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Eyeball Movement Detection System using Corner Triangle Similarity, Naïve Bayes, and Ear Approach

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Abstract

Eye movement detection is one of the most developed technology, especially in human and computer interaction. Many research is developed by using this technology such as lying detection, security using captcha of movement eye until fatigue detection. Eye movement detection also applied for controlling an electronic device like a wheelchair. Eye movement can furnish an easy input source by tracking user point of view and applied it as guided. In general, the process of tracking eyeball movement required a face detection first and also detect an eye area. Unlike the face and eye detection method, eye movement detection still needs a lot of improvement. In this paper, we use multiple approaches to detect eyeball movement by included corner triangle similarity methods, face landmark methods, and Naïve Bayes classifier. This proposed approach is able to handle many various directions of movement of the eye and produce an accuracy of detection about 85%. This multiple approaches also can be proposed as an alternative option to detect the eyeball movement.

Keywords- *corner triangle similarity, naïve Bayes, eyeball movement, classifier, face landmark, ear*

1. Introduction

Eye movement has been considerably utilized in the various field, especially in the technology such as for navigation in smart wheelchair [1-2] using the movement or the state recognition [3], fatigue warning system in the car[4], biometric authentication[5] until enhanced captcha using eye movement[6]. The process for detecting the eyeball movement is started by detecting the eye region to limit the area for pupil detection. There are many methods widely used for detecting eye region and the popular one are using Haar Cascade classifier for eye region detection such as performed by [7]. After eye region is detected, the process followed by using Hough Circle Transform for pupil detection. Hough Circle Transform is used because of its capability for circle object detection. In this research, many morphology processes should be done in order to get the best result for circle detection using Hough Circle Transform.

Methods for detecting eyeball movement are still in the development process, whilst this part is the important one. Eye movement detection process was the significant part and this accuracy will produce a reliable system to be implemented to produce console command for device controlling system. Much previous research have been done to detect eye movement direction, one of them is by divide eye region into several parts and count the black pixel value in each part [8], but this method is very limited, only for the several areas only and it can produce error due to the same value between regions. Another research use eye center coordinates and pupil center coordinates, this approach counts the projection of the pupil and find the relation between projection result and eye center [9]. Another approach is using EEG signals for detecting eye movement direction by using *electrode* for capturing EEG signals [10], but this approach consumes more budget and not practical. In another research, triangle similarity approach is used by count the corner between eyes and center vector of the faces[11], but it still produces too many errors especially in the downward detection result. In this research, we propose an improvement for triangle similarity approach by using additional methods called Eye Aspect Ratio (EAR) utilize of face alignment and many several processes in the face and eye region detection to produce a better result for eye movement detection. We focused on the several methods of triangle similarity and face landmark handled by *Naïve Bayes* to detect eye movement in 4 directions such as upward, leftward, rightward and downward direction.

In this research, we also made some improvements for eye region detection by dividing the face region into several parts to get more accuracy for eye region detection. The next step, we divide the eye region into several parts to get more accuracy for detecting pupil position. After the pupil location detected, we also count a corner value produced by the pupil center and eyes corner. Face alignment used for detecting eyelid position and combine its result with corner triangle similarity result by using *Naïve Bayes* classifier. This improvements approach are important to get a better result in eye movement detection especially in a difficult position such as downward position.

2. Proposed Method

Our approach is optimizing the previous works by added several methods and combine it to receive a better result. Naïve Bayes is used for clustering by using the result from Triangle similarity and Eyes Aspect Ratio (EAR) result. The purpose of the Corner Triangle Similarity method is to calculate an angle between

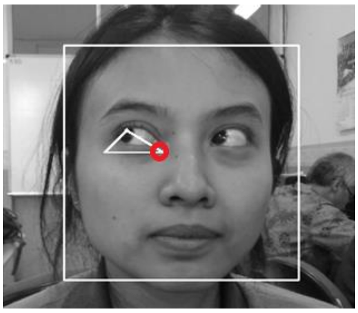


Fig 1. Triangle approach in the eye region

the vertical imaginary line from the corner of eye region straight to the left and from the center of the pupil to the corner of the eye region, that result also called a θ (marked with a red circle) shown in Fig. 1. To get a better result in locating the center of the pupil, we perform some steps in image processing algorithms.

