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EYE MOVEMENT AND BLINK DETECTION FOR SELECTING MENU ON-SCREEN DISPLAY USING PROBABILITY ANALYSIS BASED ON FACIAL LANDMARK

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Abstract. *The menu selection on a monitor screen is usually achieved using a remote control, mobile device, mouse, touch system embedded into a monitor screen, or a keypad or keyboard. Users unable to move their limbs can still utilize their eyes as an alternative method for selecting an on-screen menu display. As a breakthrough for people with movement disabilities, computer vision allowing the detection of eye movements can be implemented as a menu selection tool of a display monitor. The detection of the eye position consists of the left, right, and middle areas. Meanwhile, as an additional necessity for the execution process, eye blinking also needs to be detected by the system. The method proposed in this study for the detection of the eye movement position during the initial step includes the segmentation process and a calculation of the probability of a white pixel analysis based on the facial landmarks. Eye blinking can be detected by calculating the value between the horizontal and vertical lines in the eye area. The proposed method for detecting eye movements in three areas (left, center, and right) achieves an average accuracy of 88.1%. Furthermore, the average accuracy for detecting eye blinking is 90.5%.*
Keywords: Eye movement detection, Facial landmark, Eye movement, Eye-blink

1. **Introduction.** A stroke can affect anyone, particularly middle-aged and elderly adults [1]. A stroke can cause paralysis, preventing the movement of the hands, speech, and even whole body movements [1,2]. This problem has motivated researchers to develop devices particularly aimed at helping stroke victims with their daily activities. A physical disability can also affect the ability to effectively move one's arms or legs. Disabilities in the arms, shoulders, and hands will have an impact on the ability to carry out certain

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activities such as eating, driving, holding onto objects, or using a remote control. Most people with a disability with their hands will endeavor to use their legs as an alternative. A more critical issue will emerge however, when people have multiple disabilities, such as both their hands and their feet.

Conducting daily activities is an essential requirement for all people. However, for people with disabilities, their daily activities are frequently disrupted. Our focus is to create a system to help disabled people with their daily activities. In disabled people who cannot move their bodies, their eyes can function as a solution to communicate their desires. A system applying eye detection is useful for solving this problem. The users can move their eyes to the left, right, and center, and blink to select a menu on the screen.

In recent years, medical research has played a major role in many different sectors, such as medical image processing [2-4]. Eye detection has played an important role in several applications of image processing, such as the approach in [5], which uses the left and right eyes to obtain the region of interest of the face. Several attempts have been made to implement eye detection movements, such as blink, eye movement, head movement, and pupillary detection [6,7]. However, a recently developed method has a low accuracy and has numerous disadvantages, such as the ability to detect objects other than the eye.

The results of previous studies on eye detection using a Haar cascade method combined with a Hough circle method for the navigation of disabled individuals [8] showed an accuracy of less than 80%. This is because the Haar cascade method can detect objects other than the eye [8,9]. A Haar cascade method can detect not only the eyes but also the face. However, the method does not apply key-points as facial identifiers.

A new method to deal with this, namely, a facial landmark method [10-12], was proposed. This method has several advantages such as being able to detect parts of the face that are displayed through the facial identifier points. This method works by detecting contours on the face to obtain identifier points. Using this method, the system can detect parts of the face, such as eyebrows, eyes, nose, mouth, and face. In other studies, this method is used to detect parts of the face and achieve good results [12]. This research focuses on the points of the eye area to be processed using the proposed method.

In this system, the proposed method applies facial landmarks. Parts of the eye will be detected by the facial landmark method and cropped. A part of the eye will be processed to predict the location of the eye. Eye movements such as looking to the left, right, and center and blinking are used to select the menu options. The testing data for an experiment uses a variety of face images with various lighting conditions and backgrounds to determine the accuracy of the system and for a performance evaluation.

This research will contribute to the knowledge related to the use, development, and application of facial landmark methods for menu selection on a display screen. This study provides a basic concept of human-computer interaction through eye movement. In our system, to move from one menu to another, the eye moves left or right, thereby adjusting the menu position. Furthermore, the menu options are selected or executed through eye blinking. As the advantage of the proposed system, it does not require direct physical contact between the user and device. Thus, this system will be extremely useful, particularly for those with a physical disability of their hands. In addition, the proposed system also considers the inevitability of the computer system to generate small errors during execution.

2. **Related Studies.**

This section discusses previous studies related to menu selection using the eyes. The variables used for the menu selection were eye movements and blinking. A variety of methods can be used to detect the eye position, including the following:

1) **Appearance-based method.** This method calculates the similarity between the sample and parts of the image for detecting an eye area. Laxmi and Rao [13] detected the eye position using a combination of a Gabor filter and a support vector machine (SVM). A Gabor filter is used to obtain a candidate from an eye and then continue by classification using an SVM to obtain eye and non-eye areas. A similar eye detection procedure was also carried out by Huang and Wechsler [14], who use wavelets to represent the eye area and radial basis functions (RBFs) to conduct the eye and non-eye classification.
2) **Shape-based methods.** This method consists of a simple elliptical shape and complex shape models. The simple elliptical shape model uses an approach to model the eyelids, iris, and pupil. Nixon [15] extracted the iris and pupil using a Hough transform. However, an explicit feature detection is required. The method of applying a simple ellipse can be divided into voting-based [15,16] and model fitting approaches [17]. The voting method uses a hypothesis from voting on the selected features, whereas the fitting approaches model uses the matching of selected features. Meanwhile, a complex shape-based method uses detailed modeling of the eye shape [18], such as a deformable template model that applies parabolas representing the eyelids with 11 parameters and a circle for the iris.
3) **Facial landmark.** This method is used to detect important points on the inner parts of the face. In [19], the location template for 77 face landmarks was implemented with the active shape model (ASM) algorithm. Tracking on the face area can be achieved to change the contour and mouth of a person's face. By tracking the change in position of the mouth point using facial landmarks, it can be determined whether the mouth is closed, moderately open, or wide open. Meanwhile, detection of the position of the nose in the face was also carried out in [11].

