Real Time Blinking Detection Based on Gabor Filter

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Abstract

New method of blinking detection is proposed. The utmost important of blinking detection method is robust against different users, noise, and also change of eye shape. In this paper, we propose blinking detection method by measuring the distance between two arcs of eye (upper part and lower part). We detect eye arcs by apply Gabor filter onto eye image. As we know that Gabor filter has advantage on image processing application since it able to extract spatial localized spectral features such as line, arch, and other shapes. After two of eye arcs are detected, we measure the distance between arcs of eye by using connected labeling method. The open eye is marked by the distance between two arcs is more than threshold and otherwise, the closed eye is marked by the distance less than threshold. The experiment result shows that our proposed method robust enough against different users, noise, and eye shape changes with perfectly accuracy.

Keywords: Blinking, Gabor Filter, Eye Arc.

1. INTRODUCTION

Blinking as one of eye movement activity beside glance has been used to keep the moisture of eye. Blinking helps eye to spread the tears and also remove unwanted things from eye. This activity is controlled by brain automatically (voluntary). When eye become dry or there is unwanted things on eye, brain will send command to eye muscle in order to blink the eye. The blinking activity is also affected by fatigue, disease, drowsiness, and etc. That is why blinking also has been used as one common parameter for measuring fatigue and drowsiness. The drowsy driver can be measured based on the blinking rhythm. Vehicle safety system based on drowsiness parameter is proposed [3]. This system determines the level of drowsiness by using blinking. When it is used as drowsiness parameter, the accuracy become important because it should be able to detect not only involuntary blinking, but also voluntary blinking which is has short duration period. Beside this biological function, blinking also can be used to show the user attention. Using blinking, dumb people can communicate with others. Aid communication based on blinking has been proposed [4]. The system enables communication using "blink patterns", sequences of long and short blinks, which are interpreted as semiotic messages. Also, such Morse code can be used as one of language tool for communication among dumb peoples. Moreover, Human Computer Interaction Application has been using blinking to help the selection process [5]. User can type on computer by utilize blinking only. Such false/true choice can be selected by user using blinking only. The method of blinking detection can be broadly classified into following:

1. Biological Approach, by using EOG [1] (Attach the surface electrode onto surrounding eye. Blinking is detected by measuring eye muscle potential in vertical and horizontal direction) or EEG [2] (Attach the surface electrode into skull surface in order to measure brain activity),
2. Image Analysis: Capture eye image by using camera. Several image-processing steps are needed to observe the blinking.

The method (1) is relative expensive and not convenience compared than method (2) since method (1) burden the user as several electrodes have to be attached onto user's skin. In this paper we focus on blinking detection based on image analysis approach. Among the blinking application, the utmost important of blinking detection method is accurate against eye shape changes, varies of blinking speed, varies of users, and also noise. Ref [6] proposed blinking detection based on Hough Transform. Hough transform has been used to detect iris of opened eye. Refs [7][9][10][14] proposed blinking detection based on the motion. Such normal flow and optical flow have been used to detect the blinking. Ref [7] detected blinking based on iris of opened eye. By detect eyelids as reference points first, opened and closed eye are estimated from its points. Normal flow method has been used to improve the accuracy of iris detection. Ref [14] used combination between normal flow and deterministic finite state machine to improve the detection accuracy. Ref [8] detected blinking by variance map of sequential frames and threshold. Ref [11] detected blinking by using opened eye template. Ref [12] detected blinking by using Adaboost Classifier. Ref [13] detected blinking by using Stereo Vision.