The next step calculates an Eyes Aspect Ratio (EAR), The EAR is produced by using the capability of Face Alignment using EAR equation. Those methods are applied in every single image in the training data section, so in every data also have 2 variable value (EAR and Corner Triangle Similarity). After we got the result in every data we also have features to be classified by using Naïve Bayes classifier. The result of Naïve Bayes classifier is the direction information of the eyes, so the information also can be used for console order for wheelchair direction movement.

3. Methodology

In this chapter will explain how the system can detect the direction of the eyeball movement by using multiple methods. The process of the system is shown in Fig. 2.

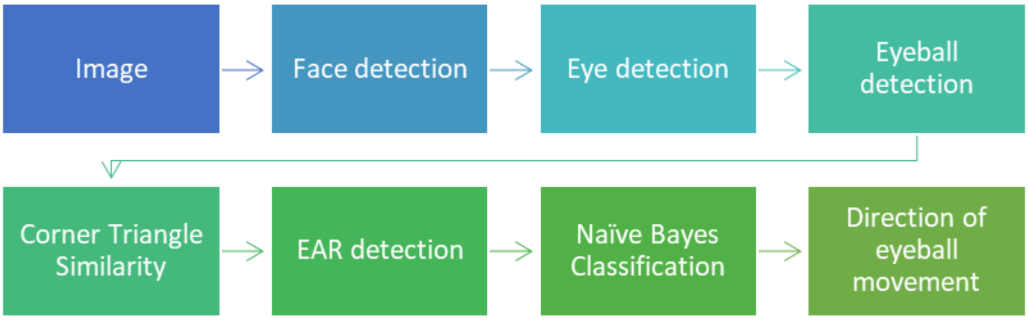


Fig 2. process flow for eyeball movement detection

3.1 Corner Triangle Similarity

Triangle is part of trigonometry and geometry knowledge. Triangle is the most basic figure studied in geometry [12]. Correlation between lines in the triangle will produce an angle value in every 3 corners of the triangle. By using *Euclidean distance,* the length value of the triangle can be measured by using the beginning and ending coordinate of line, shown in Equation 1.

$$d(p,q) = \sqrt{\sum_{i=1}^{n}(q_i - p_i)^2} \quad (1)$$

For instance, $d(p,q)$ is the eucliedan distance between point p and q, n is the length of data, p are beginning coordinates of lines and q are ending coordinates of lines. Length value of distance will be used to calculate the angle. In this research, we use a Cosine function to find an angle of the triangle by utilizing length values of the triangle as shown in Fig. 3.

By using Cosine similarity we can find angle degree shown in Equation 2.

$$CosB = \frac{a^2 + c^2 - b^2}{2ac} \quad (2)$$

For instance, *CosB* is the cosine of B. *b, c and a* are length value accorded to the Fig. 3.

After Cosine B value has measured, we use inverse cosine to determine angle value by using arc cosine function in Equation 3.

$$\theta = \text{arcCos (CosB)} \,.\, \frac{180}{\pi} \quad (3)$$

Denotes, θ is the angle value and *CosB* are the result of Equation 2.

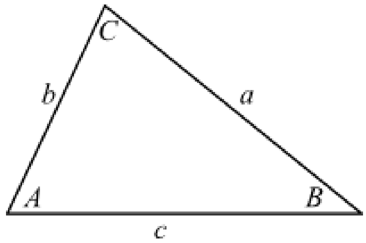


Fig 3. Triangle similarity

C variable in the Fig. 3 also changed following the movement of the eye's circle/pupil. The change of C variable caused by the changed direction of the pupil as mentioned before, pupil location detection also discuss in the face and eye pupil locating the section.

3.2 Face and Eye locating section

As mentioned before, for measure an angle between the eye's pupil and corner of the eye, it required a system that have the capability for detecting pupil circle. Many approaches were developed by the researcher for detecting face area [13]. There are many advantages and disadvantages to every method for face detection. In this study, Haar Cascade Classifier is used because it proved reliable performs face detection. Haar Cascade also has the capability to separate the positive image and negative image [14]. The positive image is an image that wants to train and the negative image is an image that will not train.

