



Electric Wheelchair Control Mechanism Using Eye-mark Key Point Detection

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Abstract: People with deficiency hands and feet, especially people with multiple disabilities has difficulty for navigation. Therefore, this research proposed an approach to help them using an electric wheelchair and control it using their eyeball movements. However, eyeball movement detection is still a problem due to the lack of standardized methods such as low accuracy for several gazes especially for downward and forward movements that caused by failure tracking mechanisms. Failure tracking mechanism mostly caused by failure pupil detection and tracking processes. According to the conducted research, there is a relation between eyeball movement and eyelid movement. Due to the relation, it can be concluded that the movement of the eyeball can be detected by utilize the eyelid movement without using the tracking mechanism. Hence, in this research, we propose an approach to detect the five movements of the eyeball using *Eye-mark* based on contour and edge detection. Our proposed method produces a brisk result with 91,2% of accuracy and better computational time compared with other marking methods. Accordingly, it is interesting on how to relate between eyeball movements and electric wheelchair navigation mechanism.

Keywords: Eyeball, Eyelid, Landmark, Eye, Wheelchair, Disability, Key-point, Movement

1. Introduction

A wheelchair is equipment needed by people with disabilities for navigating from one place to another. By using a wheelchair, people with disabilities can move and navigate using their hand muscles by rotating the wheels called manual wheelchairs [1].

A manual wheelchair is still the best low-cost equipment used widely for people with disabilities. But, not all people with disabilities can utilize the manual wheelchair. A manual wheelchair problem arises when the disability user of a wheelchair is not capable for a move and operate their hands for navigating the wheelchair, especially for people with multiple disabilities that can not move their feet and their hands wholly [2]. Therefore, in recent years, many inventions were done to solve problems such as one hand drivable manual wheelchair that aimed for people with a stroke that can only move one of their arms [3]. However, one hand drivable manual wheelchair still not a solution for people with multiple disabilities that can not operate their feet and arms hands wholly.

Another invention is using the electric wheelchair that operated by using a motor to propel the seated user invented by George Klein [4]. Advanced studies and invention also invented as an advanced version of electric wheelchair such as Electric wheelchair that controlled using joystick [5]. However, the joystick controller that operates by a finger is still needed the hand muscle movements [6].

People with multiple disabilities need special attention, need to remember, they are not capable to operate their hands and feet. Thus, in this situation, any invention of wheelchair and electric-wheelchair types that controlled by hand can not be applied for multiple disabilities navigation equipment devices.

A solution also proposed by using Electromyograms, Electrooculargrams, and Electroencephalograms that utilize several electrodes that stick to the skin user to control the electric-wheelchair [7-9]. The idea of these proposed solutions is to read the amount of electricity produced by muscles especially when people with disabilities try to move their arms. However, sticking electrodes

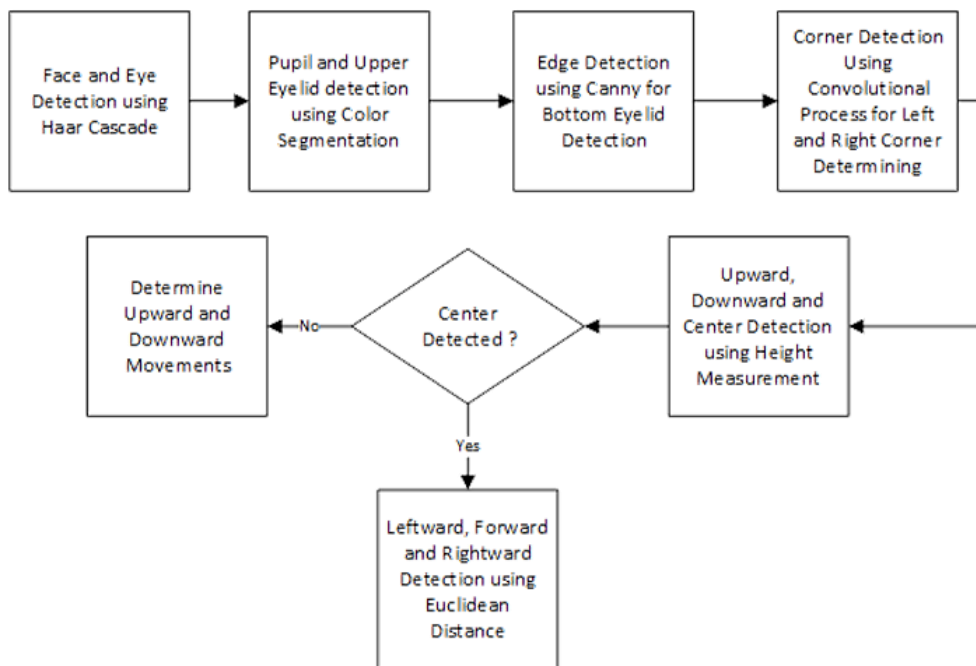


Figure. 1 Eyeball movements detection flow diagram

can be complicated because it needs assistance to stick it on appropriately into the skin, so the electrodes can read the electricity produced by arm muscles.

