A Prototype of Electric Wheelchair Controlled by Eye-Only for Paralyzed User

Paper:

A Prototype of Electric Wheelchair Controlled by Eye-Only for Paralyzed User

Kohei Arai* **and Ronny Mardiyanto*,****

*Saga University
1 Honjo, Saga 840-8502, Japan
E-mail: arai@is.saga-u.ac.jp
**Institut Teknologi Sepuluh Nopember
Keputih, Sukolilo, Surabaya, Indonesia
E-mail: ronny_mardiyanto@yahoo.com
[Received March 22, 2010; accepted June 25, 2010]

The numbers of persons who are paralyzed dependent on others due to loss of self-mobility is growing as the population ages. We have developed a wheelchair prototype exclusively controlled by eye and able to be used different users while proving robust against vibration, illumination change, and user movement. The keys to this flexibility are the camera mounted on the user's glasses and the use of pupil detection. Image processing analyzes the user's gaze for wheelchair control. Result of pupil detection method compared to others showed that our method is superior. Also, result of camera placement compared to other systems regarding vibration influence showed that our camera placement reduces vibration almost completely. Moreover, influence of illumination change has been evaluated. Experiments involving five different users in the wheelchair along a 9.73-meter track recorded an average travel time of 85.8 second. Demonstrating the feasibility and reliability of our proposal providing computer input for paralyzed user is to use in controlling wheelchair.

Keywords: wheelchair, eye gaze, paralysis, computer input by eye-only, hand-free controller

1. Introduction

The development of wheelchairs for paralyzed users is surprisingly recent starting with conventional manually powered wheelchairs and advancing to electrical wheelchairs [1]. Conventional wheelchair use tends to focus exclusively on manual use which assumes users still able to use their hands which excludes those unable to do so. Diseases or accidents injuring the nervous system also frequently cause people lose their ability to move the voluntary muscle. Because voluntary muscle is the main actuator enabling people to move their body, paralysis may causes a person cannot move their locomotor organ such as arm, leg, and others. Paralysis may be local, global, or follow specific patterns. Most paralysis are constant, however there are other forms such as periodic paralysis (mostly caused by genetic diseases) and sleep paralysis (occurs when brain awake from REM (Rapid Eye Movement) [2], but body cannot be moved during several second or minutes) caused by other factors.

Scientist Stephen W. Hawking is perhaps the most well-known victim of major paralysis – Hawking was diagnosed with incurable Amyotrophic Lateral Sclerosis (ALS) in 1962 – actively using a wheelchair [3].

Many of those suffering close to or complete paralysis usually however still can control their eye movement – which inspired us to develop an eye-controlled electric wheelchair.

Free-hand based wheelchair as assistive mobility device can be broadly categorized into following categories.

1. Biosignal-based [4, 5]. Electrooculography (EOG), electroencephalography (EEG), and electromyography (EMG) adapt user biosignals for wheelchair control. An example of an electric wheelchair [4] controlled using EOG analyzed user eye movement via electrodes directly on the eye to obtain horizontal and vertical eye-muscle activity. Signal recognition analyzed Omnidirectional eye movement patterns. Another approach proposed wheelchair control using muscle and brain signals [5]. User intent was analyzed using EMG and EEG via electrodes on the head whose output signal were analyzed and converted to wheelchair control commands.

2. Voice-based [6]. Wheelchair control has also been guided by voice commands delivered through speech recognition, motor control, a user interface, and central processor modules. Such systems usually require the user to record functional oral commands, e.g., "Forward" makes the wheelchair move forward and "Stop" makes the wheelchair stop.

3. Vision-based [7–10]. Using a camera to acquire user images and analyze user intent. Ref [7] proposed wheelchair controlled by head gestures. Viola-Jones face detection is used to recognize the face profile and omnidirectional head gestures and is

used to control speed and turning. A similar approach [8] uses horizontal gaze direction and blinking. Gaze direction is derived from the triangle locations which are formed from eyes center and nose locations. User gaze and blinking are used to provide the direction and timing commands. The direction command is related with the movement direction of electric wheelchair and the timing command is related with the time condition when the wheelchair should moves. Still another proposal involves wheelchair use with one indoor camera for monitoring wheelchair movement and another camera on the wheelchair to detect obstacles [9]. A similar proposal uses gaze control [10] in which stereo CCD cameras determine user gaze and head pose and a range finder recognizes the surrounding environment.

Many different types of wheelchairs have also been proposed by Prof. Kuno of Saitama University in Japan [11–14]. These include a wheelchair with a caregiver [12] who helps wheelchair by action such as pushes a button to call an elevator or open a door. Another [13] involves a robotic wheelchair with a speech interface that follows user speech commands using environmental range-sensor information. Still another [14] proposed a robotic wheelchair that monitors the user pedestrian and caregivers via multiple sensors. All of this still require manual control.

The problem remains that signal-based systems require direct contact with the user, e.g., electrodes attached to the user making these system expensive, invasive, and inconvenient. Although voice-based systems are easy and simple to develop, voice of surrounding people in actual practical application is still a problem. For the above reasons, we propose a wheelchair using a vision-based system whose objectives are to be usable by different paralyzed users and to be robust against vibration, user movement, and illumination change causing problems with previous systems.