Face detection is the required steps for locating the eye region and detect the center of the eye's pupil. Face detection can limit the eye search area just in the face area only. It is important to limit the process area and shorten time processing. Meanwhile, to detect the center of the eye's pupil, Hough Circle Transform is used for this research. The mechanism of Hough Circle Transform is to find circle shape in every pixel in the image. Sometimes, Hough circle can't recognize the eye's pupil properly, it is caused by many aspects such as lighting condition, image size, until the eye region. Therefore, in this research, we also process the image before it goes to the circle detection step using Hough Circle Transform method. There are many preprocessing step that we apply in this research, such as gray scaling image, cropping the image for getting better detecting area and blur process for ease circle detection step using Hough Circle Transform.

This steps also produce a center of eye's pupil coordinate. This coordinate is adaptive change following the movement of the eye's pupil. By using its coordinate, we also can produce an imaginary line that mold a triangle shape in the eye region. By using the triangle shape, we also can measure the value of the angle in that triangle. As mentioned in Fig. 3, a more far pupil from the corner of the eye region, more narrow the resulting corner degree. The shape of the triangles

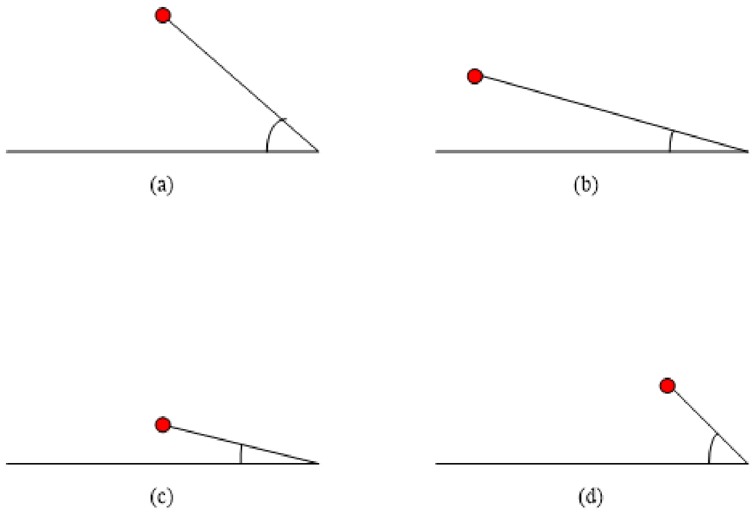


Fig 4. The angular change of the triangle (red dot) indicates the eye's pupil movement (a) upward gaze (b) right gaze (c) downgrade gaze and (d) right gaze

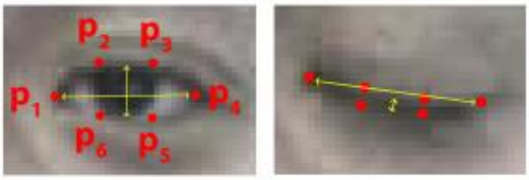
is shown in Fig. 4. Fig. 4 clarifies how the movement of the eye's pupil can affect the position of red dot and also affect the angle value in the corner. the process begins by detecting the circle in the eyes and marking that circle with a point (red dot). The red dot will automatically follow the movement of the eye's pupil. If the user moves their eye's pupil upward, it will affect the angle by increased and also diagonal line become sorter. The similar affect happens when the eye's pupil moves to the right, the diagonal line will be increased and the angle value will be decreased. Also when user moves their eye's pupil to the right, the diagonal line will be decreased and angle value will be increase.

3.3 Eye Aspect Ratio

In our research, Eye Aspect Ratio (EAR) was used to determine the state of the eyes.The EAR was obtained by apply face landmark method to map the face by coordinates. Face landmark result shown in the Fig. 5. We only utilize the point that are in the eye area only. There are 6 points which exist in the eye as

Fig 5. Face Landmark map face area by coordinates

shown in the Fig. 6.



(a) (b)

Fig 6. points which in the eye location (a) eyelid (b) eyelid covered eyeball (look down).