Another solution was proposed by using voice to be applied as an electric wheelchair controller [10-12]. Nevertheless, a noisy environment can generate incorrect command considering that voice commands depending on the clarity pronounced by the user. Indeed, this problem can be solved by using a wearable microphone installed in the head, however, it still needs assistance for wearing it.

Therefore, we propose an approach to detect and tracks the movements of the eyeball for navigating the wheelchair by using digital image processing that utilizes camera sensors. Camera sensors have an advantage especially for its ergonomics, by using a camera installed on the electric-wheelchair, it does not need wearing any wearable electrodes. By using camera and several digital image processing mechanisms, we also utilize the eyelid movements that has a relation to the eyeball movement to detects vertical movement such as upward, forward and downward. Also, horizontal movement such as rightward and leftward movement can be detected by utilizing distance between pupil and the edge side of the eyes.

In this article, the previous works of eyeball movement detection using camera sensors are discussed in the Section 2. In the Section 3, steps and methodologies to detects the movement of the eyeball is presented. Also in the Section 4, the result and



Figure. 2 Electric wheelchair ergonomics

discussion part is being included followed with conclusion described in Section 5.

2. Previous work

Plenty of research about eyeball movement detection has been done. The research proposed by Singh et al [13] uses eyeball movements as an electric wheelchair navigation controller. In his proposed research, sector measurement used to determine the directions of the eyeball movements by dividing the eye region into 3 sectors and compute the amount of the pixel in every region and then compared those 3 values to get the highest sector values. The highest values itself represent the directions of the eyeball movements. Nonetheless, this proposed method only can detect 3 directions of the eyeball movements that is leftward, rightward and forward.

A method for eyeball movement detection also proposed by Patel et al [14]. In this research, circle detection was used to detect the pupil locations. Also, canny edge detection was used to detect the edge and size of the pupil itself. Nonetheless, this proposed method also can only detect 3 directions of the eyeball movements including forward, leftward and rightward.

Improvements result in eyeball movement detection also produced by Prasetya et al [15]. Using the *Triangle Similarity* method, 4 gaze directions of eyeball movements can be detected including upward, downward, leftward and rightward. Nonetheless, the downward detection still has lacks of accuracy. The lacks of downward accuracy is caused by the lack of ability for system to detect the vertical movement especially for downward movement detection. It is because, the angle produced by *Triangle Similarity* method for downward movement is quite similar with any other gaze. The lack of the accuracy of downward detection has been improved using *Naïve Bayes* classification to determine the downward and upward movements [16]. The *Naïve Bayes* method is used to classified the vertical movement including upward and downward using angle values and *Eye Aspect Ratio* (EAR) as features. Therefore, downward movement can be distinguished with any other gazes due to the features produced.

However, 4 gazes of eyeball movement detection only produce four control mechanisms for wheelchair navigation control including upward detection for speed adjustment (speed up), downward detection for speed adjustment (slow down speed), rightward for turn right, and leftward for turn left. According to those navigation menus, forward detection was needed to determine the neutral position. The neutral position is required to avoid the confusing movements of the eyeball. As an example, when the user just looking forward to checking the terrain to be traversed, if there is no forward detection mechanism, a system will choose the most suitable possibilities whether upward, downward, leftward or rightward. Therefore, the decision taken by the system will influence the wheelchair movements.

Several research such as using *Region Division* [17] and *Geometry Approach* [18] also proposed 5 gaze eyeball movement detection. However, those methods still lack in the forward movement detection accuracies.

According to those problems, we proposed an eyeball movement mechanism to control the electric/smart wheelchair-using 5 directions of movements including upward, downward, forward, leftward and rightward.

3. Methodology

In this research, several processes of digital image processing and computational process are used to determine the direction movements of the eyeball as shown in Fig. 1.