Ref [6] proposed method for identifying the opened and closed state of eye in real time video. First, they separated the eye region then applied Hough transform to detect circle on eye which represent iris. This method has 94% accuracy on eye state detection. Ref [7] located eye corners, eyelids, and irises of each frame and analyzed its motion to detect the change of gaze direction and blinking. By using simple model of head and eye, they determine the head-independent motions of the irises and eyelids. They detect blinking by tracking upper eyelid and measuring distance between its apex and center of iris. The normal flow has been used to track all features points. Ref [9] proposed blinking detection for eye fatigue measurement. They recorded video of user by using head mounted camera. First, they separate face image then continue with detect the eyes. Eyes locations are also detected by optical flow. Blinking is detected by using normal flow and adaptive threshold. Ref [10] implemented GPU on real-time eye blink detector. After eyes locations have been detected, eye is separated as region of interest. By using optical flow, closed eye is marked when the dominant motion is downward. Otherwise, opened eye is marked when the dominant motion is upward. Ref [14] used combination between boosted classifier and Lucas-kanade for tracking the face and eyes positions. Basically, blinking is detected by using normal flow. In order to improve accuracy, discrete finite state machine is used. Ref [8] used spatio-temporal filtering to locate the head position in an image sequence. The located head position is tracked and use variance map to identify any possible eye blink pair candidates. After eye-blink pair is detected, the contours around are adjusted and record four feature points for each eye. These feature points are tracked by using modified version of Lucas-Kanade method. Ref [11] detected user's eye blink and analyzed the pattern and duration to provide input to computer input as a mouse click. Eye is tracked in real time using correlation with online template. Opened eye template is used to find and track the eye position. Blinking is estimated by comparing the similarity between opened eye template and current image. When user closes the eye during blinking process, the similarity will decrease. Otherwise, the similarity will maximum when user fully open the eye.

Among previous methods, the disturbance such as noise, varies of eye shapes, and varies of blinking speed still challenge to be solved. Hough transform-based has problem against noise and varies of eye shapes. Normal flow and Optical flow have advantage robust against varies of eye shape, but its have weakness against varies of blinking speed. When it is operated in normal speed, optical/normal flow looks success detects the blinking. Unfortunately, when it is operated very slow or very fast condition, accuracy become decrease (If it is too slow, no motion will be detected. Likewise, if it is too fast, motion will hard to be captured). Template matching based has problem against varies of eye shapes (varies of users).

The objective of this research is to overcome different users, noise, and accuracy problem of previous blinking detection methods. In this paper we propose blinking detection method by utilizing Gabor filter. Gabor filter extract the eye arcs and then measure the distance between these arcs to determine the blinking. Web camera mounted on top of display is used to acquire the image. First, eye location is detected by using adaboost classifier (proposed by Viola-Jones). The advantage of this method is fast and robust against different users. After Adaboost classifier success detects the eye location, eye is cropped as region of interest (ROI). To avoid user's movement problem, the stabilizer of ROI image is used. The facial feature points such as eye corners and eye lids are used to stabilize the ROI by applying affine transformation. Affine transformation and the features points guarantee that the preprocessing image has same size and rotation angle between each frame. After the stable eye image has been obtained, we apply Gabor filter into account. Gabor filter extracts the pattern of eye based on the orientation angle. Gabor filter can distinguish the orientation angle of each line on eye. Because of this, Gabor filter can separate between top arc and bottom arc of eye based on the rotation angle (because both of arcs are close with horizontal lines, so its can be separated by using orientation angle is 0º). By using connected labeling method, the positions of both arcs are easily detected. Blinking is detected by measuring the distance between these two arcs. If this distance is more than threshold then opened eye is detected. Otherwise, if the distance is less than threshold then closed eye is detected. We made experiments to measure the accuracy of our proposed method by involving several users. Users blink the eyes in different gaze directions to prove that our proposed method robust against varies of eye shapes (different gaze directions make eye shape looks different on each). Moreover, we compare the accuracy of our proposed method with well-known methods such as opened eye template and normal flow methods.

This paper is organized as follows: section 2 describes our proposed system involving hardware configuration, eye detection and tracking, ROI stabilizer, and blinking detection by using Gabor filter. Section 3 describes our experimental results involving blinking detection performances against noise, varies of eye shape, and accuracy. Section 4 describes the conclusion.

2. Proposed Method

In this paper we propose new blinking detections method by using Gabor filter. Gabor filter extracts the pattern of eye to top and bottom arcs. While two arcs have been detected, the distance between both is measured and used to determine the blinking.

