Eyes Based Eletric Wheel Chair Control System

- I (eye) can control Electric Wheel Chair -

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***Abstract*— Eyes base Electric Wheel Chair Control: EBEWC is proposed. The proposed EBEWC is controlled by human eyes only. Therefore disabled person can control the EBEWC by themselves. Most of the computer input system with human eyes only consider in specific condition and does not work in a real time basis. Moreover, it is not robust against various user races, illumination conditions, EWC vibration, and user's movement. Though experiments, it is found that the proposed EBEWC is robust against the aforementioned influencing factors. Moreover, it is confirmed that the proposed EBEWC can be controlled by human eyes only accurately and safely.**

Keywords-computer input by human eyes only; gaze estimation; electric wheelchair control.

I. INTRODUCTION

The existing computer input devices such as keyboard, mouse, and the other input devices have been used to interact with digital instruments. These computer input devices cannot be operated by handicap persons. In this paper, a computer input device by human eyes only is proposed for handicap person and also for wearable computing.

The existing computer input devices without finger, voice, and gesture can be divided into five categories;

(1) Bio-potential based method which utilizes potential from user's body actions acquired by using special instrument. Instrument such as Electrooculograph (EOG), Electromyograph (EMG) [1], and Electroencephalograph (EEG) [2], Search coil can be used for measuring bio-potential. The search coil output can be used as sources of computer input for handicap person. EOG method [7], [16] uses voltage differences between fore and aft surface of eyes.

(2) Voice Based method [3], which use user's voice as source input. Voice analysis is used to analyze user's voice and convert into digital data. The weakness of this system is vulnerable against noise. Other voices which come from surrounding user may affect the system.

(3) Motion based method [4], utilizes other normal movement organs to operate computer input. Head, foot, and etc can be used to control computer input.

(4) Image Analysis method [10]-[15], utilizes camera to analyze user's desire and convert into digital data. Several image processing methods are used to analyze user's desire. The user's desire itself can be done by Gaze based [5], [6], [9], analyze user's desire from users gaze, Face based analyze user's desire from face expression, and the others.

(5) Search coil method [8] uses induced voltage with coil including in contact lenses attached to user's eyes.

Methods (1) and (5) insists psychological and physical burden to users because these methods require direct sensors which are attached to user's face. Also these methods are relatively costly. On the other hand, the image analysis method does not insist any load to users and is realized with comparatively cheap cost. For the aforementioned reason, we propose an image analysis based method.

Electric Wheel Chair: EWC for assisted mobility is presented [16]-[20]. There is the proposed system for assisted mobility using eye movements based on Electrooculography. EWC is controlled by eye movement which is acquired using Electrooculograph [16]. Also there is the proposed integrated solution to motion planning and control with input from three sources [17]. At the highest level, the human operator can specify goal destination using visual interface by pointing to location or features on display. This input lets the chair automatically generate a deliberative plan incorporating prior knowledge. At the intermediate level, the human operator must use reactive controller to avoid obstacle and features that the sensor detect. At the lowest level, the human operator can directly provide velocity command using joystick. There is the proposed vision-based navigation for an electric wheelchair using ceiling light landmark [18]. The wheelchair is equipped with two cameras those are used for self-location and obstacle avoidance. The fluorescent ceiling lights are chosen as landmarks since they can be easily detected and do not require an additional installation. Also there is the proposed head gesture based control of an intelligent wheelchair [19]. This system used Adaboost face detection. By detecting frontal face and nose position, head gesture is estimated and used to control the wheelchair.

There is the proposed EWC control with gaze direction and eye blinking [20]. The gaze direction is expressed by horizontal angle of gaze, and it is derived from the triangle form formed by the center position of eyes and nose. The gaze direction and eye blinking are used to provide the direction and timing command. The direction command related to the movement direction of EWC and the timing command related to the time condition when the EWC should move.