Although paralyzed users may use their eyes, we decided to focus on gaze, rather than blinking, to show intent because long-term blinking makes users inordinately tired, which could result in erroneous communication.

Our proposal is basically same as that in [10] in that both use the user gaze to capture user information. Whereas [10] uses a stereo CCD camera to analyze the gaze, we use only a single camera on the user's glasses. The camera mounted on user's glasses also has been developed by NAC Company (NAC Image Technology). The EMR-9 tracks the eye movement using camera on the user's head and Purkinje-based method. This product allows user to move freely and record data into memory card or transfer by using wireless LAN. This data then can be read and analyzed by computer. The difference with our system is that our camera mounted on user's glasses detects eye movement using pupil knowledge. The increasing of pupil detection accuracy will improves robustness against different users.

Our system is designed for indoor purpose use with: (1) illumination less than 1500 lux (direct sunlight), (2) a flat travel surface – no slopes – on a road at least 1.2 m, no passing on stairs, and (3) a minimum rotate space of 2 m^2. Although designed for paralyzed users who can at least move their eyes, it is not designed for those with vision problems such as squinting and those who use excessive eye makeup such as mascara.

When using this wheelchair, user must be accompanied with assistant (nurse or family member). Assistant will help them sit on the chair, turns on the power supply, turns on the computer, put the glasses with camera, and unlock the chair's hand brake. The assistant must also aid in reversing all of this when user is finishing using the wheelchair.

Our system consists of a single infrared camera mounted on the user's glasses, netbook PC, a microcontroller, and a modified Yamaha JW II wheelchair. Infrared LEDs adjust illumination during environmental changes and camera position follows head movement to keep up with user movement while eliminating vibration thanks to the body's stability in the chair. Once the user's image is acquired by the camera, Adaboost Classifier (proposed by Viola-Jones) eye detection, adaptive threshold, and pupil detection determine the gaze. A single ultrasonic sensor on front of the wheelchair is used for collision avoidance. Wheelchair control uses command invisible layout to turn left, right, and go forward which is selected by user with looking at the key on layout during 1 second. Invisible layout (which contains several keys) means that user knows the keys positions without any real mark. Our wheelchair does not use stop key for safety reason. When user changes the gaze direction, wheelchair will automatically stop. Also when system fails analyze user gaze, wheelchair will stop. By implementing this system, wheelchair will move safely and help paralyzed user's life because they get back their mobility.

This paper is organized as follows: Section 2 propose our hardware configuration, gaze estimation, eye model, microcontroller circuit, and wheelchair control. Section 3 reviews experimental pupil detection performance results for different users and illumination change and also experimental vibration performance and wheelchair feasibility results. Section 4 presents conclusions.

2. Proposal

Our proposal prime importance is that the prototype works for all types of users under real circumstances of vibration, illumination change, user movement, and type of user. The system must also move safely. The infrared camera on the user's glasses enables user movement and reduces vibration. The infrared LED automatically adjusts illumination and stabilizes image. Our gaze estimation uses pupil knowledge such as size, color, shape, sequential location, and movement locates the pupil location. The simple model then converts pupil location to user gaze. A microcontroller circuit connects

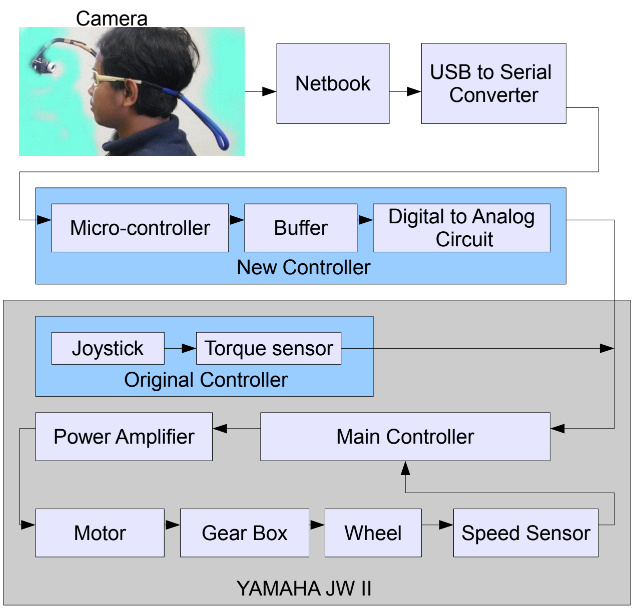

Fig. 1. Block diagram of proposal with microcontroller circuit replacing the original Yamaha JW II wheelchair controller.

and adjusts communication between the Netbook PC and wheelchair, converting RS 232 serial data communication to wheelchair commands. When the user looks at the key (on commands invisible layout) for 1 second, the Netbook PC sends a command to the wheelchair to move it in a selected direction. When the user changes the gaze direction, the wheelchair automatically stops. No stop key is used for safety reason. To avoid collisions, the ultrasonic range finder detects obstacles in front and when an obstacle is detected, the wheelchair automatically stops and user only can turn left or right. No backward key is used also for safety reasons because it is dangerous if the wheelchair moves backward while the user cannot see in back. **Fig. 1** diagrams our proposal.