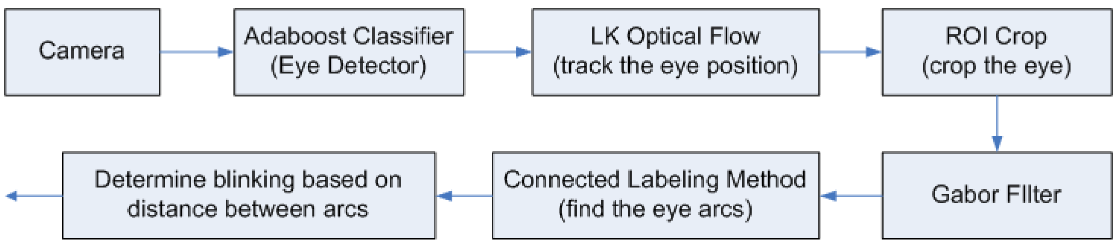

FIGURE 1: Block diagram of proposed blinking detection method

In our blinking detection method, we use IR camera as main source for acquiring eye image. The light sensor on camera is covered by the tape to make IR LEDs always ON. This way is worthwhile to maintain the illumination on eye image and eliminate the illumination changes and yield the stable eye image. After the stable eye image is obtained, Adaboost Classifier is used to detect the eye position for the first time only. After the eye location is founded, the next eye image is obtained from the use of Lucas-Kanade optical flow by tracking the new position of eye. This obtains ROI of eye image and only this image is used to detect the blinking in next process. We apply Gabor filter onto this ROI to extract two of eye arcs. The locations of all arcs are detected by using Connected Labeling method. After all locations of arcs have been detected, the closed eye is marked when the distance between top and bottom arcs is below than threshold. Otherwise, the opened eye is marked when the distance is above than threshold. The block diagram of entire process is shown in Figure 1.

2.1 Hardware Configuration

We setup our hardware configuration as depicted in Figure 2. The NetCowBow DC-NCR 131 IR camera, 1.3 Mega pixels with eight IR LEDs, is used as input. The IR LED will compensate every the illumination changes. By using this type of camera, the preprocessing image will be robust against the illumination changes (we will get the stable and robust image against illumination changes). The Camera is placed on top of display as depicted in Figure 2. The distance between user and display is 30cm. We use Optiplex 755 dell computer with Core 2 Quad 2.66 GHz CPU and 2G RAM. We develop our software using C++ Visual Studio 2005 and open source of OpenCv Image processing Library.

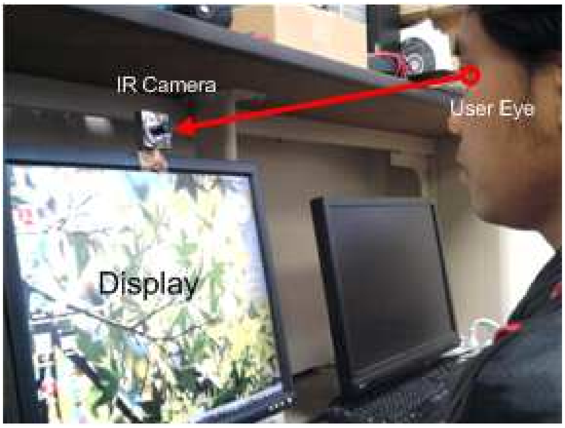

FIGURE 2: Hardware Configuration.

2.2 Eye Detection and Tracking

Before detect the blinking, it is very important to prepare the stable eye image. Because the positions of users always change, the position of eye also may change due to this. The user's movement may affect the stability of image because the ROI of eye always change. Unstable image will decrease accuracy of blinking detection. Also, it must guarantee that the eye image must have same size, heads rotation, and symmetry between right and left. Head rotation means that the rotations value of eye image must same even if the user rotate their head. In order to obtain the good and stable eye image, we detect eye location first. Eye location is detected by utilize Adaboost Classifier (One of OpenCv function). In order to detect eye location by using Adaboost Classifier, the following code is used,

```
cvHaarDetectObjects(small_img,cascade,storage,1.1,2,0|CV_HAAR_FIND_BIGGEST_OBJECT,cvSize(30,30));
```

By using the above code, the eye location will fast and easily detected. After once eye location is detected, next is tracking this eyes location by using Lucas-Kanade optical flow. Because LK optical flow needs good feature points to tract the eye location, we use eyebrows as tracked points. The new eye location is estimated based on these tracked points.