In this paper, we propose computer input system with human eye-only and used for controlling EWC. It is called Eye Based EWC: EBEWC hereafter. EBEWC works based on eye gaze. When user looks at appropriate angle/key, then computer input system will send command to EWC. EBEWC is controlled by three keys: left (Turn left), right (Turn right), and down (Move forward) in order to give command to electric wheelchair: turn left, turn right, and go forward. This three combination keys are more safely than others combination keys. The stop key is not required because EWC will automatically stop when user change the gaze. Gaze estimation system still faced with problem such as robustness against a variety of user types, accuracy, illumination changes, vibration, and calibration.

In order to estimate gaze based on image analysis, it is common that gaze location is estimated with pupil location. The previously published pupil detection methods can be divided into two categories: the active Infrared: IR-based approaches [22], [23], [31] and the traditional image-based passive approaches [24]-[30]. Eye detection based on Hough transform is proposed [24]-[26]. Hough transform is used for finding the pupil. Eye detection based on motion analysis is proposed [21], [22]. Infrared lighting is used to capture the physiological properties of eyes (physical properties of pupils along with their dynamics and appearance to extract regions with eyes). Motion analysis such as Kalman filter and mean shift which are combined with Support Vector Machine: SVM used to estimate pupil location. Eye detection using adaptive threshold and morphologic filter is proposed [27]. Morphologic filter is used to eliminate undesired candidates for an eye. Hybrid eye detection using combination between color, edge and illumination is proposed [30].

In order to estimate the gaze, we use pupil knowledge for improvement on robustness against different users. In gaze estimation based on image analysis, almost all utilize pupil location as reference. In this stage, pupil detection accuracy is very important because all the gaze calculations are made based on the detected pupil location. Many researches did not give much attention on this part because most of them use ideal images as the source in order to find pupil location. When user looks at forward, pupil can be detected clearly. Meanwhile, it is usually not so easy to detect pupil location when user looks the other directions. A variety of skin colors, races, interference with eye lids, disappearances, and changes of eye shape (when eye move) make the pupil detection very difficult. Pupil knowledge such as shape, size, location, and motion are used in the proposed method. This knowledge works based on the knowledge priority.

Pupil appearance such as size, color, and shape are used as first priority. When this step fails, then pupil is estimated based on its location as second priority. When all steps fails, pupil is estimated based on its motion as last priority. Last, we use eye model in order to convert pupil location into gaze direction. This gaze direction will be used to control EWC. In order to improve the robustness against user's movement, illumination changing, and vibration, IR camera mounted glass is used.

The proposed system is tested by several users with different race and nationality. The experimental results with the proposed eye gaze estimation method are compared to well-known adaptive threshold method and template matching method. Also robustness against illumination changing, noise influence, vibration, and accuracy has been confirmed. In the section 2, the proposed EBEWC system is described followed by some experimental results. Then section 4 describes some discussions followed by conclusion.

II. PROPOSED METHOD

The problem of the utmost importance of a proposed EBEWC system is the robustness against different user types, illumination changes, user's movement, vibration, and accuracy. In order to consider these as vehicle system, if the user changes, the system should be works without any input parameter changes. In accordance with EWC movement, illumination condition may change. Also, disturbances due to EWC vibration is potentially problem.

In the conventional EWC control system with human eyes only, camera is mounted on EWC. This may cause a vulnerable when EWC is vibrated. Also, when user moves their head, gaze estimation is difficult. Furthermore, illumination condition may change during EWC movement. The proposed EBEWC system utilizes IR camera which mounted on user's glass. This way will eliminate problems of illumination changes, user's movement, and EWC vibration. Furthermore, the pupil detection based on pupil knowledge will improve the robustness against different users.

A. Hardware Configuration

Hardware configuration of the proposed EBEWC is shown in Fig.1.