3.1 Face and eye location detection

The first process for detecting eyeball movements is to detect the face location. There are several ways to find the face location. The most commonly used method is using the *Haar Cascade* process proposed by Viola and Jones [19, 20]. Also, there is another approach to detect the face location by using a *Histogram of Gradient* (HoG) [21, 22], until using the *Convolution Neural Network* (CNN) [23]. CNN produces an accurate detection for face location compared with *Haar Cascade* and *HoG*. However, CNN needs a multiple convolution process for *Neural Network Classification* schemas. Therefore, it will produce more computational processes rather than using *Haar Cascade* and *HoG*.

Due to our electric wheelchair user interaction mechanism, it is only driven by one user and the position of the user is relatively static as shown in Fig. 2. Therefore, we do not use CNN as a face detection algorithm according to its slower computational times [24]. Therefore, *Haar Cascade* and *HoG* are interesting choices for face and eye location detection.

Both *Haar Cascade* and *HoG* produce a high frame rate rather than CNN. Interestingly, *Haar Cascade* methods produce more accuracy compared with *HoG* for object recognition [25]. Based on those results, we used *Haar Cascade* as the face and eye location detection.

In this research, we use images data that we have collected before. Each image is captured using a 1.3 MP camera resolution. Using *Haar Cascade*, the face area has been located by utilizing *Haar features* assisted with *Integral Image* to reduce computational

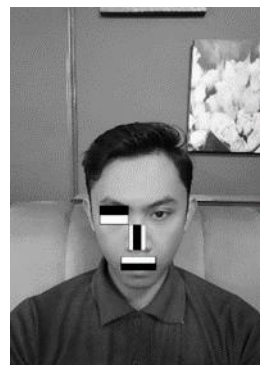


Figure. 3 Haar cascade illustration using Haar features

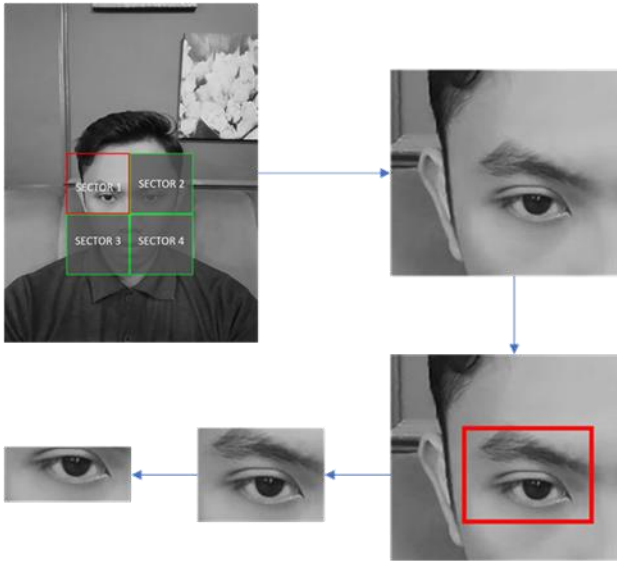


Figure. 4 Eye selection process

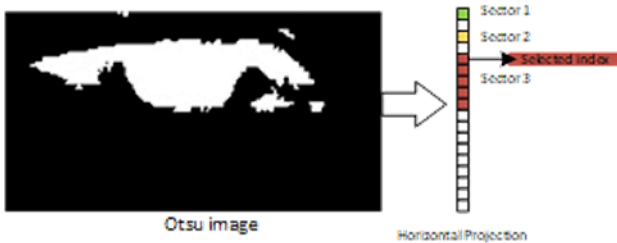


Figure. 5 Sectors generated using the Horizontal projection method

times as shown in Eq. (1):

$$\int(x, y) = \sum_{x' \leq x, y' \leq y} i(x', y') \quad (1)$$

For instance, $\int(x, y)$ is the *integral image*, and $i(x', y')$ are the values of the original image at the location (x, y) .

Using the “cascading” process, an image window will be determined as a “face” area if the window can go through the whole cascading mechanism [26]. *Haar Cascade* process illustration was shown in Fig. 3.

Similar to the face location detection, the eye location detection process is using the same process as the face location detection did. The difference is the sliding window scanning process does not scan entirely image/frame, but scanning in the inside face location that detected on the previous detection. Also, we restrict the scanning area of the eyes location by dividing the face area into 4 sectors and do a scan in sector 1 only. After eye location is detected in sector 1, we also crop the unnecessary eyebrows part so it will focus only on the eye region as shown in Fig. 4.

