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Powered wheelchair controlled by eye-tracking system

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In this paper, we use the optical-type eye tracking system to control powered wheelchair. The userís eye movements are translated to screen position using the optical-type eye tracking system. The pupil-tracking goggles with a video CCD camera and a frame grabber analyzes a series of human pupil images when the user is gazing at the screen. A new calibration algorithm is then used to determine the direction of the eye gaze in real time. We design an interface with nine command zones to control powered wheelchair. The command at the calculated position of the gazed screen is then sent to move the powered wheelchair.

Keywords: eye tracking system, powered wheelchair, new calibration algorithm.

1. Introduction

A powered wheelchair is a mobility-aided device for persons with moderate/severe physical disabilities or chronic diseases as well as the elderly. In order to take care for different disabilities, various kinds of interface have been developed for powered wheelchair control; such as joystick control, head control and sip-puff control. Many people with disabilities do not have the ability to control powered wheelchair using the above mentioned interfaces. The eye-controlled powered wheelchair offers them a possible alternative [1].

Different measurement systems for eye motion have been developed, such as coil searching method, electro-oculography (EOG), Limbus tracking, dual-Purkinje -image (DPI), pupil tracking and infrared oculography (IROG). Some contact eye -tracking methods, such as EOG technology detects eye movement from the electrical measurement of the potential difference between the cornea and the retina. Essentially, eye movements are accompanied by the appearance of electric signals. In the front of the head, the corneal to retinal potential creates an electric field, which changes its orientation as the eyeballs rotate. Electrodes placed near the eyes can detect these electrical signals. However, the sweat may affect the electrical signal read out. In coil searching method, a magnetic field is created around the eyeball, in which the movement of contact lens with coil can be observed after signal processing. This is not comfortable for the user wearing contact lens with coil. Optical type eye-tracking device can provide non-contact operation which eliminates the above problems. GRATTAN and PALMER [2, 3] created an eye-communicating apparatus and a method employing eye closure for the disabled. In an eye-tracking system, the user's point of view on the computer screen is estimated, using the vector distance from the center of the pupil in a digitized eye image. Our team has studied the optical eye tracking system [4–6], which was composed of a pinhole CCD, a light source, an image capture card and an image processing program.

Some effort has been made to develope the interface able to control the computer with eye or head movement [7, 8]. This eye-tracking system or eye-mouse, combines the techniques of eyeball tracking with hardware equipment and software. The movement of eyeball is used to control the mouse coordinates instead of hands. This new type of interface between the human and the machine can help the disable patients who cannot use keyboard or mouse to perform the vision control. There are many previous systems which have used eye gaze or direction in which the face is pointed to control a smart wheelchair [9–12]. In this study, two different research domains, namely, the optical pupil tracking and the powered wheelchair control, are combined to provide a control device for people with physical disabilities.

2. Systematic framework

A powered wheelchair includes the following main components: a the prop structure, a mechanical transmission system, a controller, a motor, batteries and an operation interface, as shown in Fig. 1. Usually, the operation interface uses a joystick as the input device to control the operation of the motor.

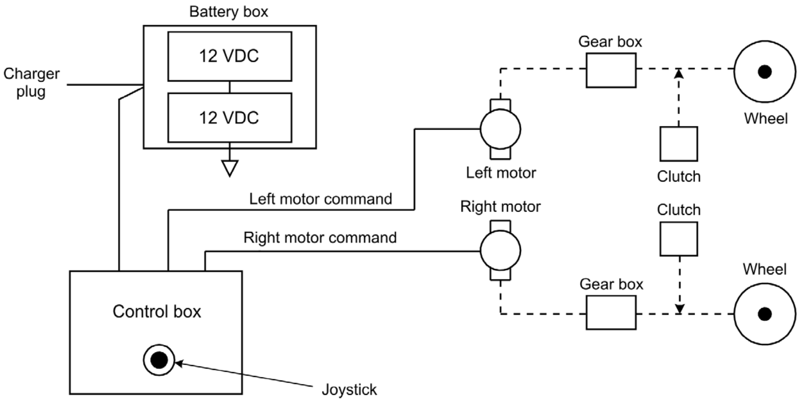

Fig. 1. Systematic framework of powered wheelchair.