2.1. Hardware Configuration

Our proposal uses NetCowBoy DC NCR-131, an infrared camera to acquire the user image. The camera's 7 LED automatically adjusts illumination to produce stable images when environment illumination changes. The use of IR camera will solve problem of illumination changes. The camera fits on the user's glasses. The distance between the camera and eye 15.5 cm is derived from design sensor steps assuming that the camera acquires the user's eye gaze and camera placement does not disturb the user's view. The camera is in front and a bit above the eye to avoid disturbing the user's view and to reduce vibration, e.g., when then wheelchair moves along an uneven road. When vibration occurs, user body automatically reduces it and makes it does not influence the camera. The camera position is shown in **Fig. 2**. We use Netbook Asus Eee PC 1002 HA with Intel Atom N270 CPU (1.6 GHz),

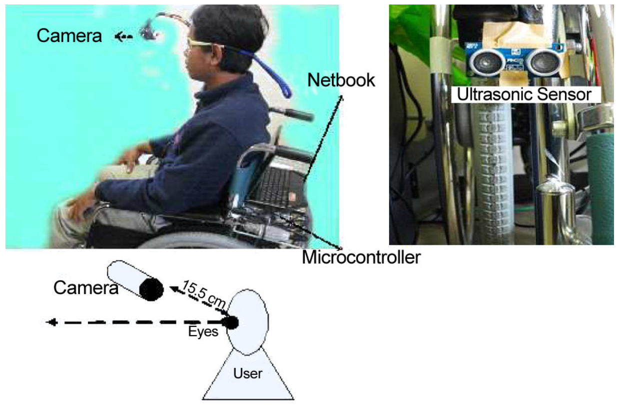

Fig. 2. Wheelchair hardware.

Table 1. Ultrasonic range finder.

Supply voltage	5 V (DC)
Supply current	30 mA (Typ), 35 mA (Max)
range	3 cm to 3 m
Input trigger	Positive TTL pulse, 2 μSmin, 5 μS (Typ)
Echo pulse	Positive TTL pulse, 115 μS to 18.5 mS
Echo hold off	750 μS from fall of Trigger pulse
Burst frequency	40 kHz for 200 μS
Delay before next measurement	200 μS
dimension	22 mm H $\times$ 46 mm W $\times$ 16 mm D

1 GB Memory, 160 GB sata HDD, and a screen display of 10 inches. To convert from universal system bus (USB) to serial communication, we use a Keyspan USA 19Qi converter. Microcontroller AT 89S51 is used to change the original controller (joystick controller module). Our software was developed using C^{++} Visual Studio 2005 and OpenCV, an image processing library, downloaded free from the website. A ping ultrasonic range finder is used to detect obstacles. This range finder is able to detect obstacle around 3 cm until 3 m and the detail specification is shown in **Table 1**. **Fig. 2** shows the hardware.

2.2. Gaze Estimation

The user's gaze is detected using image processing such as Adaboost Classifier (proposed by Viola-Jones) eye detection, deformable templates, adaptive thresholds, and pupil knowledge.

The gaze estimation flow shown in **Fig. 3** begins with eye detection to be used as the static eye location assuming that because the camera is on the user's glasses, the next eye location has the same position as the previous

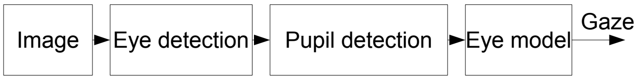

Fig. 3. Gaze estimation.

one, i.e., that the eye is detected only once at the beginning. Pupil location is detected using pupil knowledge such as color, size, shape, sequential location, and movement. An eye model converts pupil location to user gaze as detailed bellow.

Normally the eye is detected using a deformable template. After the eye image is captured, a Gaussian smoother is applied to this image. Matching the eye image and deformable template locates the eye. This method is fast and can be used for many more users than original template matching, but unfortunately does not always detect eye, so Adaboost classifier eye detection [15] is used as backup. It will take over eye detection when deformable template fails to detect eye location. An XML file is required to runs Adaboost classifier eye detection using an OpenCV Image processing library created by collecting object (positive samples) and non-object (negative samples) images. This is used with the following code:

CvSeq objects = cvHaarDetectObjects(small_img, cascade, storage, 1.1, 2, 0, cvSize(30, 30))*;

These two methods have the advantage of fast processing time and robustness against changing circumstances. Once the eye location is found, it is used to lock in the eye image, enabling eye detection to be skipped thereafter. In pupil detection, pupil location is estimated as stated earlier using pupil knowledge extracted using an adaptive threshold to separate the pupil from other eye components. The threshold value T is 0.27% below the mean μ of eye image I and is derived from adjusting illumination intensity of 150 lux. Our threshold is suitable only for this condition but enables the camera to automatically adjust illumination as it changes.

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

$$T = 0.27\mu \quad \text{. . . . . (2)}$$

Output from the adaptive threshold is black pixels representing the pupil in the image. To eliminate noise, we use a median filter. Widely adaptive threshold output is divided into three categories: (1) case 1, in which noise-free black pixels clearly represent the pupil, (2) case 2, in which noise appears and is the same size and shape as pupil, and (3) case 3, when no pupil properties can be used to locate pupil. Cases are shown in **Figs. 4**, **5**, and **6**.