2.3 Gabor-based blinking detection

Since Gabor [15] introduced Gaussian-modulated complex exponentials and Daugman [16],[17] generalized it to 2D form, 2D Gabor has been well-know method for analyzing the pattern. Also the used of Gabor wavelet to represent the image has been introduced by Tai Sing Lee [18]. In this paper, we use 2D Gabor filter to extract the eye pattern based on their angle. Before we extract the eye pattern, we broadly classify eye image into (1) line (such as eye lids, eye arcs) and (2) circle (such as iris, pupil). We will use Gabor filter to separate the eye arcs from other eye`s components and then estimate its positions.

Typically, we can extract the pattern by using edge detector such as sobel, canny, and etc. Unfortunately, the edge detector will not give information about their angle. Also, it cannot distinguish between line and bar. Because of this, we use Gabor filter to separate arcs from others eye's component and estimate its locations. The 2D Gabor can be written as equation (1) [19].

$$G(x,y) = \exp\left(\left(-\frac{x'^2+\gamma^2 y'^2}{2\sigma^2}\right)\cos\left(2\pi\frac{x`}{\lambda}+\varphi\right)\right) \quad (1)$$

Where,

$$x' = x\cos\theta + y\sin\theta$$

$$y' = -x\sin\theta + y\cos\theta$$

In equation (1) we can see that it compose from Gaussian function (with σ is variance modulated with sinusoidal function (with λ is wavelength). θ is orientation, φ is phase offset, γ is spatial aspect ration.

In our system, we use Gabor filter by creating Gabor kernel. We create Gabor kernel by set the variance, wavelength, orientation, phase offset, and spatial aspect ratio. The example of Gabor kernel is depicted in Figure 3. This kernel contains 2D array values obtaining from the calculation using Gabor equation.

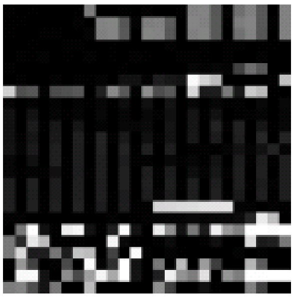

FIGURE 3: Example of 25 by 25 of Gabor kernel.

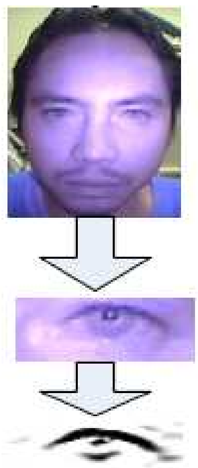

FIGURE 4: Process of converting from image source to the eye arcs image

In this paper we use Gabor filter to separate the arcs from all unnecessary eye features such as skin color, eyelid, eyebrow, iris, pupil, sclera, and etc. it will eliminate unused eye's component but keep the outer shape of eye. So the result image is line/arcs which represent the outer shape of eye (remove iris, pupil, and etc). The process from original source image to arcs image by using Gabor filter is shown in Figure 4.

After eye arcs image is created, next is estimation of the arcs locations. In order to measure the arcs length, we utilize connected component labeling method. This method estimate the arcs location based on their connectivity. Arcs are grouped into components and counted the amount of pixels. We estimate the top and bottom arcs based on their length, highest and lowest position, and relation between the arcs itself. By using this way, the noise will be automatically eliminated. After the arcs locations are found, the final value of blinking is estimated by using following rules:
If distance < threshold **then** closed eye detected
If distance >= threshold **then** opened eye detected
If opened eye detected -> closed eye detected -> opened eye detected **then** blinking detected

3. EXPERIMENT RESULTS

To measure the performance of our proposed method, the experiments have been done by involving three different users. Each user has to blink their eyes in three different gaze direction conditions (forward, left, and right) as depicted in Figure 5. This kind of experiment will prove that our proposed method does work when the user's gaze direction changes. As we can see in Figure 6, Figure 7, and Figure 8, the images change when the users look at different directions. When the users change their gaze directions, the eye shapes change because the eye ball rotate and iris (black eye) also change. This situation makes eye shape change and may affect the accuracy of blinking detection.

