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Selecting Control Menu on Electric Wheelchair Using Eyeball Movement for Diffable Person

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***Abstract*— Each country's number of people with disabilities and strokes increases yearly. Hand defects and stroke make them have limitations in doing activities. It caused their hand has paralyzed. Hence, they find it difficult to do daily activities, such as running a wheelchair, choosing a menu on the screen display, and so on. One solution offered is utilizing eye movement as a navigation tool that can replace the role of the user's hand, so they can run a wheelchair independently or choose a menu selection on display by themselves through the movement of their eyes. Detection of eyeball movements in this study only utilizes a camera as a sensor mounted in front of the user. So that it is more practical and easier to use than if we have to pair an electrooculography sensor in the area around the user's eyes. This research proposed a new approach to detect the five gazes (upward, downward, leftward, rightward, and forward) of the eyeball movements by using Backpropagation Neural Network (BPNN) and Dynamic Line Sector Coordinate (DLSC). Line Sector Coordinate is used to detect the eyeball movement based on the pupil coordinate position. The eyeball movement direction was analyzed from four lengths of a line. Our proposed method can detect five gaze directions that can be used for selecting four menus on the display monitor. The mean accuracy of our proposed method to detect eye movements for each gaze is 88.6%.**

***Keywords*— Disabilities; detection; eyeball movements; eyeball movements; dynamic line sector coordinate.**

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I. INTRODUCTION

Currently, people with disabilities and strokes are increasing every year. Stroke sufferers usually have a decreased ability to do an activity, such as difficulty walking, moving their hands, etc. Similarly, disabled people, if they have leg paralysis, cannot walk, and if they have hand paralysis, they cannot move their hands and cannot be used for activities. So, people with stroke or hand and leg disabilities have difficulty running a wheelchair or choosing a menu on the touch screen display. Hence, we use eyeball movement to solve that problem, so they can do activities to operate an electric wheelchair. The eyes became the essential body parts for humans. Eyeball movement detection can be used in many fields. For example, the utilization of eyeball movements used to control a smart wheelchair, choosing a menu on the screen display, etc. Many approaches are used to detect the gaze of the eyeball movements [1]–[5].

Previous research uses an eye as biometrics identifications using the retina's characteristic features [6]. Not only the distinctive features but the eye movements also can be utilized widely as a person identifications [7], used as a navigator of smart-wheelchair [8], [9], cognitive measurement based on eyeball movements [10], until used for passing the captcha [11]. Regarding eye movement utilization, accurate and effective ways to detect and recognize eyeball movements are needed. There are many approaches to seeing and recognizing an eyeball movement, one of the most popular uses is Electrooculography for detecting, tracking, and recognizing it [12], [13].

Unfortunately, the utilization of Electrooculography is not practical due to the mechanism that requires sticking Electrodes in the skin. The price of Electrooculography is also higher compared to other sensor detectors. Regarding those problems, a cheap and effective solution is needed. The camera is one of the alternative solution devices that can be implemented as a substitute or replacement for sensor Electrooculography for detecting eyeball movements. The camera makes the user easier to use and relatively inexpensive. Several kinds of research focus on seeing the eyeball movements' gaze. The research proposed by Arai [14] for detecting the pupil also can produce a satisfying result. Unfortunately, the previous method can see only two eyes of the eyeball movement, including leftward and rightward. Another research to detect eyeball movement is proposed by Utaminingrum et al. [15]. They used Hough Circle Transform.