3. **Proposed Method.** A flowchart of the proposed method is shown in Figure 1. The input image is captured using a webcam, and the image is then processed using facial landmarks. A facial landmark is used to detect the facial area, such as the eye parts. The important part is only required the eye, that to be cropped. The image obtained in RGB color is converted into binary colors. The purpose is to make the system execution process run effectively and to perform the detection process during the next step. The image obtained in the eye area is divided into two areas: left and right areas. The goal is to separate the white area from the pupil area found in the eye. Eye movement detection is categorized into three detections, i.e., looking to the left, right, and center. The three regions are obtained based on the probability of the white area of the eye. The probability of the white area of the eye is represented by P_w. A value of $P_w \leq 0.6$ indicates a gaze toward the right. Furthermore, if the resulting value is $0.6 < P_w < 1.2$, it produces a center gaze. Meanwhile, another P_w value is for the left gaze. In blink detection, a horizontal and vertical line measurement is used to calculate whether someone blinks or not. The condition of the eye blink is searched by calculating the probability of a blink. The probability of a blink is symbolized by the variable P_b. If the value of $P_b \geq 5$, it indicates that the eye is closed. Meanwhile, if $P_b < 5$, it indicates an open eye. Menu execution on the display can be performed when the eyes are closed for $t > 4$ s. If the time is less than 4 s, the menu selecting feature will not be executed. In this study, we used 4 s as a blinking time limit to distinguish natural blinking and the blink selection function.

This research is proposed for someone who has certain physical limitations, such as after a stroke or for people with disabilities. The application implements a menu selection and displays it on an LCD screen. The selection menu contains various needs of disabled