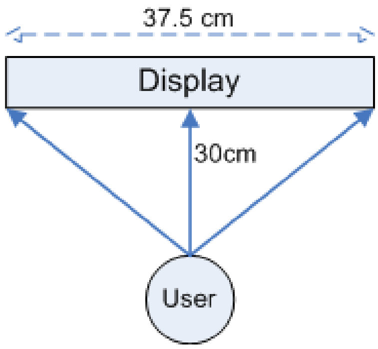

FIGURE 5: User looking at three different gaze directions

The taken images from three users are shown in Figure 6, Figure 7, and Figure 8. The number of images of user 1, user 2, and user 3 are 895, 567, and 609 images. The user's images look blue because it was obtained from IR camera.

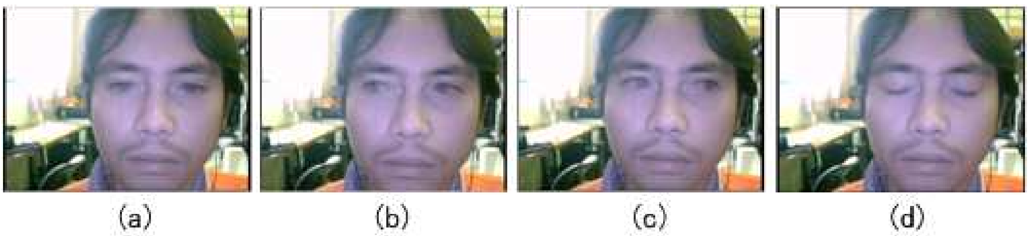

FIGURE 6: Taken images from user 1, (a) looking forward, (b) looking at right, (c) looking at left, and (d) blink

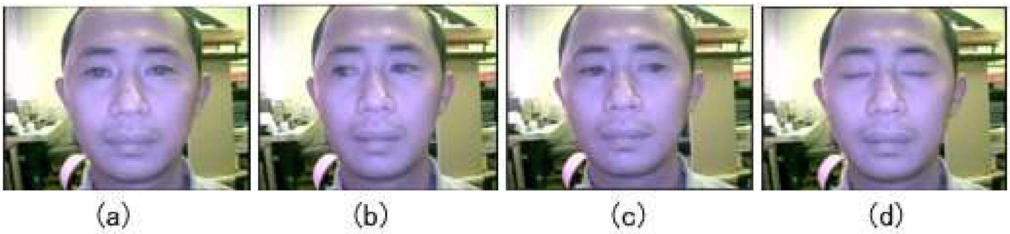

FIGURE 7: Taken images from user 2, (a) looking forward, (b) looking at right, (c) looking at left, and (d) blink

FIGURE 8: Taken images from user 3, (a) looking forward, (b) looking at right, (c) looking at left, and (d) blink

3.1 Accuracy

The first experiment investigates the accuracy and variance of proposed method against varies users (varies eye shape) and different gaze directions. First, we counted all blinking from the video sources manually. The total blinking is used as the reference correct number of blinking. After we counted the total of all blinking, we counted the blinking by using our proposed method, template matching method, and motion template method.

In template matching method, we use opened eye image as template which is taken from one of users. The similarity between template image and actual eye image are compared in order to determine the blinking. One template is used to detect all users. In motion template method, we use motion template functions in OpenCv. These functions will give use information about the magnitude and angle of motion which is happen on image. We detect the blinking if the magnitude is more than threshold and the angle is around 90° and 270° (Upward and downward directions which represent the blinking activity (closed eye is estimated by detect the downward direction (angle is 270°) and opened eye estimated by detect the upward direction (angle is 0°))).