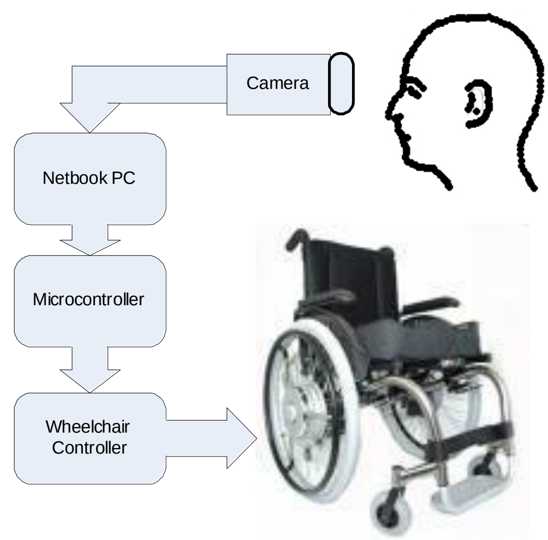


Figure 1. Hardware Configuration

Netbook of Asus EeePC with 1.6 GHz Intel Atom processor, 1GB of RAM, 160GB hard drive, and run Windows

XP Home edition is used. We develop our software under C++ Visual Studio 2005 and Intel provided OpenCv image processing library [21]. The proposed EBEWC system utilizes infrared web camera, NetCowBoy DC-NCR 131 as face image acquisition in a real time basis. This camera has IR Light Emission Diode: LED. Therefore it is robust against illumination changes. In order to allow user movement and EWC vibration, IR Camera mounted glass is used. The distance between camera and eye is set at 15.5 cm as shown in Fig.2. The EBEWC uses Yamaha JWX-1 type of EWC which is controlled by human eyes only through microcontroller of AT89S51. This microcontroller can convert serial output from Netbook to digital output for control.

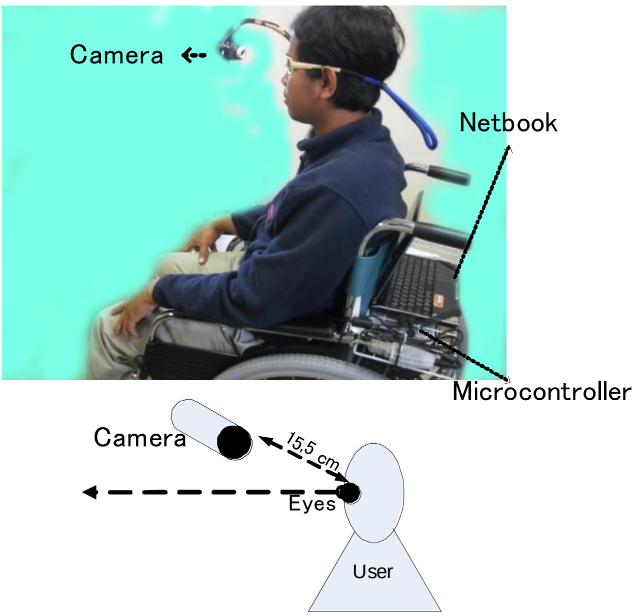


Figure 2. Electric Wheelchair Hardware

In order to control EWC using Netbook PC, custom micro controller circuit is used to modify standard control of Yamaha EWC. Default control of the EWC is made by joystick. Micro controller is replaced to the joystick. Command is delivered by Netbook PC, and then micro controller works to move EWC. USB interface on Netbook PC is used to connect with the other peripheral. The interface of the micro controller circuit is RS232. To connect between Netbook PC and the micro controller, USB to Serial converter is used. The micro controller is driven by the relay equipped with the EWC. Micro-controller connection is shown in Fig.3.

B. *Gaze Estimation*

In order to estimate gaze, eye should be detected and tracked. Fig. 4 shows the process flow of eye detection and tracking. The proposed EBEWC system detect eye based on deformable template method [32]. This method matches between eye template and source images. We create eye template and apply Gaussian smoother. Deformable template method detects rough position of eye. Benefit of deformable template method is that it takes less time than classifier methods. Although this method is faster than the other classifier methods, the aforementioned robustness is not good enough.