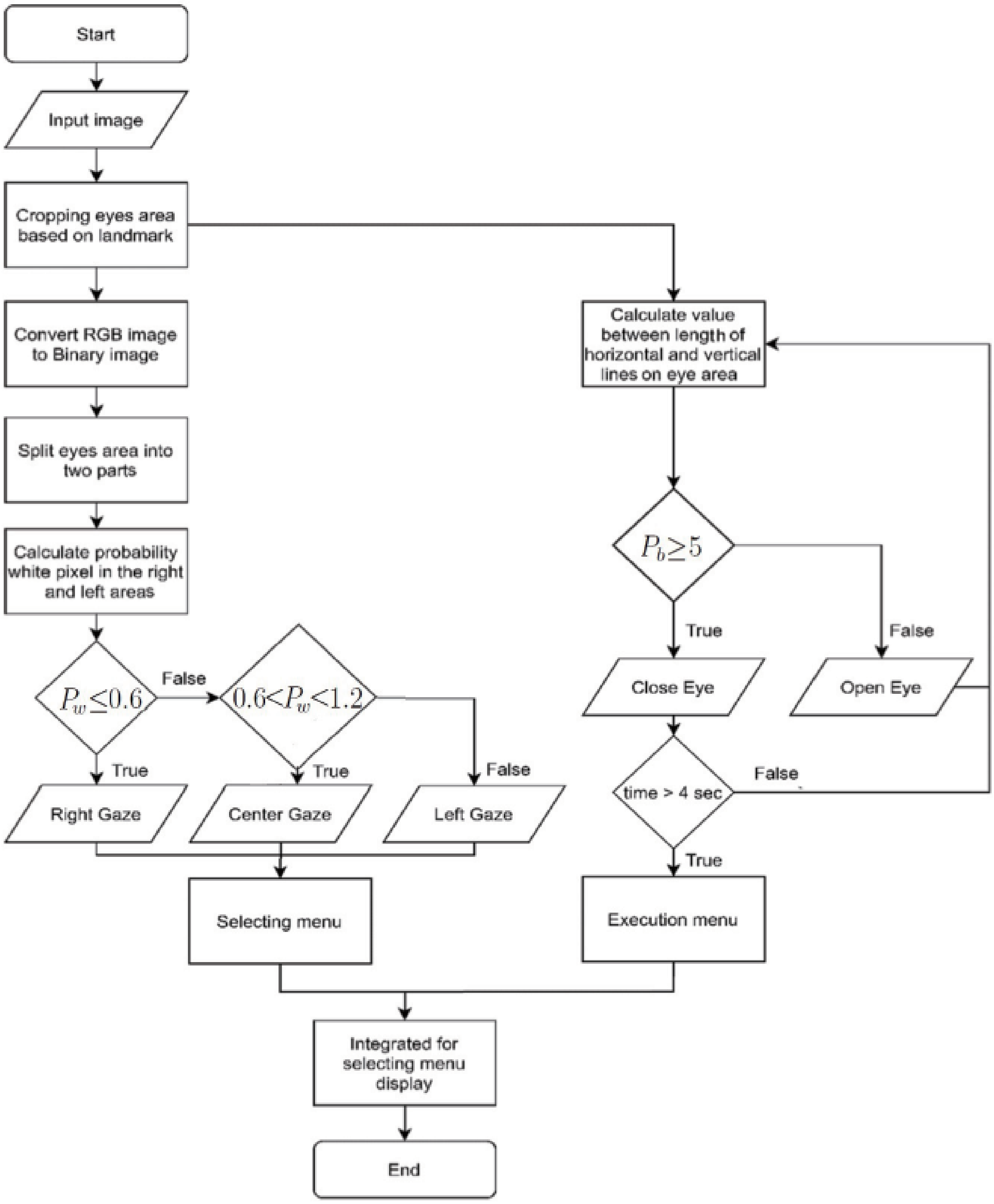


FIGURE 1. Algorithm for eye movement detection

people in carrying out daily activities such as calling a nurse, calling for help, or choosing food from a menu. To use the system, users do not need to move their hands or body, and users simply move their eyes to select the menu available on the LCD screen.

3.1. **Image dataset.** This research uses 42 test data for each eye movement of the face image from 10 different people with dim lighting settings for 1-10 lux, normal lightning for 40-70 lux, and bright lighting for 90-110 lux. The lighting effects are used to measure the performance of the systems during the detection process. Image capture uses a Logitech webcam type c170 with a pixel resolution of 640 × 480. The captured image must cover the entire face area from the tip of the hair to the tip of the chin. The distance between the camera and the object was determined to be as high as 30 cm. Image taking is conducted in a place that has a flat and crowded background.

The human eye can be divided into three areas: the pupil, iris, and sclera. The sclera is the white area of the eye. During the eye detection process, the part used for processing is the sclera area, not on the iris or pupil. The iris and pupils in each person have a different color, whereas the sclera is only white. When a researcher uses the pupils and the irises, it makes it challenging to detect the colors in the area, and thus with these factors, the area to be processed is the sclera.

3.2. **Eye area recognition.** The facial landmark is an algorithm used to detect the position of a human face. The facial landmark algorithm has many advantages compared to other algorithms. This is because this algorithm can detect all parts of the face starting from the eyebrows, eyes, nose, mouth, and eye parts. The facial landmark algorithm detects the contours of faces using database sampling because this algorithm has a high accuracy in detecting human faces. The facial landmark method used to identify the facial parts and only the eye part will be processed. During this process, the facial landmark point of the eye is taken from points 37 to 46, as shown in Figure 2. After the eye point is obtained, the next step is to crop the eye area of the two eyes and produce two eye images, as shown in Figure 3.

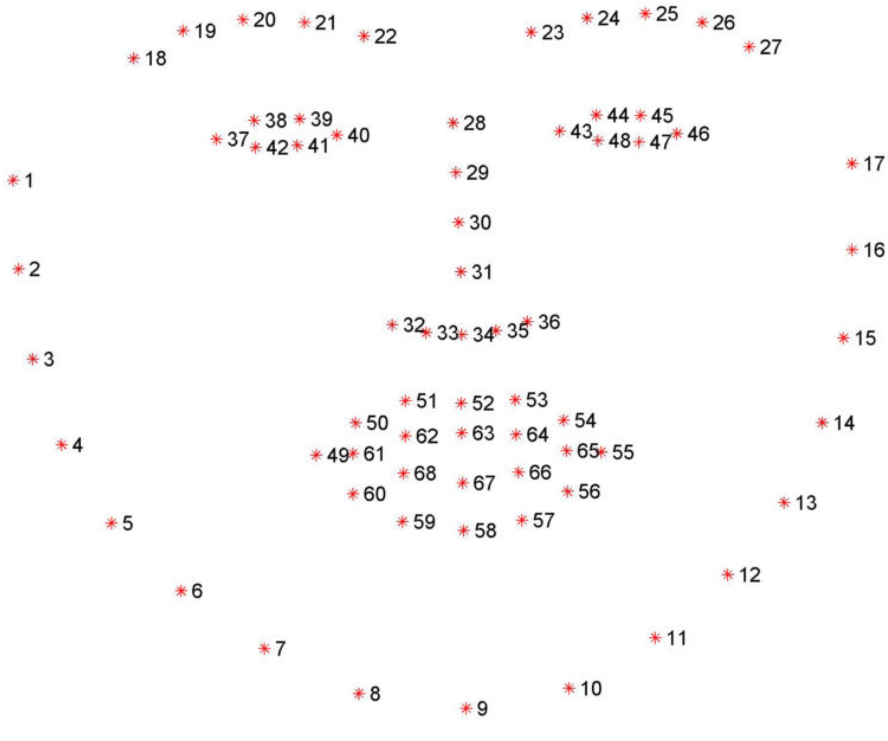


FIGURE 2. Facial landmark

3.3. **Prepossessing eye movement.** After obtaining the image of the eye area, the next step is to convert the RGB image into a binary image. Binary images of the eye area are divided into two areas. In this step, the image is divided into two areas, as shown in Figure 4, where the goal is to make a comparison of the total pixels in the white area between the two halves of the eye image.