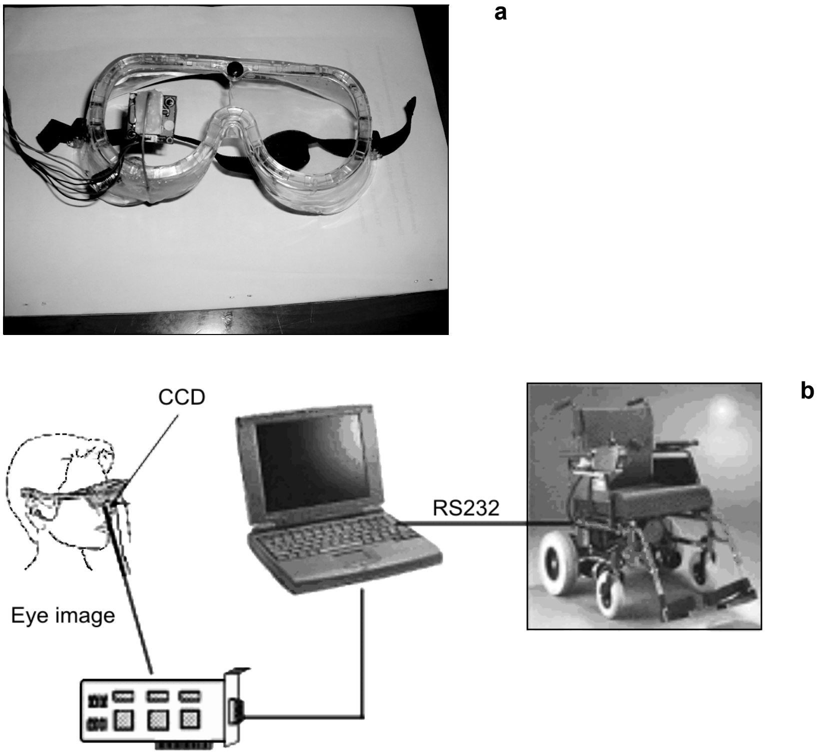

Fig. 2. Pupil tracking goggles for eye (**a**). Representative structure of a powered wheelchair controlled by the eye-tracking method (**b**).

The pupil tracking system uses a camera to capture eye images, and tracks pupil motion by means of an image processing program. To ensure accurate eye image to be captured without affecting the user's field of view, we mount the pinhole CCD camera under the rim of goggles [13, 14]. We also install a small bulb in order to enhance the image brightness, as shown in Fig. 2**a**.

Figure 2**b** shows the structure of vision-controlled wheelchair. The center position of the moving pupil is computed. The calculated result is then transmitted to the powered wheelchair controller by way of USB to RS232 converter for controlling the movement of the wheelchair.

3. Correctional computation

The pupil color is originally darker than the eye white, iris and skin around the eyes. When appropriate light incidents on the pupil, the brightness difference will be more enhanced, as shown in Fig. 3. We use the brightness difference between the pupil and its side to make a binary processing; thus getting a complete pupil binary image.

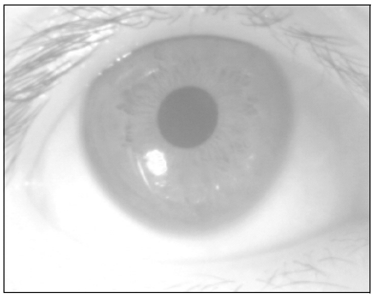

Fig. 3. Eye image when light is incident on it.

Using programming computations, we count the total pixel number k and the coordinate point (i, j) of the pupil image. Moreover, we can figure out the central point coordinates (m, n) of the pupil by the following formula:

$$(m, n) = \left(\frac{1}{k} \sum_{a=1}^{k} i,\ \frac{1}{k} \sum_{a=1}^{k} j \right) \tag{1}$$

Suppose that the eye motion range is regarded as a rectangle, whose four corners correspond to the four corners of the screen, as shown in Fig. 4. Any point in eye motion range can correspond to coordinate points of the screen by using the due transformation and interpolation method. The direction of CCD towards eye is inclined to the optical axis of the lens, so we have to use the coordinate rotation method to make a calibration before the normal operation.

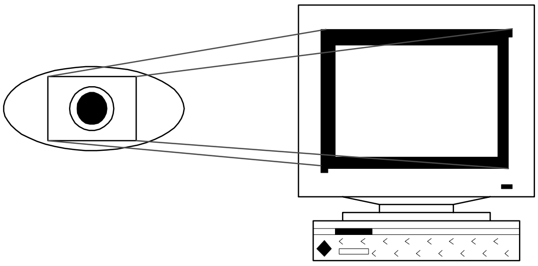

Fig. 4. Corresponding range between the eye motions and the screen.