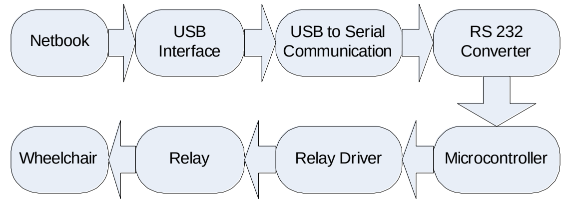


Figure 3 Microcontroller AT89S51 connects to other peripheral through serial communication. Serial communication type should be converted to USB communication using USB to serial converter

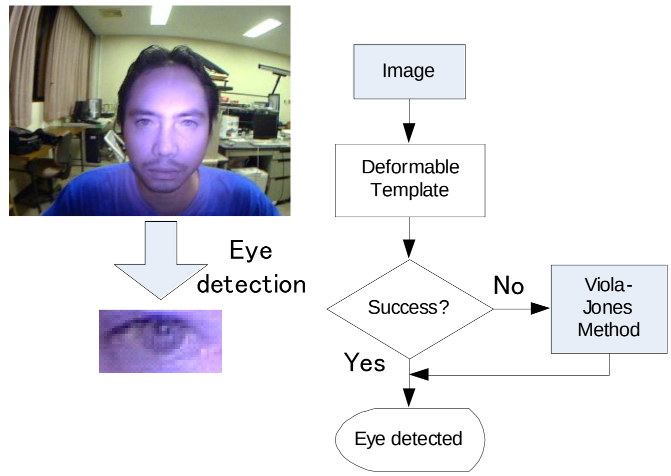


Figure 4. Flow of Eye Detection, eye is detected by using combination between deformable template and Viola-Jones methods.

In the proposed EBEWC system, the well known Viola-Jones classifier in the OpenCV library [21] detects eye when the deformable template fails to detect eye position. The Viola-Jones classifier employs Adaboost at each node in the cascade to learn a high detection rate the cost of low rejection rate multi-tree classifier at each node of the cascade. The Viola-Jones function in OpenCV is used for the proposed EBEWC system. Before using the function, we should create XML file through learning processes. The training sample data (face or eye image) must be collected. There are two sample types,: negative and positive samples. Negative sample corresponds to non-object images while positive sample corresponds to object image. After acquisition of image, OpenCV will search the face center location followed by search the eye center. By using combination between deformable eye template and the Viola-Jones method, eye location will be detected. Advantages of this proposed method is fast and robust against circumstances changes.

After the roughly eye position is founded, eye image is locked and tracked. Therefore, there is no need to detect eye any more. The detected eye position is not going to be changed because the camera is mounted on the glass. Eye gaze is estimated based on pupil center location. Because of this system rely on the pupil center location; pupil detection has to be done perfectly. Pupil is detected by using its knowledge. Process flow of the pupil detection is shown in Fig.5. Three types of knowledge are used. We use pupil size, shape, and color as the first knowledge. First, adaptive threshold method is applied for pupil detection. Threshold value T is determined by the average pixel value (mean) of eye image μ. We set the threshold value of 27% bellow from the average value empirically.

$$\mu = \frac{1}{N}\sum_{i=0}^{N-1} I_i \quad (1)$$

$$T = 0.27\mu \quad (2)$$

Pupil is signed as one black circle in the acquired eye image. In the first stage, pupil is detected with adaptive threshold method when the pupil is clearly appears in the acquired eye image. By using connected labeling component, we can easily estimate the pupil center location. Meanwhile, noise is usually appears in the image, we can distinguish them by estimate its size and shape as knowledge. The situation is shown in Fig.6 (a). In another case, shape and size of eye is changed when user looks to right and left directions. In this situation, pupil detection is hard to find. Noise and interference due to eyelid have to be eliminated. In this situation, knowledge of size and shape can be used. Also previously detected pupil center can be used when user close eye. The pupil center location is determined using the following equation,

$$P(t-1) - C < P(t) < P(t-1) + C \quad (3)$$

The reasonable pupil location P(t) is always in surrounding previous location P(t-1) with the area C. Fig.6 (b) shows such this situation.