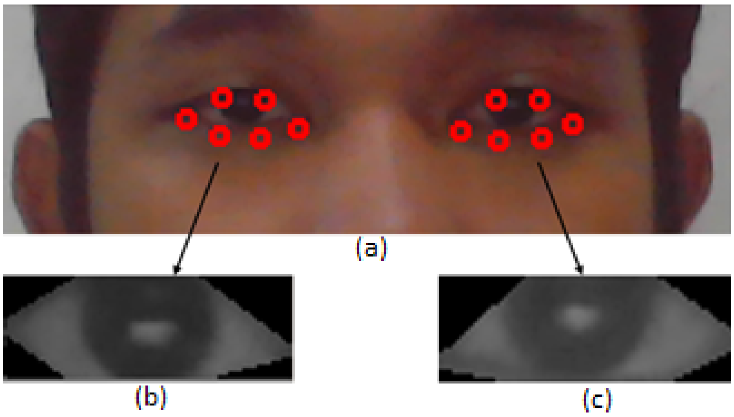


FIGURE 3. Right and left eyes 1: (a) Eye facial landmark, (b) left eye, and (c) right eye

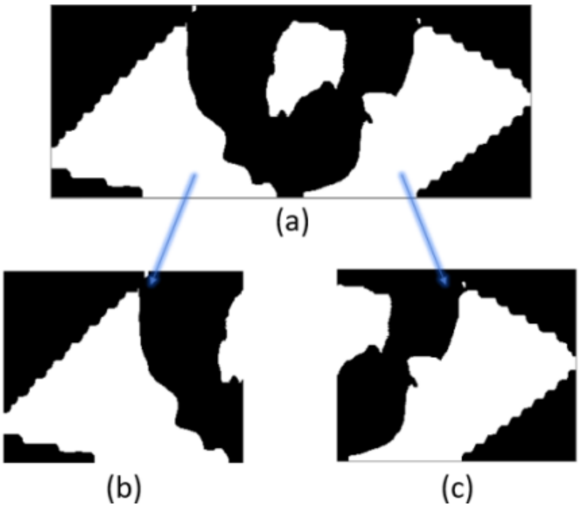


FIGURE 4. Segmentation of eye using (a) binary image and (b), (c) image divided into two areas

3.4. **Eye movement detection.** Eye movements are conditioned into three states. The first state is when the eye looks toward the left, and the menu selection then moves to the left. The second state is when the eye looks toward the right, and menu selection then moves to the right. Finally, the third state is when the eye looks forward, and the menu selection does not move.

To classify eye movements into three states, the goal is to compute or process the white area based on the total pixels. When the number of white pixels in the right area is greater than that in the left area, the eye is considered to be looking toward the right. When the number of white pixels on the left area is greater than the right area, the eye is considered to be looking toward the left, and when the number of white pixels between the left and right is equal, the eye is considered to be looking forward. Figure 5 shows a pixel comparison when an eye is looking toward the left, right, and front.

The value of the eye movement can be obtained by dividing all pixels of the left and right areas, as illustrated in Equation (1). The value obtained allows the distance between the eyes and camera avoid affecting the eye movement detection based on the white area.

$$P_w = \frac{\sum Lw_{(i,j)}}{\sum Rw_{(i,j)}} \tag{1}$$

where P_w = probability of a white area; $Lw_{(i,j)}$ = left white area in row (i) and column (j); $Rw_{(i,j)}$ = right white area in row (i) and column (j).

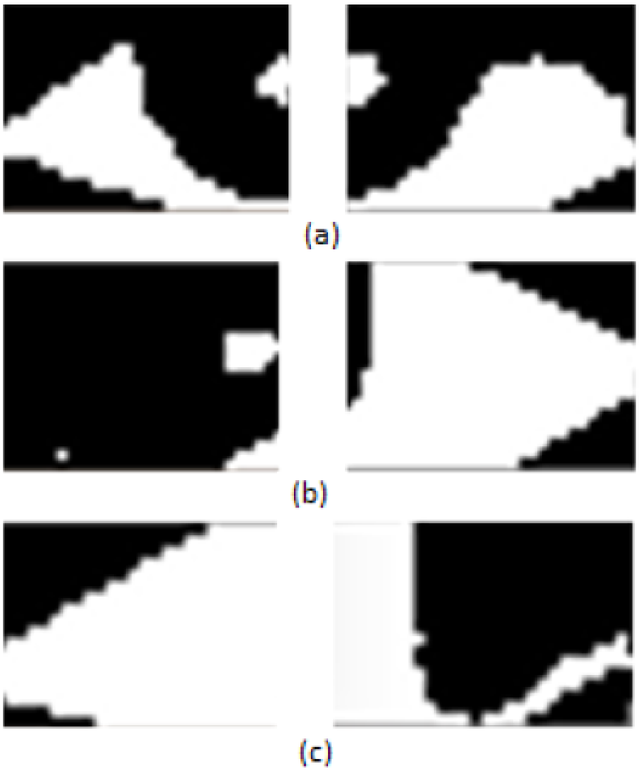


Figure 5. Eye movement with segmentation: (a) Center, (b) left, and (c) right eye movements

Table 1. Total white area in eye movement

Eye movement	Complete white area
Left gaze	$P_w \geq 1.2$
Center gaze	$0.6 < P_w < 1.2$
Right gaze	$P_w \leq 0.6$

The method used to determine eye movements based on the probability of the white area value from both sides is shown in Table 1. The detailed information is as follows:

- When the eye moves to the right, the value of the probability white area (P_w) is equal to or less than 0.6.
- When the eye moves to the left, the value of the probability white area (P_w) is equal to or greater than 1.2.
- When the eye is in condition for looking forward, the value of the probability (P_w) is between greater than 0.6 and less than 1.2.