As shown in Fig. 5, the top of the left corner is chosen as the original point of the computer screen. Transverse coordinates increase from the left to the right which makes the vertical coordinates also increases from top to bottom. We define the top-left, bottom-left, top-right and center points of screen as the four correction points for calculating the coordinate transformation. The rotational angle θ, which is

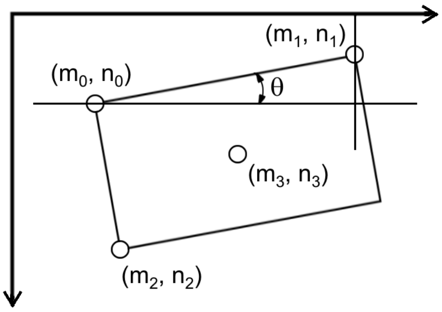

Fig. 5. Correction reference points.

defined as positive when it rotates counterclockwise, can be obtained from the following formulae:

$$\begin{cases} \tan\theta = \dfrac{n_1 - n_0}{m_1 - m_0} \\ \theta = \tan^{-1}\left(\dfrac{n_1 - n_0}{m_1 - m_0}\right) \end{cases} \tag{2}$$

Reference coordinate points after rotation can be obtained from the following formulae:

$$\begin{cases} m_0' = m_0\cos\theta + n_0\sin\theta \\ n_0' = n_0\cos\theta - m_0\sin\theta \\ m_1' = m_1\cos\theta + n_1\sin\theta \\ n_1' = n_1\cos\theta - m_1\sin\theta \\ m_2' = m_2\cos\theta + n_2\sin\theta \\ n_2' = n_2\cos\theta - m_2\sin\theta \\ m_3' = m_3\cos\theta + n_3\sin\theta \\ n_3' = n_3\cos\theta - m_3\sin\theta \end{cases} \tag{3}$$

Their locations are shown in Fig. 6.

Because the eyeball is spherical in shape, the center of the pupil moves along a spherical surface. When the eye rotates horizontally, we take the image from bottom

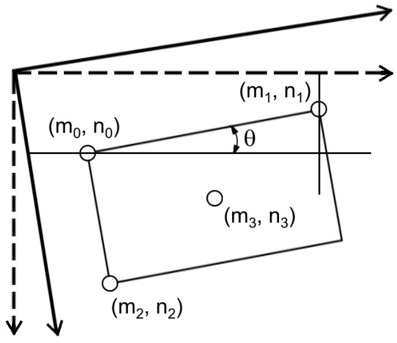

Fig. 6. Correction points after coordinate rotate.

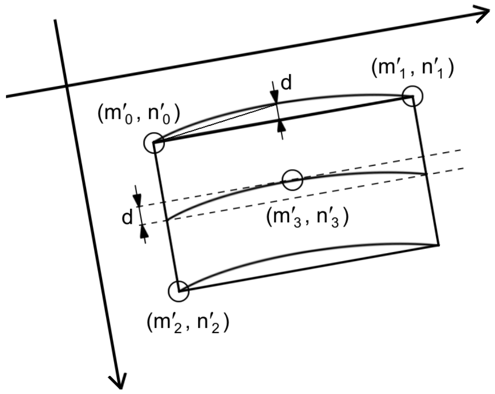

Fig. 7. Correction for curved track.

to top with an oblique angle simultaneously. So the eye movements will form a curved line, as shown in Fig. 7. Suppose that *d* is the vertical coordinate difference between the center point (m'_3, n'_3) and the mean value of (m'_0, n'_0) and (m'_2, n'_2). This can be calculated using the formula:

$$d = n'_3 - \frac{1}{2}\left(n'_2 + n'_0\right) \tag{4}$$

Then, under the triangular approximation condition, we can get the difference d' between the vertical coordinates for all points lying on the curve using the formulae below. If the coordinates of some point (m, n) fulfill the inequality $m < m'_3$