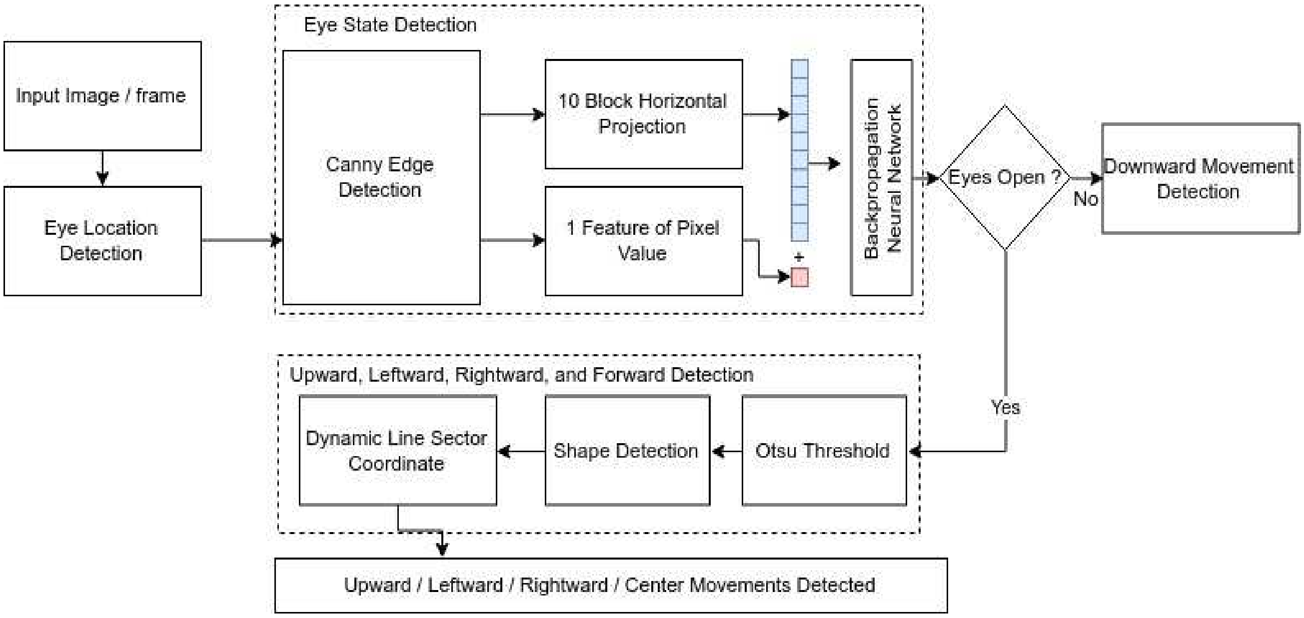

Fig. 1 Block diagram of eyeball movements detection

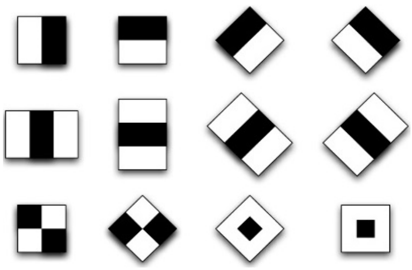
Fig. 2 Haar-like features

This method utilizes detected circles in the eyes to determine eyeball movements. However, this method can only see three gazes of the eyeball movement leftward, rightward, and center. Eyeball movement using several algorithms has been proposed by Patel and Prakash [16]. They combine edge detection and circle detection methods to find the location of the eye pupil center. If the upper eyelid moves down, that method cannot detect the pupil's circle. A better approach is to determine the eyeball movements' gaze by Prasetya and Utaminingrum [17] using the angle of the Triangle Similarity. This method can detect four eyes of eyeball movements, including upward, downward, leftward, and rightward.

Nevertheless, the accuracy of downward movement detection is deficient at under 60%. The previous research by Yaiprasert [18] has repaired the deficiency using the Eye Aspect Ratio (EAR) as an additional variable that combines with the angular of the Triangle Similarity. This research uses Naive Bayes [18] to classify the direction of an eye movement. The accuracy result of the development of that method is 80% on downward detection [19].

However, those methods just only capable of detecting four gazes of eyeball movements. There are five standards of eyeball movements (leftward, rightward, upward, downward, and center or ahead). According to that problem, this paper proposed a new approach to detecting and recognizing five gazes directions of the eyeball movement using a Backpropagation Neural Network (BPNN) and Dynamic Line Sector Coordinate (DLSC). The BPNN and DLSC will work alternately to detect whether eyes are open and looking upward, downward, leftward, rightward, and forward.