The accuracy and variance against different users is shown in table.1. Table.1 shows that our proposed method superior than others because our method didn't use direct image for blinking detection. The use of Gabor filter to extract eye arcs and continue with the use of connected labeling method to measure the distance between the arcs is effective for blinking detection because even the shape of eye changes (due to noise or different users), Gabor filter still success extract the arcs and estimate the blinking. Table 1 shows that our proposed method accurate against different users and varies of eye shape (with 100% accuracy and the variance against different users is zero). As we can see that the other methods only have accuracy 71.18 % and 83.75% and also the variances are 720.15 and 74.13. The accuracy of template matching method becomes decrease against different users because the template image only appropriate for one user. If this template is used for other users, the similarity becomes decrease. The motion template method looks more powerful than template matching method because they detect from the users motion. Unfortunately, if users blink their eye with slow speed or very fast speed the accuracy becomes decrease. This data proved that our proposed method robust against different users and varies of eye shape.

	Method						
		Our Method		Template Matching		Motion Template	
User	Total Blinking	Detected	Accuracy (%)	Detected	Accuracy (%)	Detected	Accuracy (%)
User 1	32	32	100	31	96.88	26	81.25
User 2	30	30	100	22	73.33	23	76.67
User 3	30	30	100	13	43.33	28	93.33
Average			**100**		**71.18**		**83.75**
Variance			**0**		**720.15**		**74.13**

TABLE 1: Accuracy and variance against different users

3.2 Noise Influence

In order to measure the performance of our proposed method against noise, we add Gaussian noise onto source image. The Gaussian noise with mean value is zero and adjustable standard deviation is added onto original image (8 bit/ gray image). We used OpenCv function to create the noise as follow,

```
CvRNG rng = cvRNG(-1);
IplImage* noise=cvCreateImage( cvSize(gray->width,gray->height),IPL_DEPTH_32F, 1 );
cvRandArr( &rng, noise, CV_RAND_NORMAL, cvScalarAll(mean), cvScalarAll(std_deviation) );
cvAcc( gray, noise );
cvConvert( noise, gray );
cvReleaseImage( &noise );
```

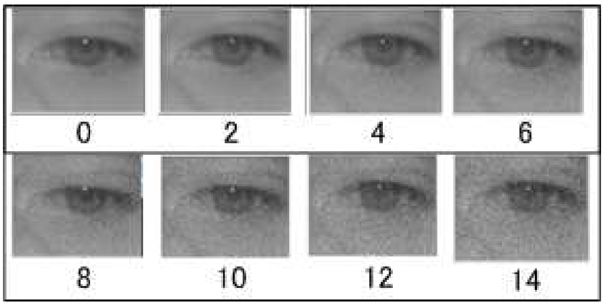

FIGURE 9: Added noise images of user 1 (standard deviation is 0, 2, 4, 6, 8, 10, 12, and 14)

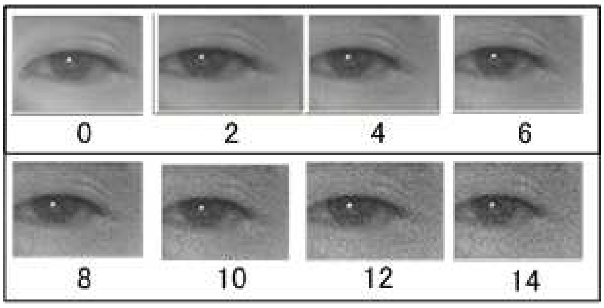

FIGURE 10: Added noise images of user 2 (standard deviation is 0, 2, 4, 6, 8, 10, 12, and 14)

In this experiment, we just add the noise (created by using Gaussian distribution with adjustable standard deviation) onto original image. The added noise image is shown in figure 9, 10, and 11. These figures show how noise can make eye images become not clear and decrease the accuracy.

FIGURE 11: Added noise images of user 3 (standard deviation is 0, 2, 4, 6, 8, 10, 12, and 14)

We used the added noise image of all users and apply our proposed method onto these. We recorded accuracy while noise is added (with varies values) of each user as shown in figure 12.