Once adaptive threshold output is classified, we estimate pupil location in three steps based on pupil knowledge. In case 1, the pupil is easily located by shape and size, even with noise in the image. In case 2, noise appears as almost the same size and shape as the pupil, e.g., when the adaptive threshold cannot be separated from other eye

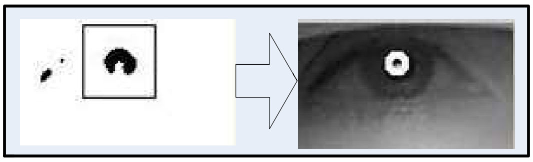

Fig. 4. Case 1, output distinguished by shape and size.

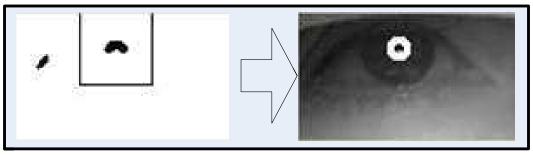

Fig. 5. Case 2, output with noise which almost the same size and shape with pupil.

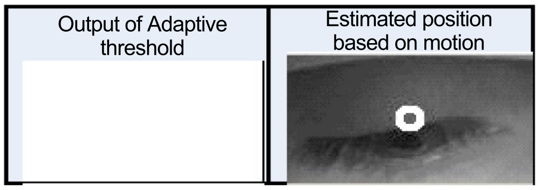

Fig. 6. Case 3, no usable pupil properties due to black pixel absence in image output.

components such as the eyelid or the corner of the eye. To minimize these problems we recorded pupil movement histories assuming that the true pupil is closest to its previous location.

$$P(t-1) - C < P(t) < P(t-1) + C \quad \text{. . . . . (3)}$$

Reasonable pupil location $P(t)$ is within the surrounding of previous location $P(t-1)$ with area C. In case 3, when features cannot be found to locate the pupil as when the user is looking from the corner of the eye, we estimate pupil location based on the movement [16].

2.3. Eye Model

To convert pupil location to a gaze, we use a simple eye model assuming that eye movement resembles a sphere with radius R, and that the pupil is at the front of the eyeball, as shown in **Fig. 7**. If the distance between the normal angle and current pupil location is r, θ_x, θ_y, R, and r are related as follow,

$$r_x = R\sin\theta_x \quad \text{. . . . . (4)}$$

$$r_y = R\sin\theta_y \quad \text{. . . . . (5)}$$

$$\theta_x = \arcsin(r_x/R) \quad \text{. . . . . (6)}$$

$$\theta_y = \arcsin(r_y/R). \quad \text{. . . . . (7)}$$

Once the pupil is located, the user's gaze $\theta(\theta_x, \theta_y)$ is found using this model. Our system requires only four

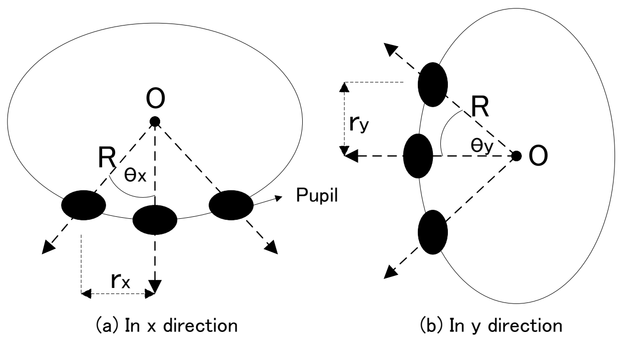

Fig. 7. Eye modeled as a sphere with radius *R*.

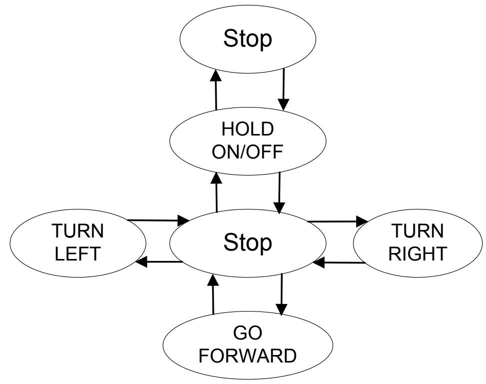

Fig. 8. Wheelchair control with command change stopping the wheelchair.

outputs: left, right, up, and down, calculated from the angle of gaze. To convert from the user gaze to a wheelchair command, we use the threshold angle. When user is looking to left or right exceeding the threshold angle, it means that either of left or right is selected. For down, we use a different threshold to avoid influencing the user's view.

2.4. Micro-Controller Circuit

After the user gaze is converted to wheelchair commands, the Netbook sends these commands to the wheelchair. Because the original Yamaha JW II wheelchair controller has no data communication port, we replaced the original controller with a new microcontroller circuit to connect the Netbook PC and wheelchair and used RS 232 serial communication. The microcontroller converts serial data to parallel I/O data that drives a relay to obtain analog output that is connected to the main controller to enable the Netbook PC control the wheelchair by serial data communication.

2.5. Control of Wheelchair

We designed a four-key invisible layout for moving forward, turning right or left, and a toggle for "hold" (on/off). No stop key and screen display is used. The user understands the key location for eye-only selection. Instance, when the user is looking to right key, the wheelchair moves to the right until the user change gaze and while user has not changes his/her gaze, the wheelchair continues moving until the user changes gaze direction at which point the chair stop automatically. This is safer, for example, than using stop key which would require more time to hit the stop key, without the guarantee of a safe stop. We did not use a back key due to danger of moving back while the user did not know the situation behind the chair. The proposed wheelchair also stops when the user is looking at a free area (area on command visible layout which not contain any keys), as shown in **Fig. 8**. To take a break, can be used the user looks upward to trip the hold toggle function.