Face landmark process has done well by using the dlib library as the implementation of the research by Kazemi and Sulivan [15]. As mentioned before, we only need the points in the eye area, there are 6 points that we had to process by using Equation 4 to get EAR result.

$$EAR = \frac{||p_2 - p_6|| + ||p_3 - p_5||}{2\,||p_1 - p_4||} \tag{4}$$

For instance, p_2 and p_3 are upside points, p_5 and p_6 are downside points, p_1 is the right corner points and p_4 is the left corner points. By using the EAR equation, the wider eyelid the greater EAR values. In our research, the EAR is a very important step. The movement of the eyeball is always followed by eyelid changes. For example, when the user looks upward they are also moving their eyeball to the top, and automatically eyelid becomes wider adapt with the movement of the eyeball. Otherwise, when the user looks down, they also move their eyeball downward and eyelid becomes smaller. The illustration of eyelid movement shown in Fig. 7.

(a) (b)

Fig 7. Movement of eyeball affect the size of eyelid (a) eyeball not covered with eyelid (b) eyeball covered by eyelid because it looks down

In our research, we combine the capability of EAR and Corner Triangle Similarity and *Naïve Bayes* classification method to detect movement of the eyeball with high accuracy. In order, we use the classifier method to train and detect the movement by using EAR and Corner Triangle Similarity. The explanation of the classifier method is explained in the Naïve Bayes Classifier section.

3.4 Naïve Bayes Classifier

Naïve Bayes classifier is a family of a simple probabilistic classifier based on applying Bayes theorem. Our research applies a Naïve Bayes method to train and detect the direction of the eyeball movement. Our Naïve Bayes features use EAR and Corner value for classifying. The first step of Naïve Bayes is determining the mean value of the data shown in Equation 5, there are about 50 image data to be classified using Naïve Bayes. Every image data will determine the EAR and Corner value by using several methods as mentioned before.

$$\mu = \frac{1}{N} . \sum_{i=1}^{N} x_i \tag{5}$$

For instance, N is the total of data and x_i are the value of the data. Using μ value, we can determine unbiased sample varians (δ^2) as shown in Equation 6.

$$\delta^2 = \frac{1}{N-1} . \sum_{i=1}^{N} (x_i - \mu)^2 \tag{6}$$

By using μ and δ^2, mean and varians from training data are obtained. There is 4 class classified by Naïve Bayes that generate a total of 16 equations included means and varians in every class.

μ and δ^2 needed to determine probability density. Probability density can be measured using Equation 7 by substituting μ and δ^2 value.

$$f(x; \mu, \delta^2) = \frac{1}{\sqrt{2 . \pi . \delta^2}} . 3^{-\frac{(x-\mu)^2}{2 . \delta^2}} \tag{7}$$

For instance, *f* is the probability density of class and its feature, μ are meant that have been obtained before by Equation 5 and δ^2 are varians that obtained using Equation 6. By using Equation 7, will form several values that will be the input value of *Evidence* formulas as shown in Equation 8.

$$Evidence = \sum_{i=1}^{N} P . f(x{:}\mu) . f(x{:}\delta^2) \tag{8}$$

P value is the probability of class in the data, $f(x{:}\mu)$ are means which calculated by Equation 7 and $f(x{:}\delta^2)$ are variance which calculated by Equation 7 as well.

Evidence is used for divider on the equations to find *Posterior* values as shown in the Equation (9) below :

$$Posterior(x) = \frac{\sum_{i=1}^{N} P \ . \ f(x{:}\mu) \ . \ f(x{:}\delta^2)}{Evidence} \quad (9)$$

By using Equations 9 we produce 4 values that representing 4 class direction of eyeball movement including upward, downward, left and right. These 4 values are then ranked to choose the highest one. The highest one also the direction of the user eyeball movement.

4. Experimental result and discussion

Our experiments implemented on a personal computer with Intel Core i7 2670QM processor with 2.2 GHz using python 2.7. Dataset image was captured by 13 Mega Pixel camera with custom bright lighting condition. Our dataset was captured 10 respondents with many poses of the face and eyeball direction, our dataset also captured image right on the front of the face as shown in Fig. 8. It aims to minimize error scanning face area and just focus on one face only. Our dataset was written on file with some feature like EAR and corner degree and also with the class of movement direction such as up, down, right and left, representation of our dataset are in the Fig. 9.