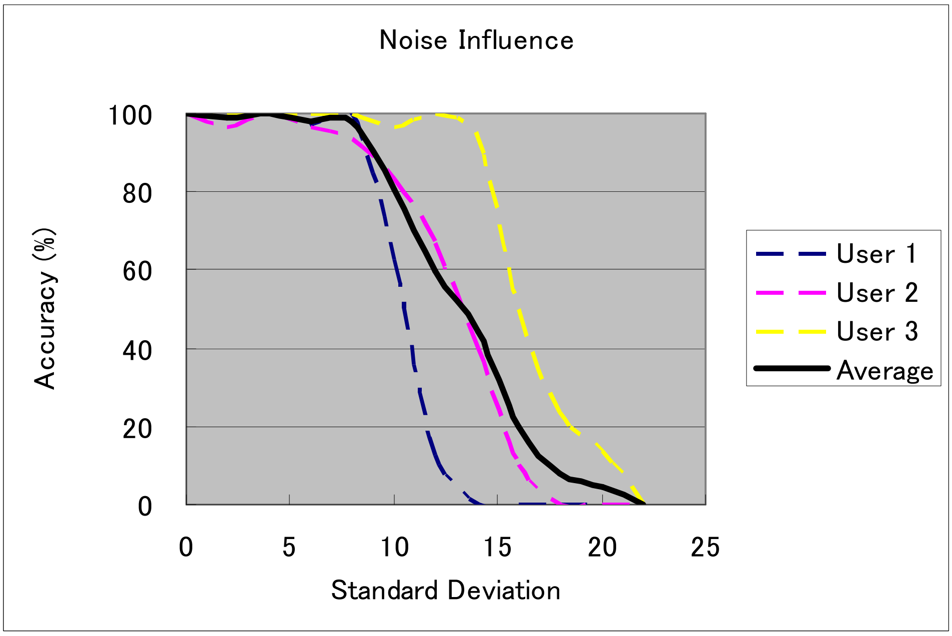

FIGURE 12: Noise Influence

Figure 12 shows the accuracy decrease as result of the adding of noise. The accuracy of user 1 decrease when standard deviation is around 9, the accuracy of user 2 decrease when standard deviation is around 10, and the accuracy of user 3 decrease when standard deviation is around 12. Between all users, it seems that user 3 is most robust against noise influence. As result, the experiment data of noise influence shows that noise gives small effect in blinking detection because Gabor filter eliminates it and the add of noise give small changes in the shape of eye arcs. Noise is detected as small point and it is automatically removed by Gabor filter as it only selects the horizontal line and ignores the others.

3.3 Comparison with Bio-potential based blinking detection method

The other approach of blinking detection is based on bio-potential analysis. Bio-potential instrument such as EMG (Electromyograph), EEG (ElectroEnchepalograph), and also EOG (Electrooculograph) have been used to detect the blinking. The most used blinking detection is based on EOG (by sticking the surface electrodes onto surrounding eyes in order to detect the eye muscle activity including eye blinking).

FIGURE 13: blinking detection by using NeuroSky blinking detector

Because EOG based on the activity of eye muscle, the accuracy of this approach is rely on how much force in the muscle. As the principle of works of muscle, it will shorter or expand based on the bio-potential which is given into this muscle. If the high bio-potential is given into the muscle, it has same meaning that the muscle is given with high power. This muscle will have high power to move something (to move the eyeball). Otherwise, if small bio-potential is given into muscle, the small power on muscle will move the eye slowly. In the bio-potential based blinking detection method, it will measure how much bio-potential is given into the eye muscle. When eye moves or blink with strong power, the EOG will detect the high bio-potential. Otherwise, when eye blink with less power, EOG will detect small bio-potential as result from blinking activity. This approach looks powerful to detect the blinking. Unfortunately, because the EOG signal is bellow 5 Hz, it means that the limit of blinking speed is 200ms. When the blinking speed is less than 200ms, the EOG will not be able to detect the blinking. Beside the EOG wave itself, the amplitude of bio-potential will also affect the accuracy. When bio-potential is very weak, the method will not be able to detect the blinking. Because of these reasons, the image analysis approach is more powerful than bio-potential approach in order to detect the blinking.

In order to measure the accuracy of bio-potential approach, we test the blinking of user by using NeuroSky Blinking detector as depicted in Figure 13. This tool will detect the signal from eye and determine the blinking. The user blinks 30 times. The detected blinking is 12 times. The result shows that there is error 60% (the accuracy is only 40%). This accuracy is caused that the NeuroSky instrument cannot detect the blinking if the blinking power is less.