When the entire above step is fail to detect pupil center location, and then we estimate pupil center location by using eye motion. This situation is happened when the black pixels are mixed with others or no black pixel at all in the acquired image. We employ this knowledge as a last priority to avoid an ambiguous motion that causes misidentification of pupil to the other eye components. We tracked a pupil location using its previous location based on the well-known Kalman filter [23],[33]. Kalman Filter corrects the estimated pupil location and velocity. In each pixel as detected as a pupil, we assume the location of pupil is (i_t, j_t) and velocity is (u_t, v_t). Because of the previous location is (i_t, j_t), the current location should be ($i_t + u_t$, $j_t + v_t$). We can model the state of pupil location is as follows,

$$x_t(i,j) = Ax_{t-1}(i,j) + \omega_{k-1}(i,j) \quad (4)$$

where, x_t is actual state and A is state transition while ω_k. denotes additive noise. Next, we assume that the estimated location is ($\hat{i}_t$, $\hat{j}_t$). The measurement process can be modeled as follows,

$$z_k(i,j) = Hx_k(i,j) + v_k(i,j) \quad (5)$$

where v_k represents noises in the measurement, H represents observation matrix. This method works when the estimated pupil location becomes entrusted. Such a condition may happen when the other components disturb the pupil location estimation. By using time updating algorithm and measurement update process, a better estimated pupil location will be obtained.

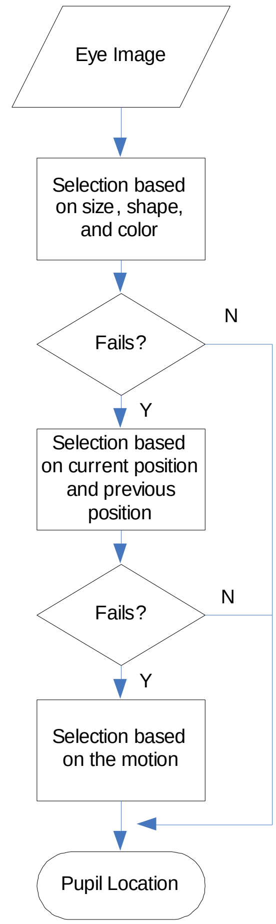
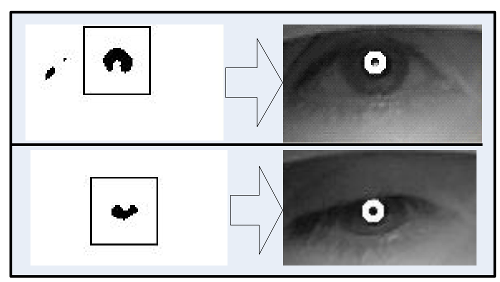
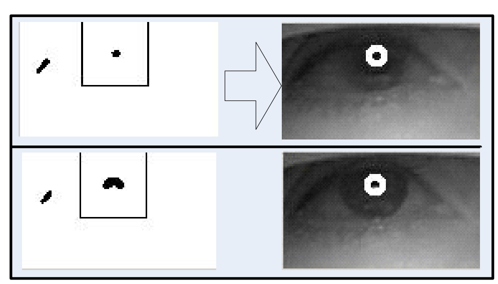


Figure 5. Flow of pupil detection



(a) Case 1, Pupil clearly appears



(b) Case 2, Pupil clearly appears with some defect by eyelids

Figure 6 Examples of the acquired pupil images

C. Eye Model

A simple eye model is defined as shown in Fig.7.

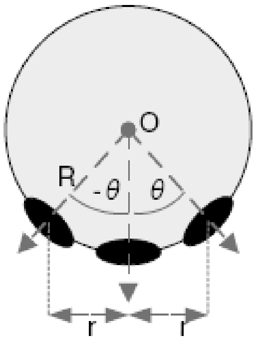


Figure 7. Shape model of eye

The eyeball is assumed to be a sphere with radius *R*. Although the typical eyeball shape is ellipsoid, sphere shape assumption does not affect to the pupil center location estimation so much that spheroid shape of assumption of eyes ball shape does not affect too much to the pupil center location estimation accuracy. The pupil is located at the front of eyeball. The distance from the center gaze to current gaze is assumed to be *r*. Gaze is defined as angle θ between normal gaze and r. The relation between *R*, *r* and θ is as follows,

$$r = R\sin\theta \tag{6}$$

$$\theta = \arcsin\left(\frac{r}{R}\right) \tag{7}$$

The typical radius of the eyeball ranges from 12 mm to 13 mm according to the anthropometric data [34]. Hence, we use the anatomical average assumed [35] into the proposed algorithm. Once *r* has been found, gaze angle θ is easily calculated. In order to measure *r*, the normal gaze is should be defined. In the proposed EBEWC system, when the system runs as the first time, the user has to look at the computer display then user looks at the center of the computer screen. At this moment, we record that this pupil location is normal gaze position. In order to avoid error when acquire normal gaze, it is verified by compare between its value and center of two eye corners. Next if user look at same key within 0.7 second, then gaze value will be send to EWC. This way will avoid noise gaze which is caused by user intention is not always focus in same key.