Fig 8. Several results of eyeball movement detection with our method

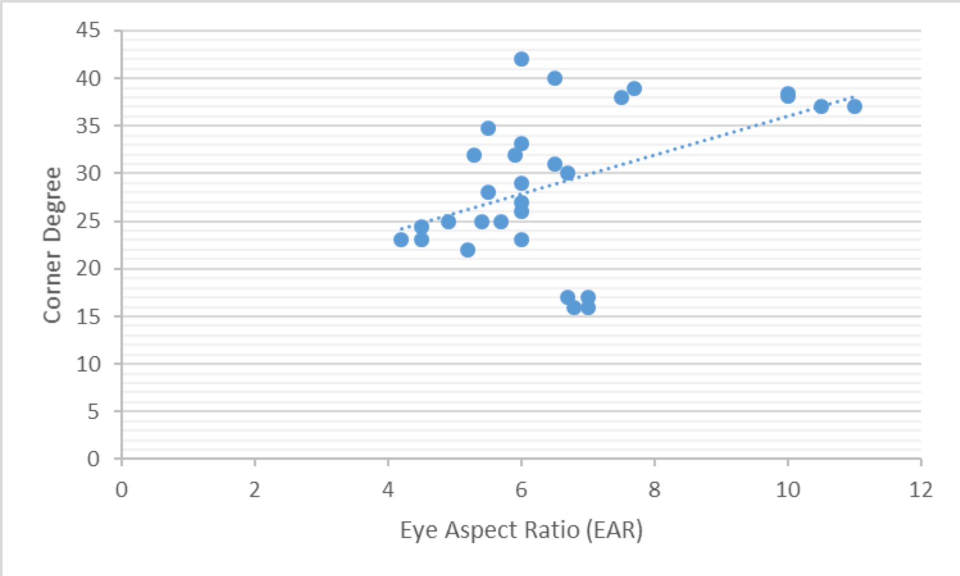


Fig 9. Our dataset graphic with Corner feature and EAR feature

As limitation dataset, our dataset was captured in the bright light condition without electronics addition flash included, considering lighting condition can affect the computing process. We also determine that combined midpoint of the eyeball and left the corner of the eye region produced a better result compared to the point in the midpoint of the face. Therefore, the closer the distance between the midpoint of eyeball and point of origin, the more visible also the change of the angle.

In addition, considering that eyelid shape change following the movement of the eyeball, it can generate a problem for the system to detect an eyeball circle because it covered by the eyelid. The example is shown in Fig. 10. This often occurs when eyeball move down, when the eyeball moves down the eyelid will cover most of the eyeball. This situation made the system difficult to detect eyeball. In the previous research done by Prasetya Renaldi [10], they do not even consider this situation. As a resut, their system produces many error detection especially in the downgrade direction detection. According to this problem, we propose a new approach to detect eyeball movement with better accuracy using the additional method with the improvement of the previous method and combine it by using *Naïve Bayes* classification. Our new additional method is using EAR to handle eye closure especially when eyeball moves down. Also the improvement of the previous method makes the corner of the triangle similarity to the corner of eyes, it can produce more varied data value so it can be more easily to classified. The different approach of our method and previous method are shown in Fig. 11.

From our experimental result, our approach for detecting eyeball movement successfully detected 34 files corrected of total of 40 data. Our system also can handle the detection of downward movement direction better than previous work. Table 1 shows our experimental result with our dataset, and Table II shows the comparison between our work and previous work.