The total white area (P_w) in Table 1 is obtained by experimenting with some prediction values of the dataset. To obtain a proper accuracy for every value, the values are tested for eye movement detection such as looking to the left, right, and center. The value with the highest accuracy was used for the system. The experiments listed in Table 2 tested the prediction values of 1.3 and 0.7 and the average accuracy obtained was 85.3%. As listed in Table 3, the experiments tested using prediction values of 1.2 and 0.6 achieved an average accuracy of 88.1%. The experiments listed in Table 4, tested using prediction values of 1.1 and 0.5 with an average accuracy of 86.3%. Considering the tendency shown in Tables 2-4, the boundary values of 0.6 and 1.2 in Table 3 were used as the balance in accuracy for the eye movements toward the left, center, and right. The value range of the total white area P_w should be divided into three parts: left, center, and right. As can be seen, the wider the value range, the higher the accuracy; for instance, 87.3% for $P_w \geq 1.3$, 90.5% for $P_w \geq 1.2$, and 99.2% for $P_w \geq 1.1$. However, there is a trade-off because a wider value range for a specific eye movement causes a narrower value range for other eye movements. Therefore, the balanced values in Table 3 were used. Indeed, the good performance of our proposed method, which is shown in Table 10, suggests the validity of range boundary values of 0.6 and 1.2.

Table 2. First experiment eye movement detection

Eye movement	Complete white area	Accuracy
Left	$Pw_{(i,j)} \geq 1.3$	87.3%
Center	$0.7 < Pw_{(i,j)} < 1.3$	78.5%
Right	$Pw_{(i,j)} \leq 0.7$	90.1%
Average accuracy		85.3%

Table 3. Second experiment eye movement detection

Eye movement	Complete white area	Accuracy
Left	$Pw_{(i,j)} \geq 1.2$	90.5%
Center	$0.6 < Pw_{(i,j)} < 1.2$	88.1%
Right	$Pw_{(i,j)} \leq 0.6$	85.7%
Average accuracy		88.1%

Table 4. Third experiment eye movement detection

Eye movement	Complete white area	Accuracy
Left	$Pw_{(i,j)} \geq 1.1$	99.2%
Center	$0.5 < Pw_{(i,j)} < 1.1$	87.4%
Right	$Pw_{(i,j)} \leq 0.5$	72.3%
Average accuracy		86.3%

3.5. **Eyes blink detection.** Eye blink detection uses a measurement method based on the length of the horizontal and vertical lines. The horizontal and vertical lines are formed based on the points of the facial landmarks around the eyes, as shown in Figure 6. The horizontal line of the left eye is formed from point 37 until point 40, whereas a vertical line is formed between points 38 and 42. The horizontal line of the right eye is formed between points 43 and 46, and a vertical line is formed between points 44 and 48. The number of points can be seen in Figure 3. The next step is to calculate the length of the vertical and horizontal lines based on the pixels. Eye blink detection uses a horizontal line because when the eyes blink, the horizontal line shrinks. However, a horizontal line is

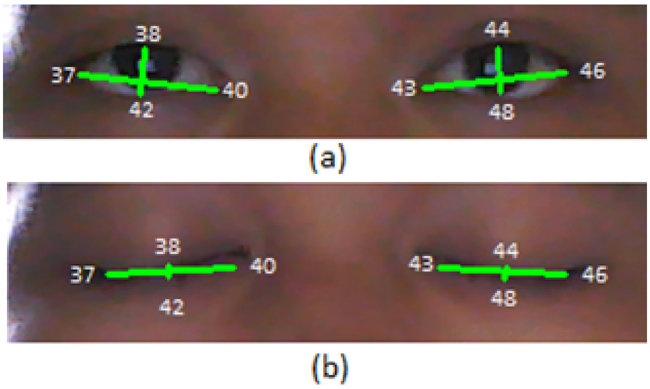


Figure 6. Eyes blink detection: (a) Open and (b) blinking eyes

also affected by the distance between the eyes and the camera. Equation (2) was created to solve this problem.

$$P_b = \frac{H_{37\text{-}40} + H_{43\text{-}46}}{V_{38\text{-}42} + V_{44\text{-}48}} \tag{2}$$

where P_b = probability blink; $H_{37\text{-}40}$ = horizontal line from points 37 to 40; $H_{43\text{-}46}$ = horizontal line from points 43 to 46; $V_{38\text{-}42}$ = vertical line from points 38 to 42; $V_{44\text{-}48}$ = vertical line from points 44 to 48.

Referring to Equation (2), the horizontal line divided by the vertical line makes the value of the blink unaffected by the distance between the eye and camera. When the value of P_b is greater than 5, the eye is detected as blinking. The limit value of P_b was 5, as obtained from the experimental results, which involved 15 participants, where each participant was taken under open and closed eye conditions with a variety of distances between the eye and camera and several combinations of brightness. The P_b value is calculated from the conditions when the eyes are closed and open. Regarding the experimental results, 98% of the total data had a P_b value of less than 5 when the eyes were open. Meanwhile, 96% had $P_b \geq 5$ when their eyes were closed. Table 5 shows the condition of the eye blink detection.