3.2 Pupil and upper eyelid detection

After eye location is detected, the next step is to detect the upper eyelid. According to the research by Ploch et al, eyelid movements are affected by pupil and eyeball movements [27]. Therefore, in this proposed method we assume that upper eyelids can be located by detecting the upper location of the pupil.

To detect the upper position of the pupil area, in this research we use a segmentation approach based on the *Otsu* threshold [28]. Therefore, the *Gaussian* filter was applied to the eye image using Eq. (2):

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

Denotes, $G(x, y)$ is the *Gaussian* threshold and σ is the standard deviation. Afterward, the *Otsu* threshold was applied to the *Gaussian* image by using Eq. (3):

$$\sigma_w^2(t) = w_0(t)\sigma_0^2(t) + w_1(t)\sigma_1^2(t) \quad (3)$$

For instance, $\sigma_w^2(t)$ is the class variance, w is the weight generated using Eq. (4).

$$w = \sum_{i=0}^{\theta-1} p(i) \quad (4)$$

Denotes, θ is the variable depends on the w_1 or w_2 . For w_1 , θ is t , and for w_2 , θ is L (histogram).

After the *Otsu* threshold process was done, the horizontal feature extraction process is applied to the *Otsu* threshold result image using Eq. (5):

$$P(b) = \sum_{j=1}^N i(b, k_j) \quad (5)$$

Denotes, N is the weight of matrix/image, b is the row, and P is the horizontal projection result in the k column. The result of horizontal projection will produce an array with length as the same as the height of the *Otsu* threshold result image. Following the *Otsu* threshold result, pupil area segmentation will generate a larger white color. However, the threshold result will not produce a clear result without noises as we expected. As shown in Fig. 5, horizontal projection results produce 3 different sectors. Each sector contains an array of columns that coincide and have values greater than 0. Therefore, the highest sector must be selected, in this research, we use a computational work to select the highest sector and determine the upper side of the pupil by using the first

index number of the highest sector value as a vertical coordinate of the upper eyelid.

3.3 Bottom eyelid detection

A bottom eyelid coordinate can be determined using the last index of the highest sector value that measured using *Horizontal Projection* before. Nevertheless, this approach cannot be applied if a pupil of the eyes does not intersect with the bottom eyelid, especially when eyeball looking upward. Therefore, for bottom eyelid detection, we use *Canny Edge* detection that represents in the Eq. (6).

$$|G| = \sqrt{I_x^2 + I_y^2} \quad (6)$$

Denotes, $|G|$ is the gradient intensity, where I_x and I_y are the convolved image using k_x and k_y respectively (Eq. (7) and Eq. (8)).

$$k_x = \begin{bmatrix} -1 & 0 & 1 \\ -2 & 0 & 2 \\ -1 & 0 & 1 \end{bmatrix} \quad (7)$$

$$k_y = \begin{bmatrix} 1 & 2 & 1 \\ 0 & 0 & 0 \\ -1 & -2 & -1 \end{bmatrix} \quad (8)$$

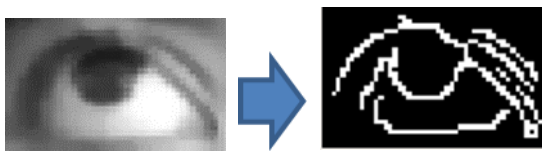


Figure. 6 *Canny edge* detection result from *Gaussian* blur image

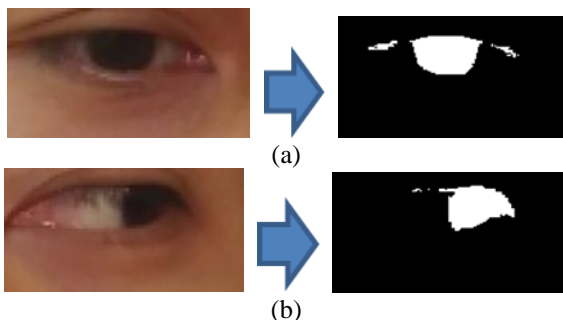


Figure. 7 Otsu threshold result does not represent the edge and corner of the eyes: (a) eyeball looking forward and (b) eyeball looking leftward



Figure. 8 Convolution result for edge sharpening

To minimize the resulting edge caused by skin scratches, *Canny Edge* detection was applied to *Gaussian* blur image generated before (Eq. (2)). The result of *Canny Edge* detection was shown in Fig. 6.