D. EWC Control

In order to control EWC, we design three functional keys invisible layout, move forward, turn right, and turn left at the three specific portions. If user looks at the other portion, then EWC is stopped for safety reason. There is no need to display the key layout at all. Users understand the location of desired key so that it can be selected. For instance, when user looks at the right direction for more than 0.7 second, EWC is then turn right until user changes the gaze direction. If user keep look at the same direction, then EWC is continued the previously determined moving action. Fig.8 shows the proposed key layout.

Stop	Stop	Stop
Turn left	Forward	Turn right
Stop	Stop	Stop

Figure 8. 3 by 3 of key layout for EWC control

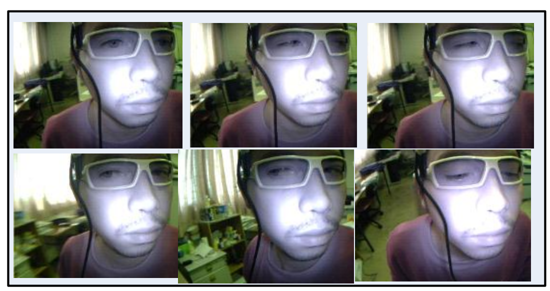
III. Experiemnts

A. Exampel of Acuired Face Imagesl

Fig.9 shows the examples of the acquired face images of the three different Indonesian users. The experiments are carried out with six different users who have the different race and nationality: Indonesian, Japanese, Sri Lankan, and Vietnamese. We collect data from each user during user makes several eye movements and EWC actions.

(a)Indonesian No.1

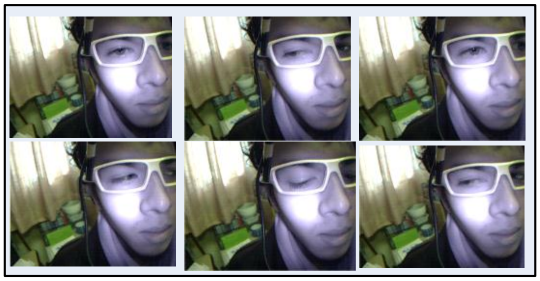
(b)Indonesian No.2



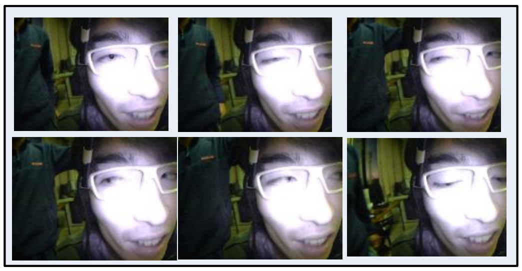
(c)Indonesian No.3

Figure 9. Example of Indonesian Images

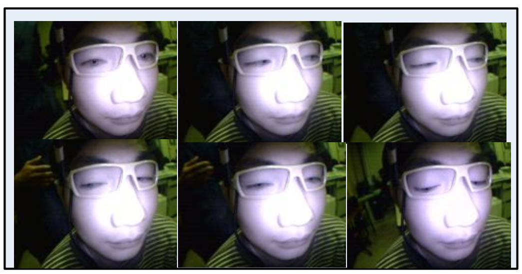
The collected data contain several eye movement such as look at forward, right, left, down, and up. Two of Indonesians have width eye and clear pupil. The number of images is 552 samples and 668 samples. Another Indonesian has slanted eyes (Off-axis viewing) and the pupil is not so clear. The number of images is 882 samples. We also collected the data for Sri Lankan people as shown in Fig.10 (a). His skin color is black with thick eyelid. The number of images is 828 samples. The collected data of Japanese is shown in Fig.10 (b). His skin color is bright with slanted eyes. The number of images is 665 samples. The Vietnamese data is shown in Fig.10 (c).