Table 5. Eye blink line length

Eye blink	Blink line length
Blink	$P_b \geq 5$
Not blink	$P_b < 5$

The value of the eye blink prediction (P_b) is obtained from the experiment on eye blink detection conducted to obtain the highest accuracy value from the prediction of the eye blinks such as with open and closed eyes. In Table 6, experiments were tested using a prediction value of 4.9, and the accuracy obtained was 82.7%. In Table 7, experiments were tested using a prediction value of 5, and the accuracy obtained was 90.5%. In Table 8, the experiments were tested using a prediction value of 5.1, and the accuracy obtained was 86%. From these results, the predicted value of eye blink detection was 5.

3.6. **Design menu display.** The eye detection movement was applied to the display menu selection. The menu display was designed as effectively as possible allowing users to use the menu selection properly. There are three display menus, the designs of which are shown in Figure 7(a). One menu display box has a total height of 200 pixels and a width of 200 pixels, and three menu display boxes has a height of 200 pixels and a width

TABLE 6. First experiment on eye blink detection

Eyes blink	Blink line length	Accuracy
Blink	$P_b < 4.9$	69.1%
Not blink	$P_b \geq 4.9$	96.3%
Average accuracy		82.7%

TABLE 7. Second experiment on eye blink detection

Eyes blink	Blink line length	Accuracy
Blink	$P_b < 5$	88.1%
Not blink	$P_b \geq 5$	92.9%
Average accuracy		90.5%

TABLE 8. Third experiment on eye blink detection

Eyes blink	Blink line length	Accuracy
Blink	$P_b < 5.1$	90.3%
Not blink	$P_b \geq 5.1$	81.7%
Average accuracy		86%

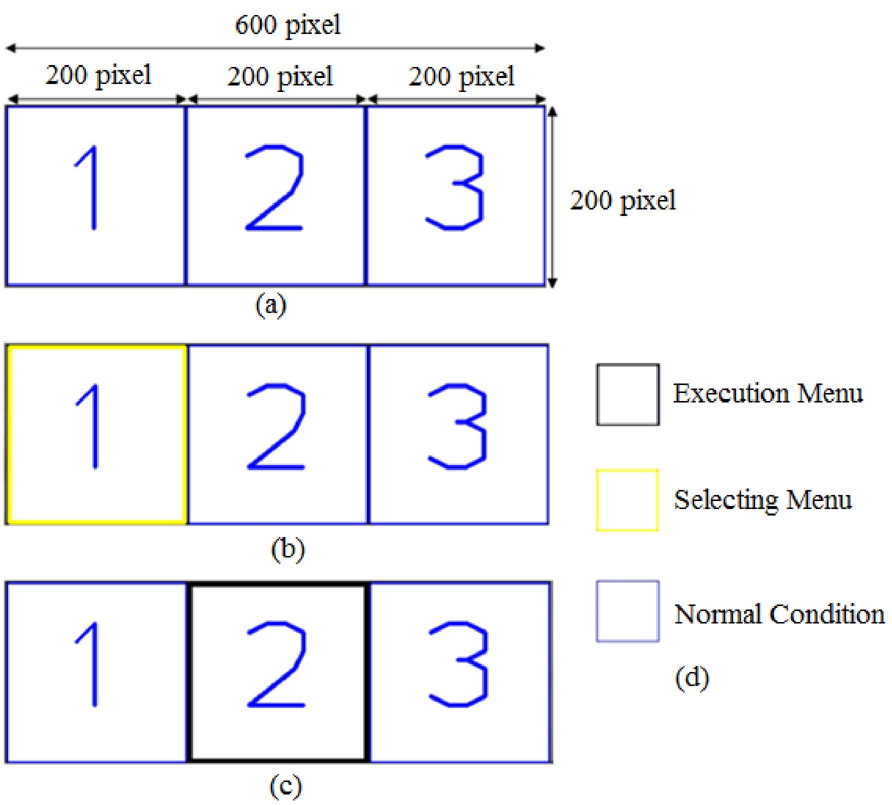


FIGURE 7. (color online) Menu design: (a) Size of the menu display, (b) menu selection, (c) menu execution, and (d) description of the selection menu

of 600 pixels. When users move their eyes, the selected box turns yellow, as shown in Figure 7(b). In Figure 7, (b) shows when the user selects box 1. When the users move their eyes to the right, the selection box moves to box 3. When the users move their eyes to the left, the selection moves to box 1, and when the user looks forward, the selection is in box 2. To select an item from the menu, the user must blink for 4 s to distinguish when the user is blinking normally and when the user wants to execute a menu. When the user enters the selected menu, the box turns black, as shown in Figure 7(c). More details are provided in the description in Figure 7(d).

4. **Result and Analysis.** The conclusion of the eye movement detection can be applied to the option method for menu selection. The analysis using eye movement detection was carried out using various sample images taken under various conditions. The test data used 42 images for each eye movement that were used to measure the performance of the proposed method. Experiments were conducted using different backgrounds, lighting, and people.