3.4 Left and right corner detection

Left and right corner detection are needed to determine the corner of the eyes. Using the left and right corner coordinate, the horizontal movements of the eyeball can be detected. Slightly different from upper eyelid detection, sector mechanism can not be applied due to the not optimal *Otsu* threshold for edge and corner detection result especially when the eyeball is not right in the middle as shown in Fig. 7.

Accordingly, the edge sharpening method is needed. The filtering approach using the convolution method is applied to the grayscale image of eye location by using a 5x5 matrix kernel as shown in Eq. (9).

$$G(x, y) = (f * h)[x, y] = \sum_j \sum_k h[j, k]f[x - j, y - k] \quad (9)$$

Denotes, f is the input image, x and y is the index of rows and column respectively, and h is the filter or kernel generated using Eq. (7).

$$h = \begin{bmatrix} -1 & -1 & -1 \\ -1 & 10 & -1 \\ -1 & -1 & -1 \end{bmatrix} \quad (10)$$

Convolution process will generate a binary image with sharpened edges. The result of the convolution process is cropped with upper eyelid as an upper edge of the image as shown in Fig. 8.

After the convolution process, the next process is to select the right and left edge. In this research, we used a *Vertical Projection* method to sum the pixel based on the column. The *Vertical Projection* result will produce an array, using those array, the left and right edge of the eye location can be determined using the first and the last of a sector that contains values greater than 0 as shown in Fig. 9.

3.5 Upward, forward, and downward detection

By utilizing the result of upper eyelid detection, bottom eyelid detection, and left and right corner detection, we can determine the boundary of the eye using those key-point coordinates, we also call it *the Eye-mark* approach.



Figure. 9 Threshold result after convolution process

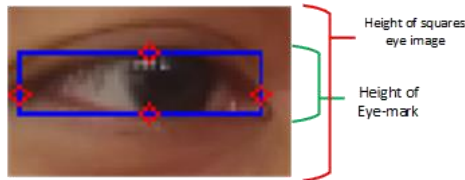


Figure. 10 The eye-mark result using Contour and Edge detection

In this research, we propose a method to detect upward, forward and downward movements of the eyeball by using the comparison between the height of *Eye-mark* and height of square eye image called *Height Ratio*, shown in Fig. 10. and explained in Eq. (11).

$$Es = \begin{cases} h > \sigma_u, \text{upward} \\ \mu_d < h < \sigma_u, \text{forward} \\ h < \mu_d, \text{downward} \end{cases} \quad (11)$$

Denotes, σ_u is the smallest of height value when eyeball looking upward, μ_d is the highest of height value when eyeball looking downward, and h is the height value of *Eye-mark* determined using Eq. (12).

$$h = \frac{H_e}{H_T} \quad (12)$$

For instance, H_e is the height of the marked square (*Eye-mark*) and H_T is the height of the eye selection process (Fig. 4).

3.6 Leftward, forward, and rightward movements detection

By using height measurement, it can be determined the vertical movements of the eyeball including upward, forward and downward movements. Therefore, it needs an extra process to determine the horizontal movements of the eyeball like leftward, forward, and rightward. In this research, we assume that horizontal movements of the eyeball can occur when the height value of the *Eye-mark* is “forward”.

Leftward, forward and rightward detection mechanism is processed using the left and right horizontal coordinates that generated from the left and right corner detection process (Fig. 10). The left and right coordinates will be the point of reference as same as center coordinate that generated from the average calculation between left and right, as shown in Fig. 11.

Referring to Fig. 11, the eyeball horizontal movements can be measured using Eq. (13).

$$D = \min(L_1, L_2, L_3) \quad (13)$$

Denotes D is the direction of eyeball horizontal movements (leftward, forward and rightward), L_1 is a distance between the center of the pupil to the right point, L_2 is a distance between the center of the pupil to the center point, and L_3 is a distance between center of pupil with left point coordinates.