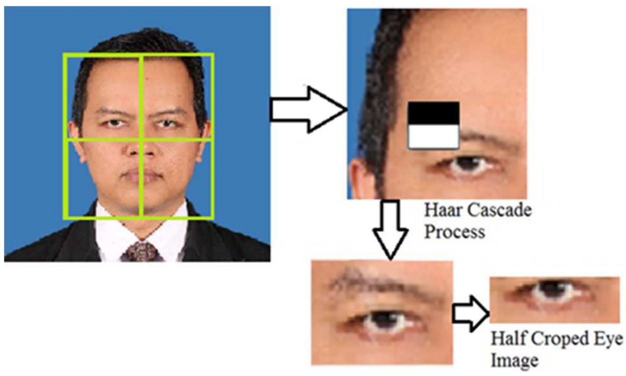

Fig. 3 Eye location using Haar Cascade

II. Material and Method

As mentioned earlier, this research proposed two related approaches for detecting eyeball movements. Fig. 1 shows the process of eyeball movement.

A. Eye Location Detection

This research uses a Haar Cascade method [20]–[23] for detecting eye location in the face image. The Haar Cascade method uses" Haar-like features" to find an object [24]. Haar-like features were selected to find the object because it has a fast computation time. Haar-like features use an Integral Image to find an object. The Integral Image process is computed as Equation (1).

$$ii(x,y) = i(x,y) + s(x,y+1) + s(x-1,y) - s(x-1,y-1) \quad (1)$$

Denotes, $ii(x,y)$ is the Integral image, $i(x,y)$ is the original pixel value, and $s(x,y)$ is the summed area value. This Integral Image process used the Cascading mechanism by matching the Haar-like features with an image in every stage. If the area is similar to the feature, the process will continue to the next step. Those processes is kept going until the image passed all the stages. If all the stages successfully pass, then it will be detected the face object in this image. After the face area is detected, the eye area can be found using the same process. Certainly, scanning the entire face area will lead to time-consuming.

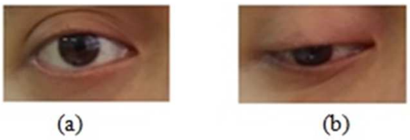

Fig. 4 The movement of the eyelids follows the movement of the eyeball (a) looking forward (b) looking Downward.

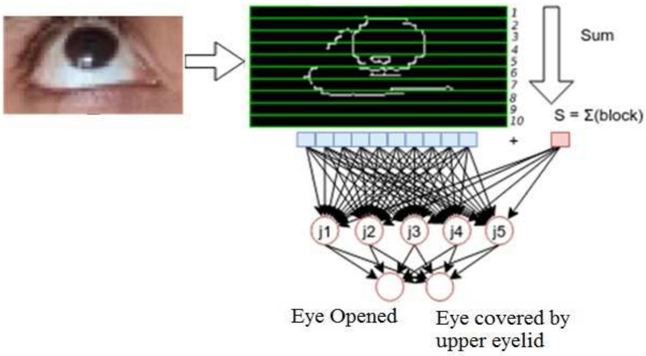

Fig. 5 Backpropagation neural network architecture with neuron input from 11 features of Canny Edge detection result

Therefore, a face region is divided into several parts, and scan a part to minimize the computational process and failure detection. Then, the result of eye location detection is cropped to be processed. The illustration of the dividing face area is shown in Fig. 3.

B. Eye State Recognition

Eye State Recognition is used to detect the position of the eyelid. The movement of the eyeball also influences the eyelid position. This means the eyelid movements will follow the direction of the eyeball [25], [26]. From that statement, if the eyeballs move downward, then the upper eyelid will cover the eyeball's upper sclera, as shown in Fig. 4. Therefore, the first step to detecting and recognizing eyeball movements is detecting whether the eye is opening wider, or the eyes are closed.