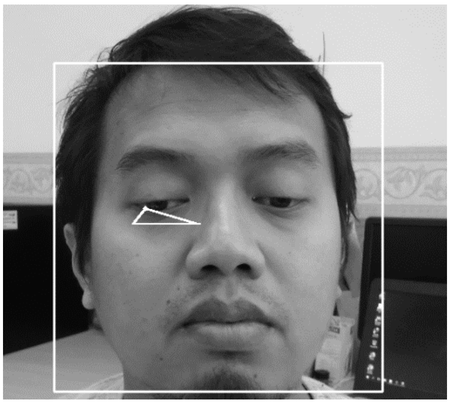


Fig 10. Eyeball detection can't perform well while eyeball covered by the eyelid

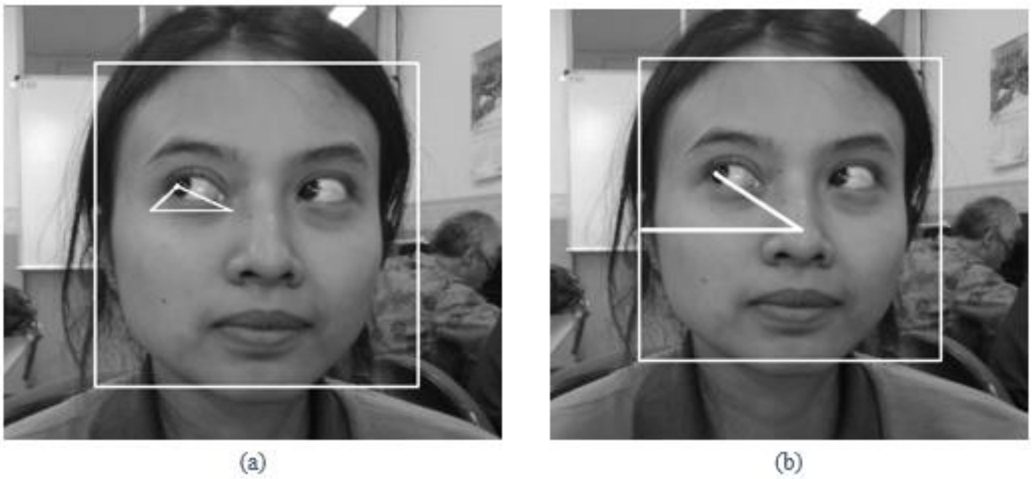


Fig 11. The different between our approach and previous work (a). our approach (b) previous work done by Renaldi [10]

Table 1 shows the result of the experiment by using our multiple approaches. From the table we get the total correct detection are 34 and incorrect detection is 6 data. As we can see, downgrade detection is slightly better with our approach, it is caused by our approach can detect eyelid movements too. The details of our work and previous work are shown in Table 2.

Table 1. Result of Eyeball Movement Detection Using Multiple Approach

Direction	Condition (mean)	Correct detection	Incorrect detection
Upward	EAR = 10 & Angle = 37	8	2
Downward	EAR = 5,5 & Angle = 29	8	2
Right	EAR = 4,5 & Angle = 24,4	9	1
Left	EAR = 5,5 & Angle = 33.4	9	1

Table 2. Different Of Our Approach with Triangle Similarity Method

No	Ability	Purposed Method	Triangle Similarity [10]
1	Detect 4 gazes including upward, downward, left and right	YES	YES
2	Detect eyelid movements	**YES**	NO
3	Accuracy of detection	**85%**	79%
4	Accuracy of downgrade eyeball movement detection	**80%**	58%

Table 2 we can measure that our approach is slightly better, it is because it has the capability to detect eyelid movement, for example when eyeball moves down. As mentioned before, when eyeball move down the eyelid will automatically cover the eye and follow the movement of the eyeball, so when the eyeball is in the downside, automatically eyelid will cover the eyeball and EAR value become smaller too. Naïve bayes are very useful in this research, this method can perform the classification process so well by using EAR feature and Corner Triangle Similarity feature.

5. Conclusion

Multiple approaches including Corner Triangle Similarity, Face landmark and Naïve Bayes resulted in a higher accuracy detection for eyeball movement. Our approach has proven to handle 4 gaze detection as good as well with accuracy until 85%. This proposed approach produce an alternative solution for controlling automated device such as for movement of a wheelchair, eye captcha for system security until replacing mouse pointer movement. However, the lighting condition still became an encumbrance by the various researcher, therefore lighting condition plays an important role in the quality of the image of the video.

For the future work, the ability to detect more directions and more condition such as low light condition and many various states like people with eyeglasses can be added to the eyeball movement detection method. It is very important for the eyeball movement detection method to have the capability for detecting an object whether in the low light condition. Hence, we can not ensure every environment had the same lighting condition as well as expect.

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