3. Experimental Results

The experiments discussed below tested methods and integrated system performance. They measure pupil detection performance involving accuracy, illumination change influence and vibration influence.

3.1. Pupil Detection Performance

Measuring pupil detection performance involved five users with different ethnicity and nationality – Indonesian, Japanese, Sri Lankan, and Vietnamese. The varied samples demonstrate the flexibility of our method used for different types of users. Eye movement data was collected from users during numerous eyes movements.

Eye images of the three Indonesians in **Fig. 9** show that individuals from the same country have different eye shapes.

Indonesian images having slated eyes numbered 882 and those for the two Indonesians having wide eyes and clear pupils 552 and 668. Collected Sri Lankan data in **Fig. 10** with numbers 828 images with dark skin and thick eyelashes. Collected Japanese data in **Fig. 11** with numbers 665 images with light skin and slanted eyes. Vietnamese data is shown in **Fig. 12**.

Pupil detection accuracy and variation are judged by success samples counted based on system output (direction) compare to manual success. After pupil detection accuracy was counted, we compared our method to the adaptive threshold and template matching. In this experiment, the adaptive threshold was used together with connected labeling. Another compared method used pupil template as reference and matched with the pupil images. Our pupil detection accuracy against different users is shown in **Table 2**. Variance was 16.27.

We measured pupil detection performance against illumination change by giving an adjustable light source to the system and measured illumination using an LM-8000 multifunctional environmental detector. First, zero illumination is given to system (dark condition). Despite the absence of illumination, our IR camera automatically ad-

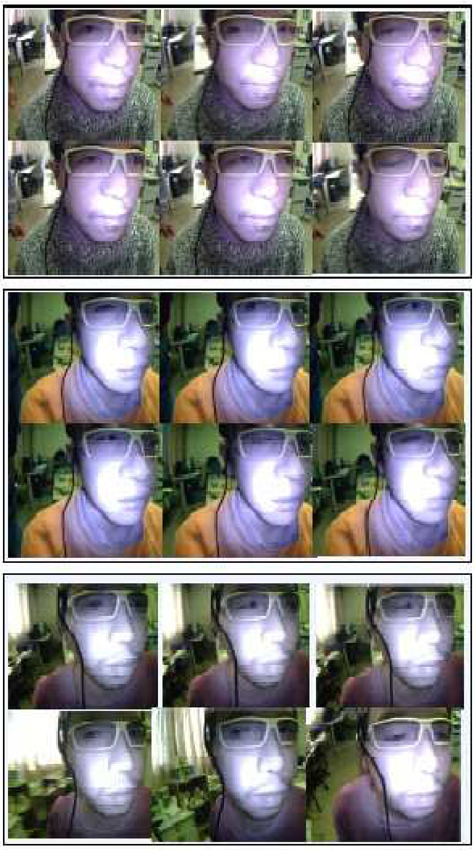

Fig. 9. Indonesian images with the top person having slanted eyes and the two bottom with wide eyes and clear pupils.

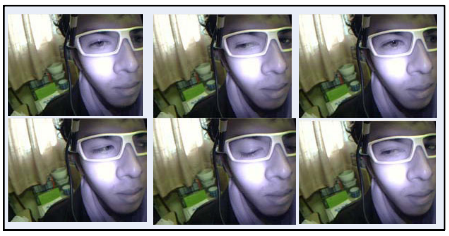

Fig. 10. Sri Lankan with dark skin and thick eyelashes.

justs illumination for this condition. With seven IR LEDs and a light sensor, the image result is stable. Unfortunately, when strong illumination hitting the camera, it causes the pupil detection is not running well. The result of illumination influence experiment is shown in **Fig. 13**.

3.2. Vibration Influence

The objective of the vibration influence experiment is to prove that the camera on the user's glasses has advantages in reducing vibration almost to zero. Vibration was recorded using G-MEN DR 10 shock recorder by comparing camera placement between our system and others [8, 10] with camera placed on the wheelchair at point 2

Fig. 11. Japanese with light skin and slanted eyes.

Fig. 12. Vietnamese.

Table 2. Pupil detection accuracy. Our method is robust against different users and is accurate.

User Types	Nationality	Adaptive Threshold(%)	Template Matching(%)	Our Method(%)
1	Indonesian	99.85	63.04	99.99
2	Indonesian	80.24	76.95	96.41
3	Srilanka	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

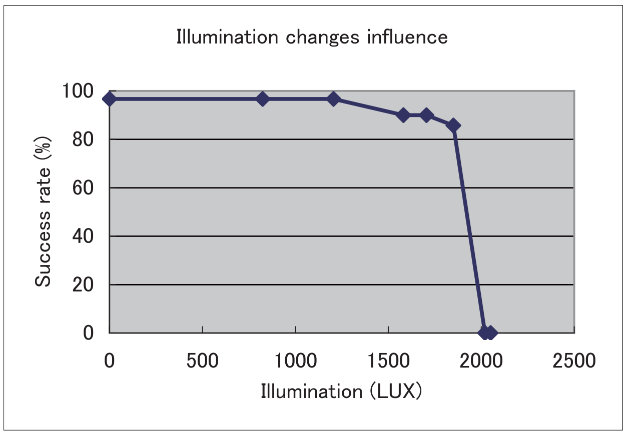

Fig. 13. Illumination influence. Our pupil detection works without illumination but not in strong light, e.g., direct sunlight on the camera.