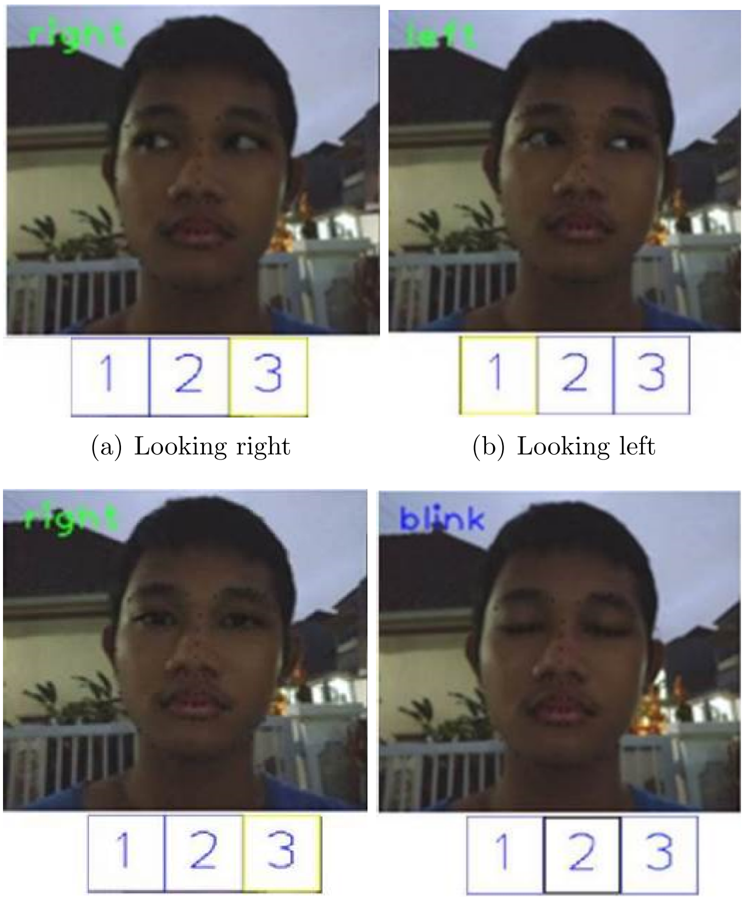
The first experiment is the facial landmark method under conditions in which the face area is on a flat background and a crowded background. Referring to Figure 8, the conditions of a flat or crowded background do not affect the results for detecting the face and eye parts. The experimental results proved that the facial landmark method can be successful in detecting the face area with various background conditions. Eye movement detection is the second experiment conducted under different lighting conditions.

(a) (b)

Figure 8. Different background test: (a) Flat and (b) crowded background

The second experiment was conducted under different lighting conditions. The lighting conditions were determined based on the lux level. The first lighting conditions used ranges of 1-10 lux, as shown in Figure 9. Figure 10 shows the test image within the range of 90-110 lux, and Figure 11 ranges 40-70 lux. The system accuracy obtained from this experiment is shown in Figure 9. In one of the images, the eye movement cannot be detected in Figure 9(c). The problem is that, when looking at the center, the system detects the viewer as looking to the right because the lighting in that part is too dim, preventing the system from reading the white pixel part properly. From this experiment, it was determined that the lighting is too dim to affect the detection of eye movements.

The third experiment was conducted with different people to see the results of the detection and the results of the eye movement accuracy. Figures 12-15 show the experimental results of eye movements when looking to the right, left, and center and blinking, respectively. This experiment shows that differences in a person's face do not affect the detection of the facial landmarks or the detection of the eye movements.



(a) Looking right (b) Looking left

(c) Looking toward the center (d) Blinking

Figure 9. (color online) Lighting test using 1-10 lux lighting

Referring to the three experiments and analysis, it was concluded that facial landmark detection and eye movement detection were not affected by differences in the background or differences in the people's faces. However, eye movement detection was affected by the value of light in the face area. When the light on the face is too dim, the method cannot detect the eye movement properly. After testing 42 test images under various background conditions, lighting, and different facial images, the accuracy of the system was calculated using Equation (3). The accuracy results can be seen in Table 9 for the eye movement section and eye blink detection. When the detection of eye movements was compared to the Hough circle method, the proposed method achieved a higher accuracy result of 5.1%, and eye blinking detection achieved a high accuracy when compared to the other methods, as shown in Table 10.

$$\text{Detection rate} = \frac{\text{True img}}{\text{Total img}} \times 100\% \tag{3}$$

where True img = image with successful eye recognition; Total img = Total image data.

5. **Conclusion.** Using a facial landmark method, the proposed system can detect the faces or parts of the face, such as the eyes. This method can be applied to detecting eye movements. The facial landmark method must be combined with other methods to detect eye movements. The probability analysis method is used to support the facial landmark method for detecting eye movements such as looking to the left, right, or center