(a) Srilankan Images



(b) Japanese Images



(c) Vietnamese Images

Figure 10 Examples of the acquired face images.

B. *Success Rate of Pupil Detection (Gaze Estimation)*

Performance of success rate of pupil detection and gaze estimation is evaluated with six users. The success rate of the proposed EBEWC method is compared to the conventional adaptive threshold method and template matching method. The adaptive threshold method is modified with inclusion of a connected labeling method. The template matching method uses pupil template as a reference and allows matching with the currently acquired images. The results of success rate evaluation experiments are shown in Table 1. The proposed EBEWC method is superior to the other conventional methods. Also it is confirmed that the EBEWC method is robust against various user types with the variance of 16.27 as shown in Table 1.

C. *Influence Due to Illumination Changes*

The aforementioned success rate is evaluated with changing the illumination conditions. The experimental results are shown in Fig.11. As shown in Fig.11, 0-1200 LUX of illumination changes do not affect to the success rate while much greater than 1600 LUX of illumination condition may affect to the success rate. Because IR Light Emission Diode: LED utilized IR camera is used for the proposed EBEWC system, low illumination is appropriate rather than high illumination. As a result, it is found that the proposed EBEWC system does work in the normal illumination condition ranges from 0 to 1500 LUX.

TABLE 1. ROBUSTNESS AGAINST VARIOUS USERS, THIS TABLE SHOWS THAT OUR METHOD ROBUST ENOUGH AGAINST VARIES USER AND ALSO HAS HIGH SUCCESS RATE

User Type	Nationality	Adaptive Threshold (%)	Template Matching (%)	Proposed Method (%)
1	Indonesian	99.85	63.04	99.99
2	Indonesian	80.24	76.95	96.41
3	Srilankan	87.80	52.17	96.01
4	Indonesian	96.26	74.49	99.77
5	Japanese	83.49	89.10	89.25
6	Vietnamese	98.77	64.74	98.95
Average		**91.07**	**70.08**	**96.73**
Variance		**69.75**	**165.38**	**16.27**

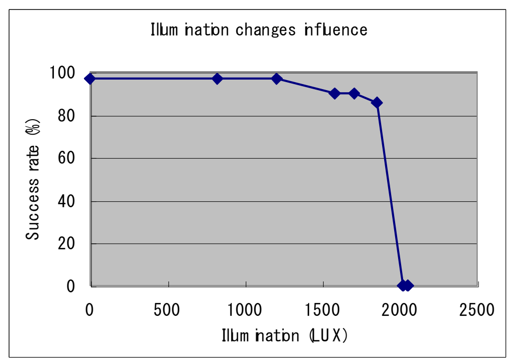


Figure 11 Influence against illumination changes

D. *Influence Due to EWC Vibrations*

Because EWC vibrates usually, influence due to vibration on the success rate and the acceleration to user has to be clarified Four types of vibrations are taken into account. Shock of acceleration in unit of m/s^2 in direction of *x*, *y*, and *z* at the HMD and IR camera mounted glass is measured with acceleration measurement instruments. *x* direction corresponds to the forward direction while *y* direction corresponds to the side direction as well as *z* direction corresponds to the up and down direction. The experimental results are shown in Fig.12. During user controls EWC with the proposed EBEWC system, EWC moves 10 m of collider. On the collider, there are some steps and it may cause the vibrations. *x* direction of acceleration is always 10 m/s^2 because the EWC is moving forward. The measured accelerations for the first two vibrations are 25 m/s^2 while the third acceleration for the third vibration is 35 m/s^2 and the fourth acceleration for the fourth vibration is 40 m/s^2.

Even vibration/ shock are happened; user body absorbed the vibrations. Furthermore, user wears the HMD and camera mounted glass so that the relative locations among HMD and eye as well as pupil are stable enough. Therefore, success rate of pupil detection is not changed results in no influence due to vibration on gaze estimation accuracy.