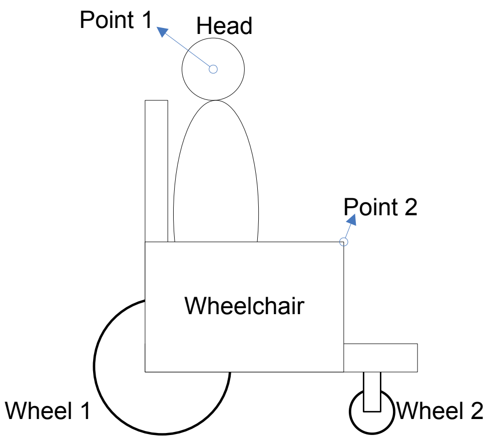

Fig. 14. Camera placement. Other systems put the camera at point 2, but we put our camera on the user's glasses at point.

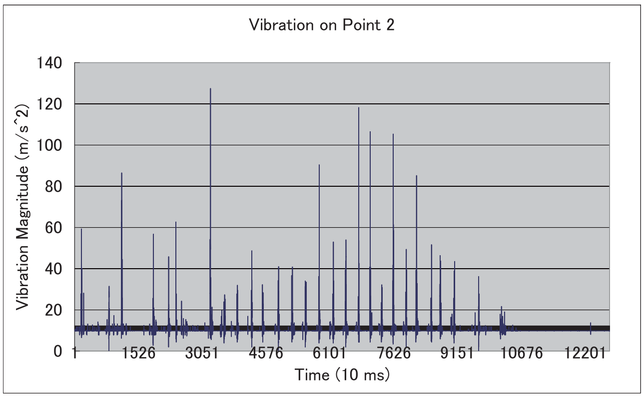

Fig. 15. Vibration at point 2 is high.

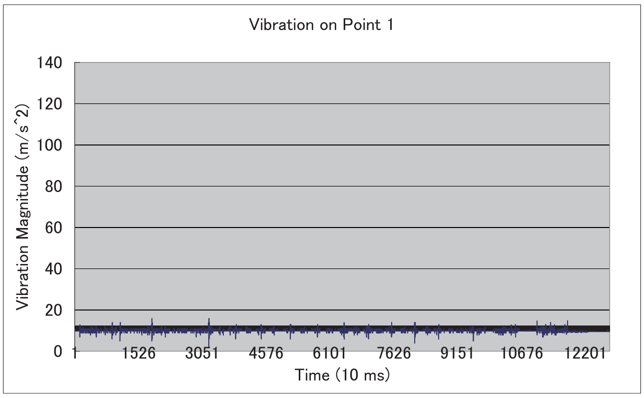

Fig. 16. Vibration at point 1 is low.

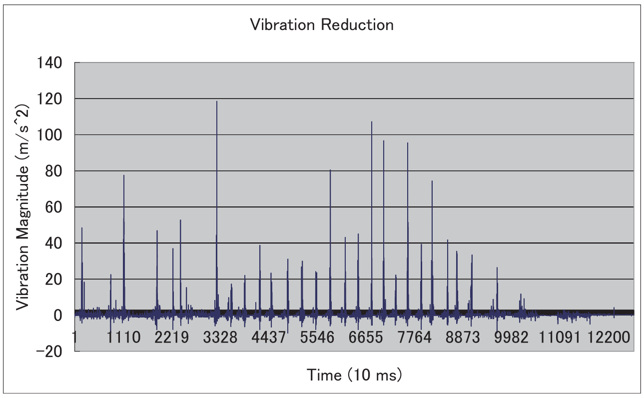

Fig. 17. Vibration reduction shows that placing the camera at point 1 greatly reduces vibration.

in other systems as shown in **Fig. 14**. Our system put the camera on the user's glasses as shown at point 1 in **Fig. 14**.

To test camera placement performance, two shock recorders are placed at points 1 and 2, turned on, and vibration is recorded when the wheelchair passes simultaneously at the two points as shown in **Figs. 15** and **16**. Vibration reduction between the two points is shown in **Fig. 17**.

The vibration reduction happens because the user's body is elastic, similar to a spring. To explain vibration reduction, we modeled camera placement as shown in **Fig. 18**.

If wheelchair mass is m_2 with spring stiffness k_2 and user mass m_1 with spring stiffness k_1, then:

$$Fs = k_1x_1 + m_1g + k_2x_2 + m_2g \qquad (8)$$

g is gravity. Two types of spring stiffness – k_1 and k_2 – absorb vibration. If we measure vibration reduction at point 2, only k_1 is involved, whereas at point 1, both types of springs stiffness are used, making the camera at point 1 more robust against vibration.

