. Movement of the moving object is considered with the 10 ms delay. And in this way the object will have an average speed for its movement. The reason for not using the high rates and speeds, is reducing the volume of the obtained data from eye tracking at high speeds, and in the lower rates and speeds the eye of the user will be tired and his winking can have effects on the results of the experiment. One of the affecting factors on the increasing the accuracy of the system, in the amount of the available data for learning the neural network, which is presented with the results obtained from training of the system with 20, 10 and 50 sample data. The results have revealed that the more data for training the system will lead to an increase in the accuracy of the system. One of the other affecting factors on the accuracy of the system is choosing and selecting the coordination of the center of the eye pupil. In order to find the status of the people, the coordination of their pupils should be studied and analyzed in different intervals. First this test and experiment was conducted with 22 dots and the accuracy of the system was calculated 82%, and finally with shorter intervals and conducting the experiment with 43 and 89 dots, the accuracy of the system was defined 84 %. In table (1) some of the results of this experiment have been shown.

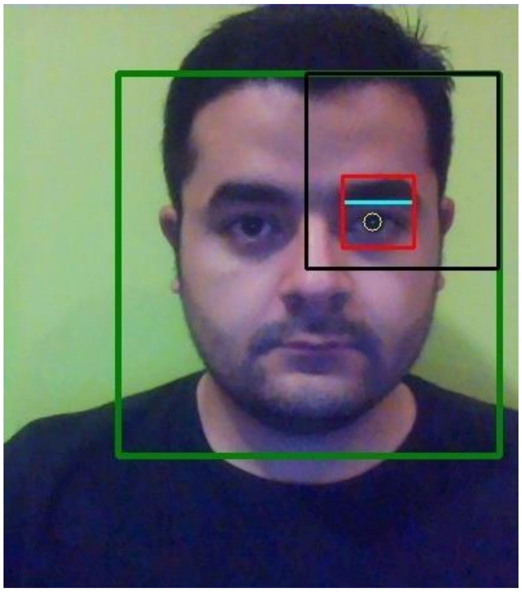

Fig. 7 Final processed frame

Shorter intervals can have some effects on higher accuracy rate of the system, because in the shorter intervals the coordination can be the same. Also with an increase in the points the time of the calculations will increase, in such a way that with 22 dots this time will takes 27sec, with 42 dots it will takes 54sec and by using from 89 dots the time required for the calculations is 108sec.

Table 1: Eye tracking result

	Patient condition	Normal prediction with 22 points	Abnormal prediction with 22 points	Result with 22 points	Result with 43 points	Result with 89 points
1	Normal	22	0	Normal	Normal	Normal
2	Normal	22	0	Normal	Normal	Normal
3	Normal	22	0	Normal	Normal	Normal
4	Normal	22	0	Normal	Normal	Normal
5	Normal	8	14	Abnormal	Abnormal	Abnormal
6	Abnormal	13	9	Normal	Normal	Abnormal
7	Abnormal	6	16	Abnormal	Abnormal	Abnormal

5. Discussion

This system in comparison to the other systems such as [20] is simpler in order to have simpler interactions, in such a way that in the presented system the capability of using the system without a meeting with the physician is considered as one of the main features, in order to implement this system independent from the special instruments. The recommended system in [20] with detecting the Eye Pupil with the Infrared Light and connected to the head can be conducted. And one of its disadvantages is being affected of the detection process of the eye pupil due to changes of its size in contact with the high or low amount of light.

Although the recommended system cannot detect the point at which the user looks at, and it is sensitive to winking and turning face, but in this system there are some advantages such as not requiring the special software and equipments which leads to not requiring the physician to inspect the patient himself, and also not physical contact with the user, and gradual learning capability of the system by recording the features of the new patient with the unknown status.

6. Conclusion and Future Work

The above mentioned system is conducted and implemented in hierarchical order, and with limiting the search region the accuracy of the detections will be higher, and also the amount of the required data for processes will be less which itself leads to an increase in the process rate of the system.
In such a way that in order to implement the recommended system, a 1.3 megapixel camera, C# programming language and the EmguCV function wrapper are used in order to use from OpenCV library.
With simulating the experiments conducted by the physician, in the form of presentation of a moving object and by detecting the center of the eye pupil of patient, it coordination will be recorded in the system. Finally the accuracy of the recommended system with 112 sample data for testing and 100 sample data for learning of the system and by using from 89 dots is 84 %. The recommended system can be used as a complementary tool for the opinion of the physician
Due to closing the eye while winking, which leads to not detecting the eye pupil, the coordination cannot be recorded in this period of time, in order to improve the performance of the recommended system, the effect of the data lost while winking will be prohibited.

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