3.4 Application of the proposed blink detection to computer input with human eyes only

One of the examples of application of the proposed method for computer input with human eyes only is introduced. Mouse is one of computer input devices which allows input the desired key into computer. Basically, eye-mouse has the same functions as those of general mouse. It, however, does work with human eyes only without any direct touch with computer. Eye-mouse is getting more important since it can be used for disable and handicapped persons as well as elderly persons who are not good at typing with keyboard to use computer. By using only one single camera, face image is captured. Based on the Viola-Jones method, face, mouth and eyes are detected and recognized. Based on the detected locations, two ends of left and right eyes as well as mouth and its surrounding region are extracted from the captured face image. Once these locations and their corresponding images are extracted, then they are tracked by the well-known template matching. Then their locations are mapped onto the 3D of real world coordinate system. 3 D head model is also created into the coordinate system. Eye gaze is estimated with the location of iris center and two ends of eyes. Absolute gaze is calculated from eye gaze itself and head location as well as attitude. From the eye gaze, location of which the user is looking at is estimated. To determine the selected location of key, eye blinking which is also detected by template matching is used. Also "fix one's eyes on" can be used for determination of the selected key. Experimental results show that the success rate is 100% perfect when the user types the designated key on Microsoft WORD using screen keyboard. An example of computer screen image is shown in Figure 14. At the top right corner, program process monitor is situated while the screen keyboard is located at the top center. Below the screen keyboard, Microsoft provided WORD window is situated while users face and detected and tracked eye (left eye) and its surrounding images are located at bottom right corner. User can input any key in the screen keyboard by looking at the designated key for a while or blink the eye then selected key is determined. User can also confirm the location on the screen keyboard that he or she is looking at by the pointer location which is moved in accordance with the estimated gaze location. The locations of user's two eyes are also identified on the computer screen (in the user's face image situated at the bottom left corner). Thus user can input his or her designated key in the screen keyboard to the computer by human eye only. The proposed system also allows user's movement.

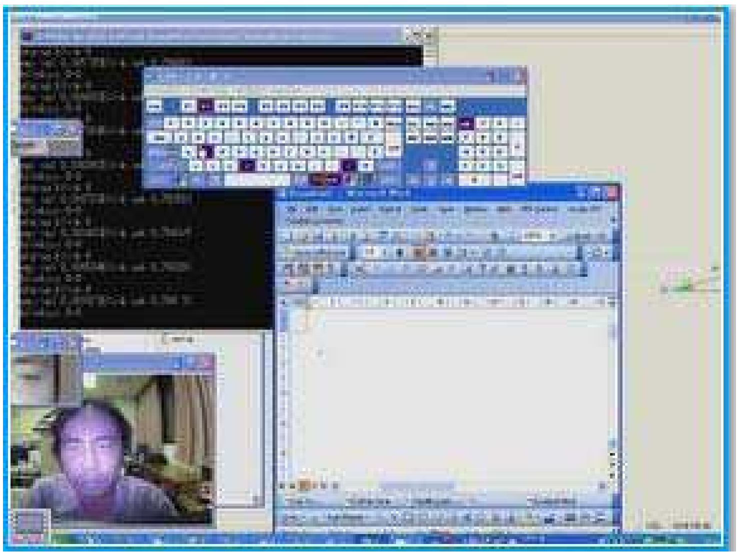

FIGURE 14: Example of the computer screen

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4. CONCLUSIONS

The blinking detection based on Gabor filter has been successfully implemented. Gabor filter success to extract eye's arcs and estimate the blinking by using connected labeling method to measure the distance between arcs. The experiment data show that our proposed method superior than other methods against different users (perfectly detect blinking from three different users), varies eye shape, and has perfectly accuracy. It is also concluded that our proposed method robust against noise. The blinking detection method give better result than bio-potential based blinking detection since it is only detected by using camera and camera always give stable input than bio-potential voltage. By implement this method, the drowsiness detectors, HCI applications, and also Aid communications can be done with perfect accuracy and also robust against different users, varies eye shape, and noise.

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