Canny Edge detection was used to determine the edges of the eye image. The Canny Edge detection method worked after Gaussian Filter blurring was employed, as given in Equation (2).

$$H(x,y) = \frac{1}{2\pi\sigma^2} e^{\frac{x^2+y^2}{2\sigma^2}} \quad (2)$$

Denotes, σ is a standard deviation of the distribution, and $H(x, y)$ is the Gaussian result. The next step is to employ the gradient finder in the Gaussian image. This research used the Sobel gradient to find the gradient given in Equation (3).

$$G = \sqrt{G_x^2 + G_y^2} \quad (3)$$

Denotes, G_x and G_y are the Sobel operator, and G can be computed using Pythagorean addition. The result of G is used to find the θ, as shown in Equation (4).

$$\theta = tan^{-1}(G_x/G_y) \quad (4)$$

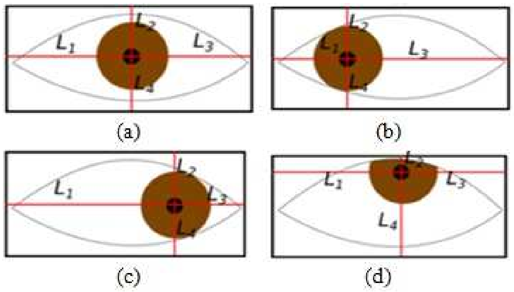

Fig. 6 Dynamic Line Sector Coordinate illustrations in (a) forward, (b) rightward, (c) leftward and (d)

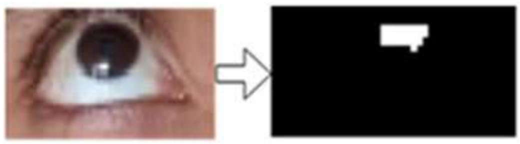

Fig. 7 The Otsu threshold process result to detect pupil area

Denotes, θ is the directions of the filter, arranged using Equation (5).

$$D = \begin{cases} 0 & 0 < \theta 225 \text{ and } \theta \geq 157.5 \\ 45 & 255 \leq \theta < 67.5 \\ 905 & 67.5 \leq \theta < 112.5 \\ 135 & 112.5 \leq \theta < 157.5 \end{cases} \quad (5)$$

For instance, the edge-thinning technique uses D to find the edge. Subsequently, ten features were extracted from the Canny Edge image filter result using the ten blocks of Horizontal Projection, as explained in Equation (6).

$$\vec{B} = \sum_{i=1}^{Phor} I(b_i) \quad (6)$$

Denotes $\vec{B}$ is the vector features, and P is the Horizontal Projection result obtained using Equation (7).

$$P_{hor} = \sum_{j=1}^{R} i(b, k_j) \quad (7)$$

Denotes, R is obtained using (8), and I is the pixel value in b and k coordinates.

$$R = \frac{\omega}{10} \quad (8)$$

By using Equation (6), ten features are generated. In this research, one more feature was added to the group of data generated by Equation (9). Hence, the full features to be used are 11 features.

$$S = \sum_{i=1}^{l} \vec{B} \quad (9)$$

Denotes, l is the length of B.

After 11 features were obtained using Back-propagation Neural Network, those features are used as neuron input and will be trained for opened and closed eyelid detection. The Neural Network architecture uses 11 input neurons and one hidden layer with ReLu activation, as illustrated in Fig. 5.