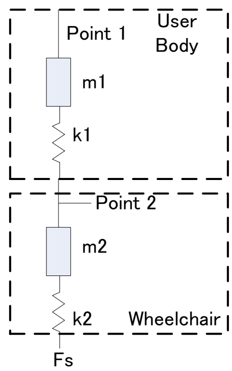

Fig. 18. Vibration model showing that point 1 has more spring to reduce vibration than point 2.

3.3. Test of Integrated System

The objective of the integrated system test experiment is to examine over all wheelchair performance during use. Beginning at a start line, the user drives the wheelchair using eye control alone with the time taken getting to the finish line recorded based on the road map shown in **Fig. 19**.

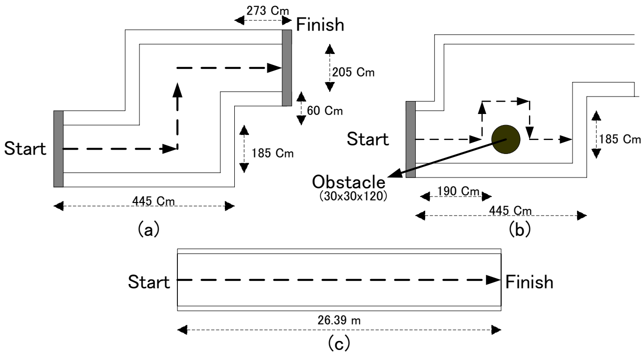

Fig. 19. Road map. (a) Users used all functions to follow the road, going forward, turning left, and turning right until the finish line. (b) Users avoid an obstacle. (c) The road is straight.

Table 3. Recorded time when users rode the wheelchair from start to finish, easily using our wheelchair even though they had never done so before.

No.	Time (seconds)	User
1	80	expert
2	70	expert
3	85	beginner
4	99	beginner
5	95	beginner

Fig. 20. Proposed wheelchair.

This experiment involves five users – two experts (ever rode before) and three beginners (never rode before). Before the experiment, users did the exercise first. We explained and taught to them how to ride this wheelchair. Because of this wheelchair also same with other vehicles such motor cycle or car, they need to practice first before riding. Users practiced for 10 minutes turning and going forward until they felt they could control the wheelchair, and then were clocked from start to finish. To go forward, they looked down and continued doing so as long as they wanted to. Unfortunately, users blinks when their eyes become tired, which automatically stops the wheelchair. Although this will makes wheelchair moves slowly, we choose this role because of safety reason. After the wheelchair stops, user can go forward again by looking down. After going forward 3.5 meters, the user should stop and turn left by looking left, then go forward 1.9 meters and stop, turn right by looking right, and go forward again 3 meters. After users pass the finish line, we recorded the time as shown in **Table 3**.

We compared the time between eye-based and hand-based movement using the same coarse as shown in **Fig. 19(a)**. Users manually controlling wheelchair took 23 seconds, almost four times faster than our system. Nevertheless, eye-based control remains a viable alternative to manual control under specific conditions.

In interviews with subject after experiments, most said control was easy, even among beginners. They could use their eyes freely in hold mode by looking up, so the system freezes, ignoring all eye movement. This lets users rest their eyes and look around.

In experiments avoiding obstacle, shown in **Fig. 19(b)**, users start by moving forward until nearing the obstacle. To avoid the obstacle, they turn left, and then stop after they feel they have gone enough to turn right, and then stop. They then turn right and continue go forward until they pass the obstacle, turn right, continue forward, turn left, and go forward until they reach the finish line. The average time for experiments is 73.5 seconds. Our last experiment measured the time users went forward on a straight course, shown in **Fig. 19(c)**. Users go forward from the start line to the finish line. The average time was 49 seconds.

Results showed that the course with turns took more time than the straight course, since turning takes time. Blinking adds to time because the wheelchair stops.

Obstacles cannot be detected adequately with ultrasonic sensors alone. The variety of obstacle shape such as wall, turned wall, and etc. make the ultrasonic sensor has less accuracy. To solve this, combining ultrasonic sensors and a forward camera could, for example, detect obstacles more precisely based on vision. This kind of method will benefit for small obstacle and others. Unfortunately, the looking forward camera can not detect the transparent obstacles such as glass walls or doors. That's why the combination between ultrasonic sensor and forward looking camera can be a good obstacle detector. The demonstration figures of our wheelchair are shown in **Fig. 20**.

4. Conclusions

We have fully realized an eye-controlled electric wheelchair prototype for paralyzed users. The infrared (IR) camera on the user's glasses enables user movement, maintains illumination, and minimizes vibration. Pupil-movement detection successfully detects the pupils of different wheelchair users. Our wheelchair control makes it easy for users to operate the wheelchair and ensures safe wheelchair operation by combining ultrasonic obstacle detection and our eye-only control.

Acknowledgements
We thank the Indonesian Direktorat Jenderal Perguruan Tinggi (DIKTI) for providing the scholarship enabling Ronny Mardiyanto to pursue a Ph.D. at Saga University, Japan.

References:
[1] R. C. Simpson, "Smart wheelchairs: A literature review," J. of Rehabilitation Research & Development, Vol.42, No.4, pp. 423-436, 2005.

[2] L. A. Cordon, "Popular Psychology: An Encyclopedia," Greenwood Press, p. 8, 2005.

[3] S. M. White and S. Hawking, "A Life in Science," 1992.