The center of the pupil can be measured using *the Otsu* threshold process. The *Otsu* threshold process produces a binary image containing a shape, therefore, a center of the pupil will be referring to the larger shape in the *Otsu* threshold image. In this research, a *Centroid* approach is applied to determine the center of the pupil using Eq. (14).

$$(x, y) = [(x \rightarrow X_\alpha + R_t), (y \rightarrow Y_\delta + R_\delta)] \quad (14)$$

For instance, x and y are the coordinates of the pupil, X_α is the beginning of weight, Y_δ is the beginning of

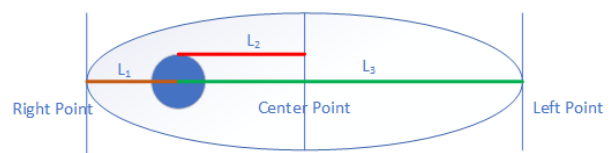


Figure. 11 Eyeball movement illustration using distance point method

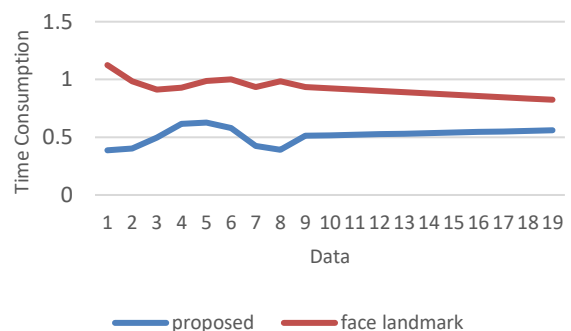


Figure. 12 Computational time comparison of the proposed method and face landmark method to determine the eye marking positions.

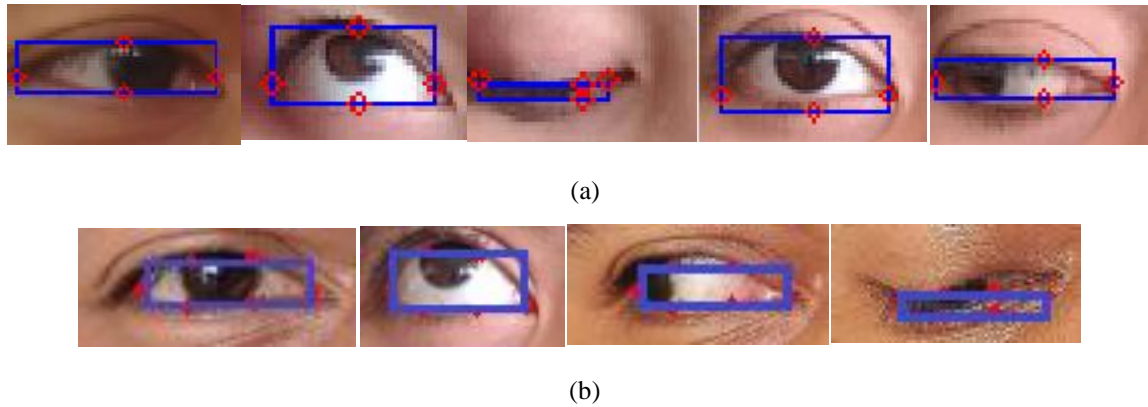


Figure. 13 Key-point generates a result: (a) using the proposed method and (b) using face landmark method

height, while R_t and R_δ were generated using Eqs. (15) and (16).

$$R_t = \frac{\sqrt{(x_\alpha - x_\beta)^2 + (y_\alpha - y_\beta)^2}}{2} \quad (15)$$

$$R_\delta = \frac{\sqrt{(x_r - x_\delta)^2 + (y_r - y_\delta)^2}}{2} \quad (16)$$

Denotes, x_α and y_α are the beginning shape coordinate of the vertical direction, x_β and y_β are the ending shape coordinate of the vertical line. x_δ and y_δ are the beginning shape coordinate of the horizontal direction and x_r and y_r are the ending shapes of horizontal directions.

4. Result and analysis

We proposed an approach to detects the eyeball movement directions using *Eye-mark* based on edge and contour. The output of this research is the marking point in the eye area especially on the upper, bottom, left and right corner for detects the movements of the eyeball.

In this research, we use 50 different person face data that captured manually using 1.3 MP of camera resolution for trial process. Every person or respondece asked for moves their eyeball with accordance of 5 gaze movement. The total image data that we are used, is 250 images data including 50 images for every movement.

Another research also uses a marking point to detects the blinks movement of the eyes called *Facial Landmark* [29]. *Facial Landmark* is the method of marking the face area using the *Tree Cascade* method proposed by Kazemi et al [30]. The problem of the *Facial Landmark* approach is the use of high computational time. In this research, we also compare the computational time needed between our proposed

method and the *Facial Landmark* method to detects the eye locations using 20 images data as shown in Fig. 12.