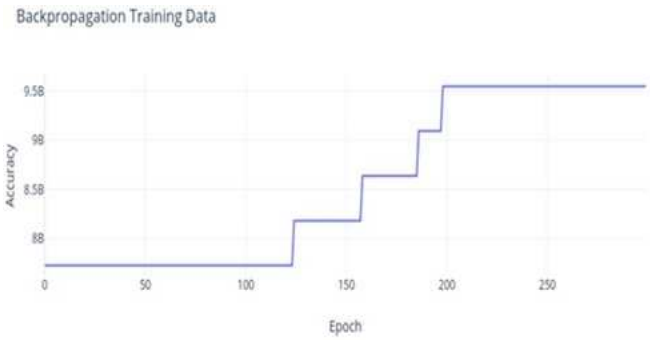

Fig. 8 Training result using 0,0001 of learning rate and 300 of epoch

Fig. 5 shows the number of hidden layers is one. Because, based on the [27], the best Neural Network architecture uses one hidden layer. With This approach, it can be determined that eyes are opened and covered. Therefore, if the eye is detected as covered by the eyelid, the eyeball movement is downward. However, if eyes were detected open, the process will be continued to the Dynamic Line Sector Coordinate process.

C. Dynamic Line Sector Coordinate

This paper proposed a method to detect eyeball movement using the center coordinate of the pupils and calculated using the Dynamic Line Sector Coordinate approach. The first is to detect the center coordinate of the pupil. After the center coordinate of the pupil can be determined, the following process is to draw a line from its coordinate to the right, left, up, and downside. The Dynamic Line Sector Coordinate illustration is shown in Fig. 6. Regarding Fig. 6, L1, L2, L3, and L4 are the length of the lines. Those values are used to determine the directions of the eyeball movements by using Equation (10).

$$\alpha = \begin{cases} L4 > L2 \wedge ||L4 > L2|| > T & Forward \\ L2 > L4 \wedge ||L2 > L4|| > T & Upward \\ L3 > L1 \wedge ||L3 > L1|| > T & Leftward \\ L1 > L3 \wedge ||L1 > L3|| > T & Rightward \end{cases} \quad (10)$$

However, the main idea of this approach is to use the center coordinate of pupils. In this research, the center coordinate of the pupil is determined by Otsu Threshold and Shape Detection approaches. The Otsu Threshold converts a grayscale image into a binary image by using the optimal threshold value. Those values can be obtained using Equation (11) to generate the variance.

$$\sigma^2{}_w(t) = w^2{}_0(t)\sigma^2{}_0(t) + w^2{}_1(t)\sigma^2{}_1(t) \quad (11)$$

Denotes, $\sigma^2 w(t)$ is the within-class variance, $w_0(t)$ and $w_1(t)$ is the weight generated using Equation (12) and Equation (13), and also $\sigma^2{}_1(t)$ is the variance generated using Equation (14).

$$w_0(t) = \textstyle\sum_{i=0} p(i) \quad (12)$$

$$w_1(t) = \textstyle\sum_{i=1} p(i) \quad (13)$$

While t is the threshold value generated to divide the array of histograms into two parts, and L is the length of the histogram arrays. The following process is to find $\sigma^2{}_1(t)$, which is shown in Equation (14).

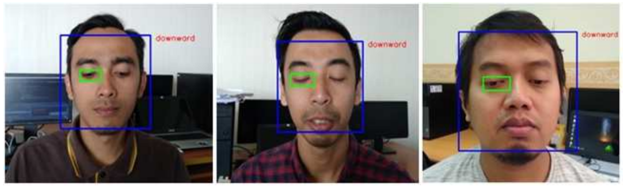

Fig. 9 Several results of downward detection using Backpropagation Neural Network

TABLE I
COMPARISON RESULT BETWEEN GAZE DIRECTION OF PROPOSED METHOD

Gaze	Detection			
	Total data	*Correct*	*False*	*Acc*
Upward	30	26	4	86,7%
Downward	30	26	4	86,7%
Leftward	30	28	2	93,3%
Rightward	30	28	2	93,3%
Forward	30	25	5	83,4%

$$\begin{aligned} \sigma^2{}_b &= \sigma^2 + \sigma^2{}_w(t) \\ &= \omega_0(\mu_0 - \mu_T)^2 + \omega_1(\mu_1 - \mu_T)^2 \\ &= \omega_0(t)\omega_1(t)(\mu_0 - \mu_1)^2 \end{aligned} \quad (14)$$