[4] R. Barea, L. Boquete, M. Mazo, and E. Lopez, "System for Assisted Mobility using Eye Movements based on Electrooculography," IEEE Trans. on Neural System and Rehabilitation Engineering, Vol.10, No.4, pp. 209-218, 2002.

[5] A. Ferreira, R. L. Silva, W. C. Celeste, T. F. Bastos, and M. Sarcinelli, "Human-Machine Interface Based on Muscular and Brain Signals applied to a Robotic Wheelchair," IOP Publishing Ltd., Vol.7, pp. 1541-1672, 2007.

[6] M. Mazo, F. J. Rodríguez, J. L. Lázaro, J. Ureña, J. C. García, E. Santiso, and P. A. Revenga, "Electronic control of a wheelchair guided by voice commands," Elsevier of Control Engineering Practice, Vol.3, pp. 665-674, 1995.

[7] P. Jia and H. Hu, "Head Gesture based control of an Intelligent Wheelchair," The 11th Annual Conf. of the Chinese Automation and Computing Society in the UK (CACSUK05), pp. 85-90, 2005.

[8] D. Purwanto, R. Mardiyanto, and K. Arai, "Electric wheelchair control with gaze direction and eye blinking," Proc. of The Fourteenth Int. symposium on Artificial Life and Robotics, Vol.GS21, No.5, B-ConPlaza, Beppu, 2008.

[9] K. Kawai, S. Hiramatu, Z. Luo, and A. Kato, "Construction of intellectual control system of autonomous, electric wheelchair," Bulletin of Aichi Institute of Technology, Part B, Vol.39, pp. 21-27, 2004.

[10] Y. Matsumoto, T. Ino, and T. Ogasawara, "Development of Intelligent Wheelchair System with Face and Gaze Based Interface," Papers of Technical Meeting on Systems and Control, IEE Japan, Vol.SC-01 No.20-30, pp. 59-64, 2001.

[11] T. Shibusawa, Y. Kobayashi, and Y. Kuno, "Robotic Wheelchair for supporting Art Appreciation," Proc. of the Annual General Assembly of the Information and Systems, The Institute of Electronics, Information and Communication Engineer 2008, Vol.2, pp. 169-169, 2008.

[12] T. Iwase, R. Zhang, and Y. Kuno, "Robotic Wheelchair Moving with the Caregiver," SICE, pp. 238-243, 2006 SICE-ICASE Int. Joint Conf., 2006.

[13] T. Iwase, A. Nakamura, and Y. Kuno, "Robotic Wheelchair Understanding the User's Intention in Speech Using the Environmental Information," Proc. of the IASTED Int. Conf. on Advances in Computer Science and Technology (ACST 2004), pp. 285-290, 2004.

[14] Y. Kuno, T. Yoshimura, M. Mitani, and A. Nakamura, "Robotic wheelchair looking at all people with multiple sensors," Proc. of IEEE Int. Conf. on Multisensor Fusion and Integration for Intelligent Systems, MFI2003, pp. 341-346, 2003.

[15] G. Bradski and A. Kaebler, "Learning Computer Vision with the OpenCV Library," O'REILLY, pp, 214-219, 2008.

[16] Z. Zhu, Q. Ji, K. Fujimura, and K. Lee, "Combining Kalman filtering and mean shift for real time eye tracking under active IR illumination," Proc. of 16th Pattern Recognition Int. Conf., Vol.4, pp. 318-321, 2002.

Name:
Kohei Arai

Affiliation:
Saga University

Address:
1 Honjo, Saga 840-8502, Japan

Brief Biographical History:
1974 M.S. degree in Electric and Electronics Engineering from Nihon University
1974-1979 Institute of Industrial Science and Engineering, The University of Tokyo
1980-1990 National Space Development Agency of Japan (Current, JAXA)
1982 Ph.D. degree of Engineering from Nihon University
1985-1987 PDF of NSERC, Canada Center for Remote Sensing
1990- Professor, Information Science Department, Saga University
1998- Adjunct Professor, University of Arizona

Main Works:
- "Computer input system based on viewing vector estimation with iris center detection from face image acquired with web camera allowing users' movement," Electric and Communication in Japan, Vol.92, No.5, John Wiley and Sons Inc., pp. 31-40, 2009.
- "Unmixing method for hyperspectral data based on sub-space method with learning process," Advances in Space Research, Vol.44, pp. 517-523, 2009.

Membership in Academic Societies:
- The Institute of Electrical Engineering of Japan (IEEJ)
- Information Processing Society of Japan (IPSJ)
- Remote Sensing Society of Japan (RSSJ)
- Japan Society on Photogrammetry and Remote Sensing (JSPRS)

Name:
Ronny Mardiyanto

Affiliation:
Institut Teknologi Sepuluh Nopember

Address:
Kampus, Keputih, Sukolilo, Surabaya, Indonesia

Brief Biographical History:
2003 S.T. degree in Electric and Electronics Engineering, Institut Teknologi Sepuluh Nopember, Indonesia
2006 M.T. degree in Electric and Electronics Engineering, Institut Teknologi Bandung, Indonesia
2008- Ph.D. Student, Saga University, Japan

Main Works:
- "Electric wheelchair control with gaze direction and eye blinking," J. of Artificial Life and Robotics, Vol.14, No.3, pp. 397-400, December 2009.