According to Fig. 12, our proposed method can overcome the *Face Landmark* methods for computational times. It is because our proposed method does not use a gradual method like *Tree Cascade*. Our proposed method only using image processing to determine the eye marking position. Several results of *Eye-mark* as proposed method and facial landmark method for determining the eye marking coordinates also shown in Fig. 13.

About 150 data of horizontal eye movements are tested to gain the *Height Ratio* including 50 data for downward, 50 data for forward and 50 data for upward. The result of the *Height Ratio* measurement is shown in Fig. 14.

Referring to Fig. 14, there is a difference evident between upward, forward and downward state. As mentioned in Eq. (11), the highest value of downward (μ_d) is represented with a blue ocean straight line, and the smallest value of upward (σ_d) is represented with a green light straight line.

Table 1. Detection result using the proposed method

Directions	Correct	False	Accuracy (%)
Upward	45	5	90 %
Rightward	46	4	92 %
Forward	46	4	92 %
Leftward	44	6	88 %
Downward	47	3	94 %
Average			91,2 %

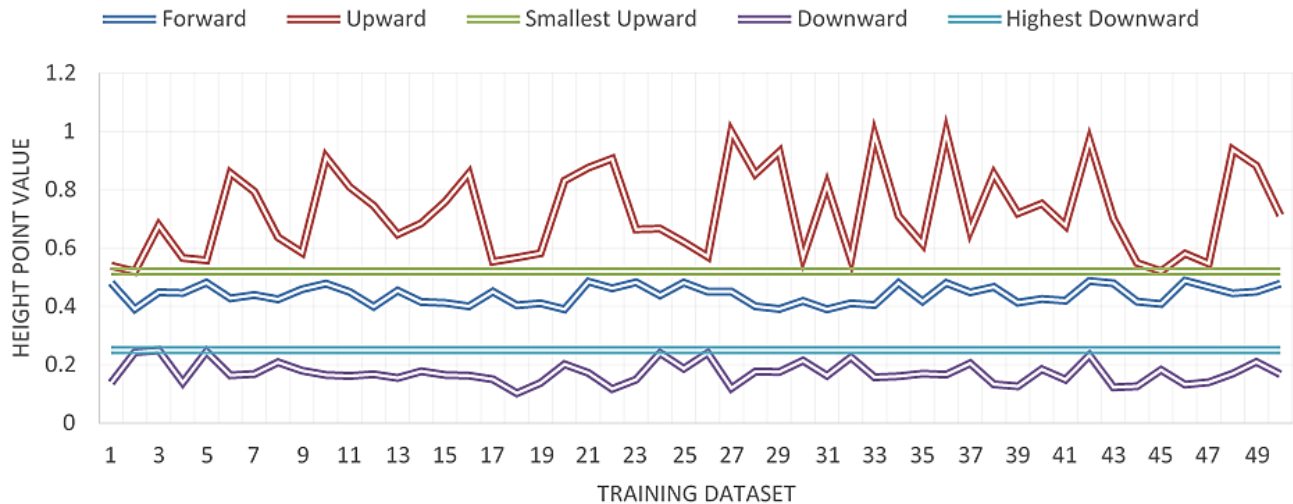


Figure. 14 Height Ratio measurement result for training dataset

Table 2. Comparison of our proposed method with Triangle Similarity and Naïve Bayes Triangle Similarity methods

Directions	Detection Accuracy (%)		
	TS [15]	NBTS [16]	Proposed
Upward	75 %	80 %	90 %
Downward	58,3 %	80 %	94 %
Rightward	91,6 %	90 %	92 %
Leftward	91,6 %	90 %	88 %
Average	79,12 %	85 %	91 %

Our proposed method also tested to detects the movements of the eyeball to 50 respondents. Every respondent also asks to move their eyeball to the five directions includes upward, forward, downward, leftward and rightward. Total data for testing is 250 data captured using the same hardware as train data. The result of the experiment is shown in Table. 1.

Our proposed method also compared with another previous method like *Region Division* (RD) method [17], *Triangle Similarity* (TS) [15], *Naïve Bayes Triangle Similarity* (NBTS) [16], and *Coordinate Geometry* (CG) method [18].

In the first comparison section, our proposed method was compared with *Triangle Similarity* and *Naïve Bayes Triangle Similarity* methods with focusing on upward, downward, leftward and rightward movements detection shown in Table 2.

According to Table 2, our proposed method can outperform the two other methods. Our proposed

method can detect upward, downward, leftward and rightward movements around 91% of accuracy. TS and NBTS method has lower average detection accuracy caused by circle detection problem. TS and NBTS method experience difficulty for pupil detection using circle detection mechanism, it is because a pupil does not visible as a perfect circle when several parts of pupil is covered by eyelid, especially for vertical movement such as upward and downward.