$$\mu_0(t) = \frac{\sum_{i=0} l(i)}{\omega_0(t)} \quad (15)$$

$$\mu_1(t) = \frac{\sum_{i=0} l(i)}{\omega_1(t)} \quad (16)$$

$$\mu_T(t) = \frac{\sum_{i=0} l(i)}{\omega_T(t)} \quad (17)$$

The Otsu threshold process will generate an optimal threshold value and uses a binarization process to generate a binary image. The Otsu process results are shown in Fig. 7. Regarding Fig. 7, the Otsu threshold process will produce a segmented binary image. Moreover, sometimes the Otsu threshold result produces a less precise result by showing several binary objects.

Therefore, correctly determining the pupil center coordinate required an area calculation to determine the biggest object available. The biggest object area is calculated by Equation (18).

$$L = \textstyle\sum_{i=0}^{K} i(i,j) \quad (18)$$

Denotes, L is the large value, N is the number of objects detected by the Otsu threshold, and I is the binary pixel containing a value of 1.

III. Result and Discussion

The experiment is conducted through training and testing. The first schema is to train the Backpropagation Neural Network architecture. The training process uses two hundred images of data divided into two classes. One hundred images for open eyes and 100 for eyes with a downward gaze. In this training process. Three hundred epochs and 0.0001 of α (learning rate) are used as a variable test. The result of the training data is shown in Fig. 8. The maximum accuracy has occurred from epoch 200 until 300 based on Fig. 8. This signified that the training process is experiencing an over-fitting and will not increase the accuracy result. In other words. by using 300 epochs and a 0.0001 learning rate, the maximum training accuracy was 95. After the backpropagation training process is completed, the second process is testing data and checking the accuracy. We use 30 data for data testing. Several sample results of downward testing are shown in Fig. 9. The proposed method's performance for detecting upward gaze movements, downward, leftward, rightward, and forward are given in Table 1.

A. Dynamic Line Sector Coordinate Experiment

In this testing part, the proposed method will detect the eyeballs' upward, leftward, rightward, and forward movements. The several results of the eyeball movement detection are shown in Fig. 10.