(a) Looking right

(b) Looking left

(c) Looking toward the center

(d) Blinking

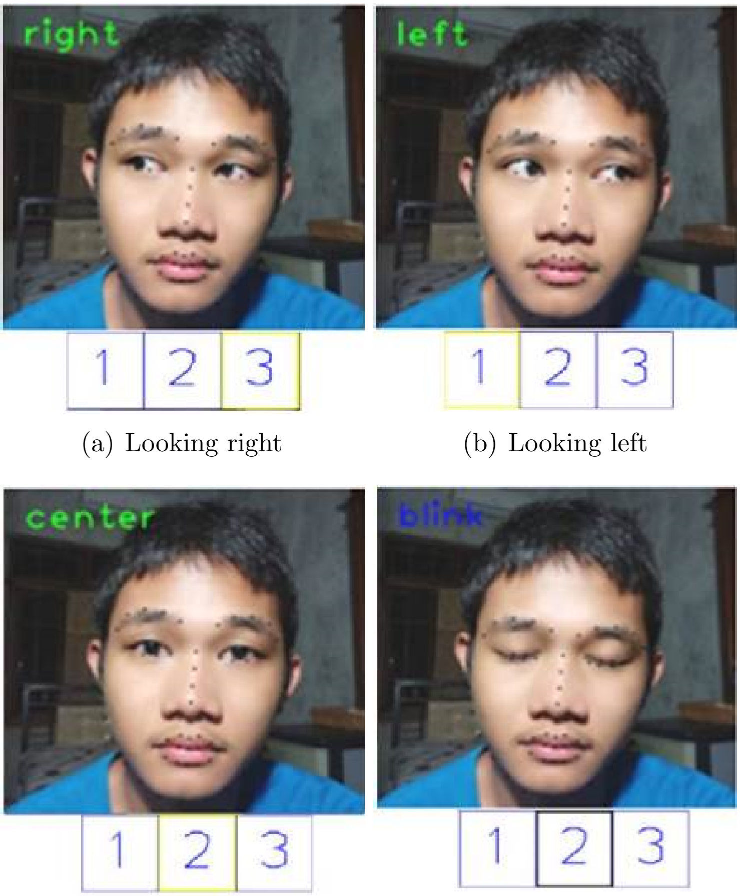
FIGURE 10. (color online) Lighting test using 90-110 lux lighting

TABLE 9. Accuracy of eye movement, open and closed eye detection

Eye position	Total image	True image	False image	Detection rate (%)
Left gaze	42	38	4	90.5
Center gaze	42	37	5	88.1
Right gaze	42	36	6	85.7
Open eye	42	37	5	88.1
Closed eye	42	39	3	92.9

TABLE 10. Comparison results with previous research for eye movement detection

Detection	Hough circle transform by Utaminingrum et al. [8]	Haar sliding window by Utaminingrum et al. [9]	Pixel value by Haq and Hasan [21]	Multiple method by Pangestu et al. [22]	Proposed method
Eye movement detection rate	83%	–	–	–	88.1%
Eye blink detection rate	–	88.1%	87%	90.32%	90.5%



(a) Looking right (b) Looking left

(c) Looking toward the center (d) Blinking

FIGURE 11. (color online) Lighting test using 40-70 lux lighting

and blinking. The eye movement results applied to the menu selection can help people with disabilities in their daily life in selecting menus on an LCD screen.

After various experiments were conducted, the proposed method achieved good results. The proposed method provides good accuracy between other eye-movement detection methods. A Hough circle transform method showed an accuracy of 83% in prior research, whereas the proposed method achieved 88.1% accuracy. The proposed method also provides a higher accuracy compared to other eye blinking rate detection methods. The proposed method achieved an accuracy of above 90%, showing a higher accuracy compared to other approaches.

As further research, to improve the accuracy of the proposed method, a binary method must be developed for the low light segmentation problems. The local binary pattern histogram method was recently used under low lighting conditions for face recognition. Occasionally, a device is used under low-lighting conditions such as at night or in a dim room, and by using the proposed method, there is a disadvantage when modifying the color space into binary colors in a low-light environment. The user does not have to worry about using the device under all lighting conditions.

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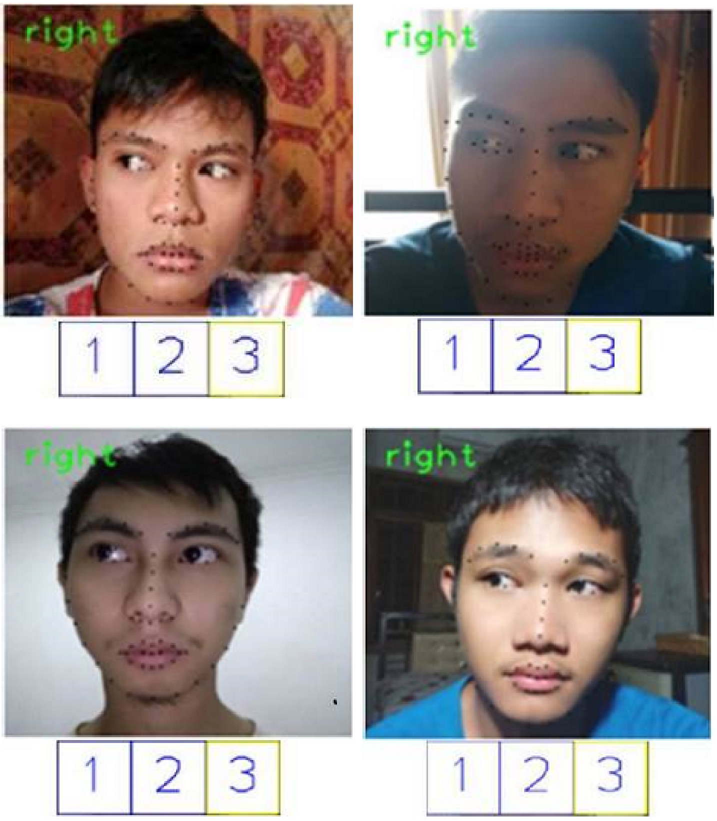

Figure 12. (color online) Different face tests for looking right

Figure 13. (color online) Different face tests for looking left

FIGURE 14. (color online) Different face tests for looking toward the center

FIGURE 15. (color online) Different face tests for blinking

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