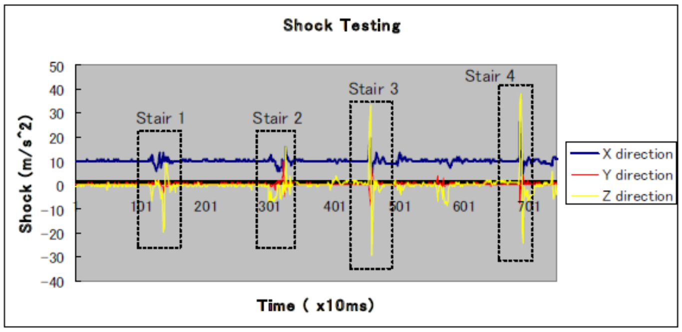


Figure 12. Shock Influence

E. Process Time Required for Eye Detection and Gaze Estimation

It is confirmed that the proposed EBEWC does work in a real time basis. The time required for eye detection is measured. It is 286.92 ms while that for gaze estimation is 14.08 ms

F. Influence Due to Noise on Success Rate

Influence due to noise on success rate is evaluated with random number generator of Mesenne Twister. Normal distribution with zero mean and 0-70 standard deviation of random number is used for the experiment. Success rate of pupil detection and gaze estimation is shown in Fig.13. As the result of the experiment, it is found that the proposed EBEWC system has 10 % degradation of success rate. Therefore, user has to input gaze twice for 1 time out of 10 times.

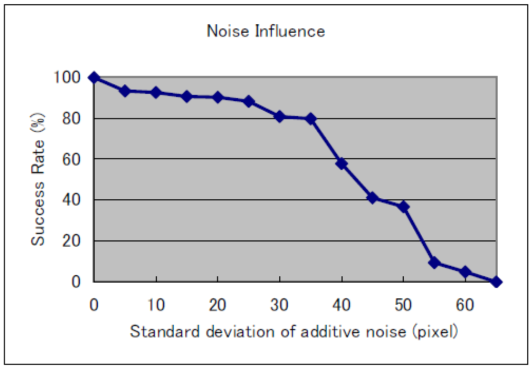


Figure 13. Influence due to noise on success rate

G. Gaze Estimation Accuracy

Gaze estimation accuracy is measured at the middle center to horizontally aligned five different locations with the different angles as shown in Fig.14. The experimental result shows the gaze estimation error at the center middle (No.1) shows zero while those for the angle ranges from -5 to 15 degrees is within 0.2 degree of angle estimation error. Because the user looks at the center middle with 5 degree allowance results in 0.2 degree of gaze estimation accuracy. Fig.15 shows the outlook of the proposed EBEWC system.

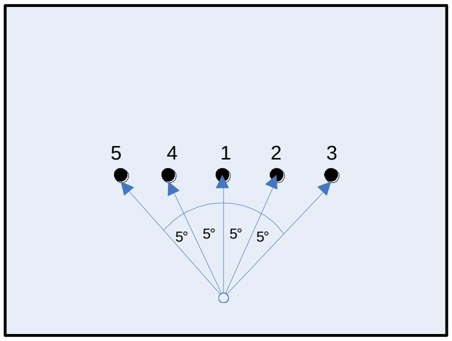


Figure 14. Measuring accuracy

TABLE 2 GAZE ESTIMATION ACCURACY AT THE DESIGNATED VIEWING ANGLES

Point	1	2	3	4	5
Error(degree)	0	0.2	0.2	0.2	3.12

Figure 15. Testing of EWC

IV. Conclusion

Specific features of the proposed EBEWC system are,

(1) It allows user movement: User can move during using the proposed EBEWC system in directions in the allowable distance of which the camera mounted on the glass acquires user face,

(2) It does not require any calibration process before using the proposed EBEWC system,

(3) It is robust against immunization changes, additive noises, vibrations to the EWC, user nationality (different color of eye as well as skin, size, and shape of eye), eyelid influence, and shade and shadow,

(4) Pupil center detection accuracy for the acceptable angle range is almost 0.2 degree,

(5) Even if pupil center is not detected when user close eye, gaze location is estimated with the knowledge of previously detected pupil center location.

In the near future, we will conduct fatigue measurement experiments with the proposed EWC control by human eyes only. Then we can ensure using the EWC for a long time period.

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