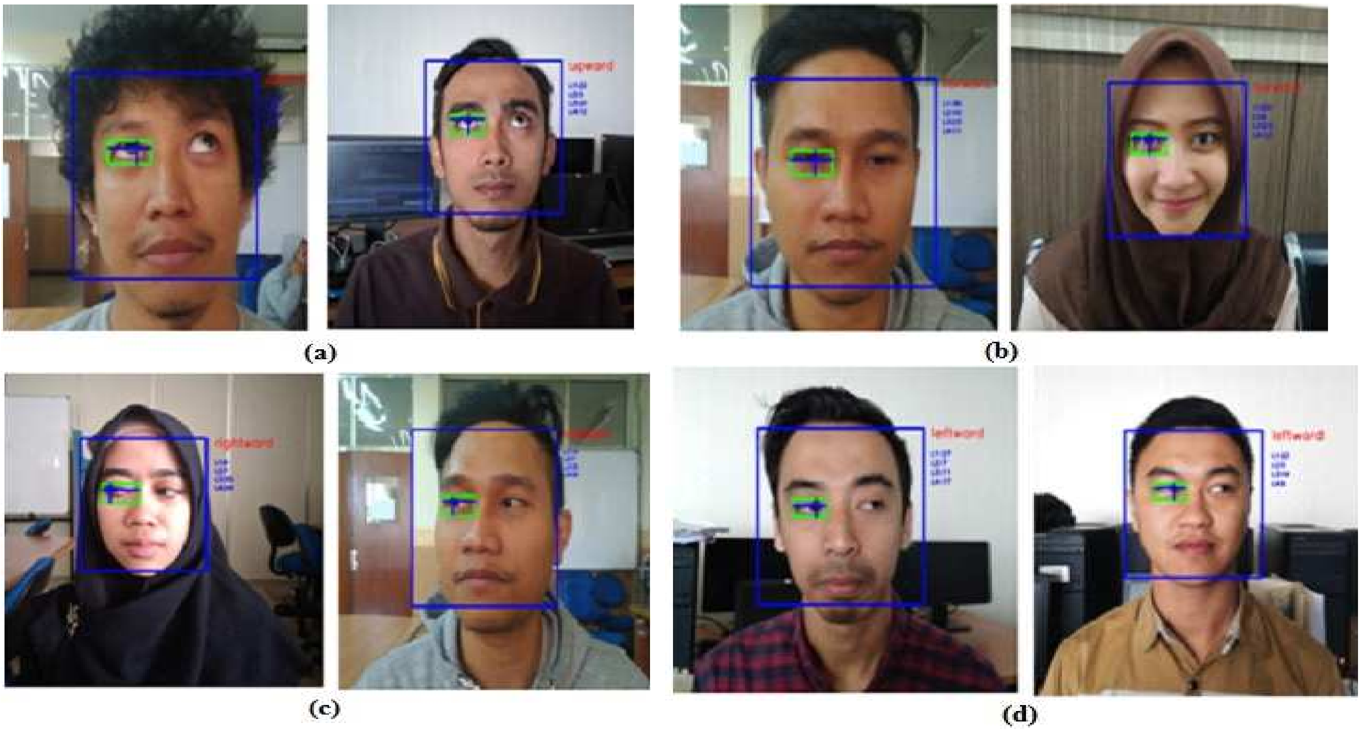

Fig. 10 Several detection results of eyeball movements in (a) upward. (b) forward. (c) leftward. and (d) rightward eyeball movements using the proposed method.

The proposed method is also compared to the other methods [17], [28]–[30], which are shown in Table 2. Regarding Table 2. the proposed method has higher accuracy than the comparison method. The proposed method also can detect five gazes of eyeball movement directions. The previous research, as the comparison method, only detects four gazes. The proposed method also has the highest average accuracy of 88.7.

TABLE II
COMPARISON OF THE PROPOSED METHOD WITH SEVERAL METHOD FOR EYEBALL MOVEMENTS DETECTION

Methods	Gaze Directions Movements					
	Upward	*Downward*	*Leftward*	*Rightward*	*Forward*	*Accuracy*
Triangle Similarity [17]	76.7%	56.7%	90%	90%	-	78.35%
Pixel Value [30]	-	-	86.7%	80%	-	83.35%
EOG Sector [29]	-	-	86.7%	86.7%	90%	87.8%
Naive Bayes + Triangle Similarity [28]	80%	80%	90%	90%	-	85%
Proposed Method	86.7%	86.7%	93.3%	93.3%	83.4%	88.6%

TABLE III
THE ANALYSIS OF RECOGNITION VALUES USING PRECISION. RECALL AND F1-SCORE

Eyeball movements	Precision	Recall	F1-Score
Upward	87.9 %	84.2 %	86.0 %
Downward	87.2 %	87.2 %	87.2 %
Leftward	91.4 %	86.7 %	89.0 %
Forward	81.7 %	90.4 %	85.9 %
Rightward	91.0 %	90.0 %	90.5 %

Table 3 shows the performance of classification using a multiclass confusion matrix. We use five classes: upward, downward, leftward, forward, and rightward. We calculate precision, recall, and F1-Score from the multiclass confusion matrix. The best value of precision, recall, and F1-Score on rightward eyeball movement detection with 91.0 %. 90.0 % and 90.5 %, respectively. The fifth eyeball movement direction is used to select the menu on the display monitor. The menu on display has two rows and two columns, as shown in Fig. 11.