Our proposed method also compared with *the Coordinate Geometry* method and *Region Division* method to shows the ability for forward movement detection as shown in Table 3.

Referring to Table 3, the results of forward eyeball movements detection generated by *Region Division* and *Coordinate Geometry* approach is surpassed by our proposed method. Our proposed method is generating 92% of forwarding movement detection using the proposed *Distance Point* method (Fig. 11). There are several reasons of why our proposed method is superior, in the *Region Division* method, there is a registration mechanism before the user can use the eyeball detection system. This mechanism only saves the registration data in the current state. Therefore, if there is some movement of the body such as come forward or away from the camera, the existing conditions or state will be different with the saved state before, especially for forward movement as the center of the eyeball movement direction. Slightly different from *Region Division* method, *Coordinate Geometry* approach has a high sensitivity issues caused by their mechanism that compare the movement with the initial state. Therefore, if there is a little movement of the eyeball, it will be detected as the movement without providing the appropriate range of the movement.

In the last, our proposed method is compared with *the Region Division* method to shows the performance of 5 gaze eyeball movements as shown in Table 4. Our proposed method has a bit of excellence compared with *the Region Division* method. Our proposed method has 91,2% accuracy greater than 91% of accuracy generated by *the Region Division* method. Furthermore, our proposed method does not require any calibration process required by the *Region Division* method. Several samples of correct detection results generated by our proposed method also shown in Fig. 15. As an approach, our proposed method also has lacks and deficiency, several results of failure detections result also shown in Fig. 16.

5. Conclusion

This research proposes an approach to detects five movements of the eyeball including upward, downward, leftward, forward and rightward. Our proposed method is utilizing the marker of the eye location called *Eye-mark*. An *eye-mark* method is the marking eye area approach by utilizing pure digital image processing approaches without involving any

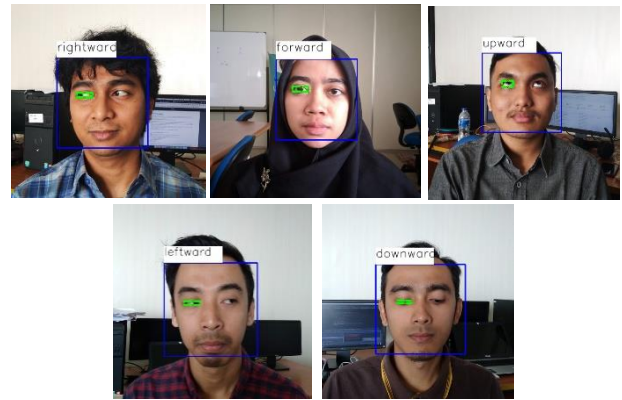


Figure. 15 Several correct detection results using our proposed method

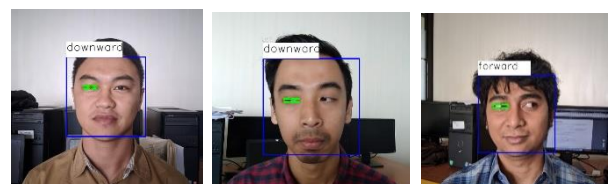


Figure. 16 Several samples of failure detection result

Table 3. Comparison of our proposed method with Region Division and Coordinate Geometry methods

Directions	Detection Accuracy (%)		
	RD [17]	CG [18]	Proposed
Forward	80 %	20 %	92 %

Table 4. Comparison of our proposed method with the Region Division method to detects 5 directions of eyeball movements

Directions	Detection Accuracy (%)	
	RD [29]	Proposed
Upward	85 %	90 %
Downward	96 %	94 %
Forward	80 %	92 %
Leftward	97 %	88 %
Rightward	97 %	92 %
Average	91 %	91,2 %

classification. Therefore, our proposed marking method can outperform the computation times generated by other marking methods and produce less time computation results. The smaller the computation time, the higher the FPS (Frame Per Second), the more information we can get.

Our proposed method also generates 91,2% accuracy for eyeball movement detection. This proposed method can outperform any other methods and can perform well without any calibration process before. Therefore, our proposed method is a worthy approach for applied as an electric wheelchair control movements like upward for increasing speed, downward for decreasing speed, leftward and rightward for left and right movements and forward for straight forward movement.

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