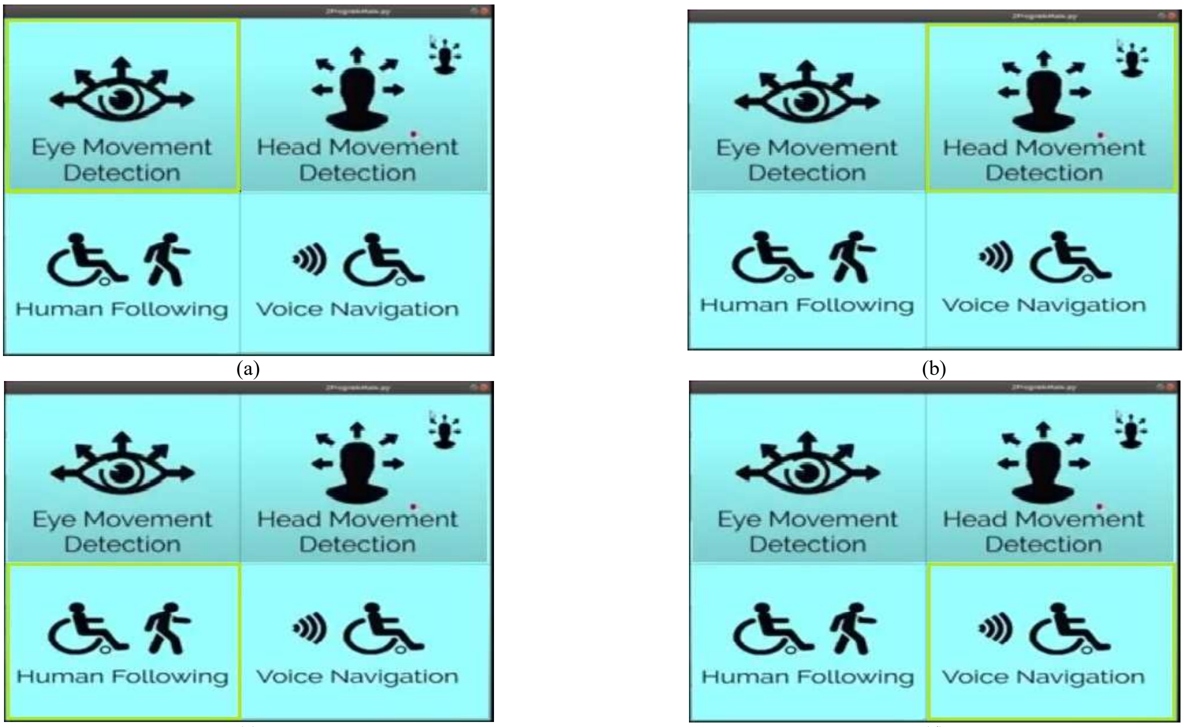

Fig. 11 Selected menu result by eyeball movements in (a) upward. (b) rightward. (c) forward. and (d) leftward eyeball movements using the proposed method

Fig. 11 (a) shows that menu" eye movement detection" is selected by upward eyeball movement. If the eyeball moves rightward, a menu" Head movement detection" will be chosen. as shown in Fig. 11(b). Fig. 11 (c) is the" voice navigation" menu set by down-ward eyeball movement from the menu in Fig. 11 (b) position. The" Human Following" menu can be selected by leftward eyeball movement based on the position of Fig. 11 (c).

IV. Conclusions

This paper proposed a new method for detecting and implementing eyeball movements to choose a menu in the monitor display. This method combines Backpropagation Neural Network and Dynamic Line Sector Coordinate. Backpropagation Neural Network can perform well to detect eye gaze positions. For the other gaze, including upward, leftward, rightward, and forward/center, the proposed method uses Dynamic Line Sector Coordinates to determine the gaze movements of the eyeball. Regarding the experiment results, the proposed method can prove its capability to detect the eyeball movements' gaze and has a higher average accuracy value of 88.6%. The proposed method could also detect five gazes of the eyeball movements' direction with average precision, recall, and F1-Score values of 87.8%, 87%, and 87.7%, respectively. The proposed method has a good value of precision, recall, and F1-Score on rightward eyeball movement detection.

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