$$d' = \frac{m - m'_0}{m'_3 - m'_0} \times d \tag{5}$$

while if $m > m'_3$, then

$$d' = \frac{m'_1 - m}{m'_1 - m'_3} \times d \tag{6}$$

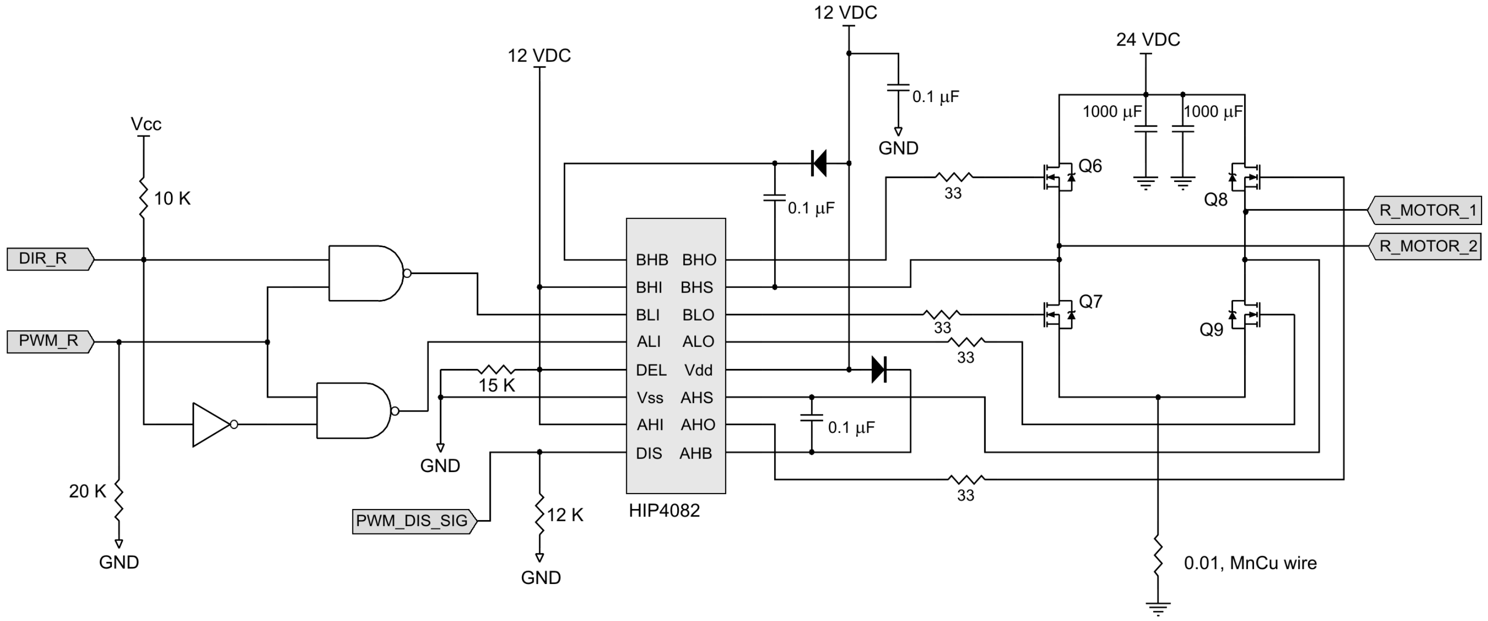

Fig. 8. Driving circuit layout of powered wheelchair with eye-tracking system.

Finally, after curved track correction, we can obtain correctional coordinates (m', n') using:

$$\begin{cases} m' = m \\ n' = n - d' \end{cases} \tag{7}$$

If we set the resolution of screen as A times B pixel, by coordinate transformation, the below formulae define the relationship between the pupil center and gaze point on screen (where Dm represents the value of horizontal coordinates, and Dn represents the value of vertical coordinates)

$$\begin{cases} Dm = \dfrac{A}{m'_1 - m'_3} \times (m' - m'_0) \\ Dn = \dfrac{A}{n'_1 - n'_3} \times (n' - n'_0) \end{cases} \tag{8}$$

4. Experiments

Figure 8 shows the design of the driving circuit of the powered wheelchair with eye-tracking system. Here we adopt the second-order command gradient in output driving force to obtain precise adjustment of the output power of the DC motor.

When the rotating direction and speed of two DC motors are different, the powered wheelchair can rotate, turn left, and turn right, respectively. The structure of the control formula of the powered wheelchair with the eye-tracking device is shown in Fig. 9.

The eye movement is regarded as a 640×480 pixel rectangle, which was to be divided into nine zones, as shown in Fig. 10. The upper zone represents forward movement, the lower zone represents backward movement, the right zone represents

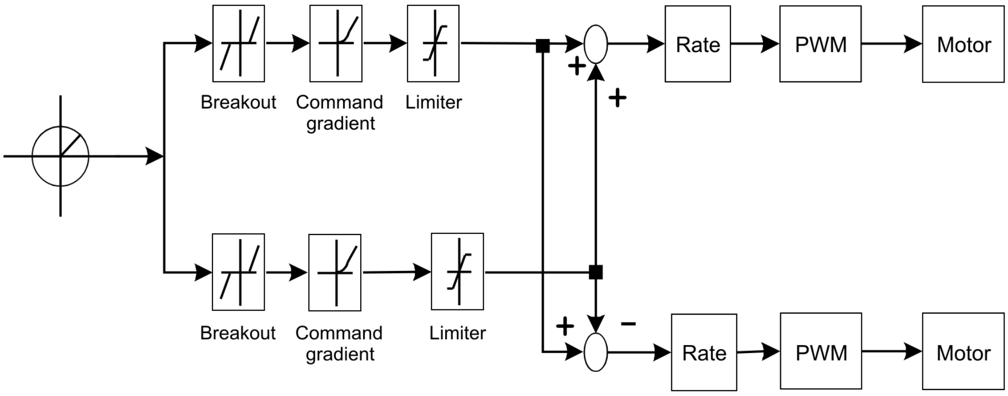

Fig. 9. Structure of control formula of powered wheelchair with eye-tracking device.

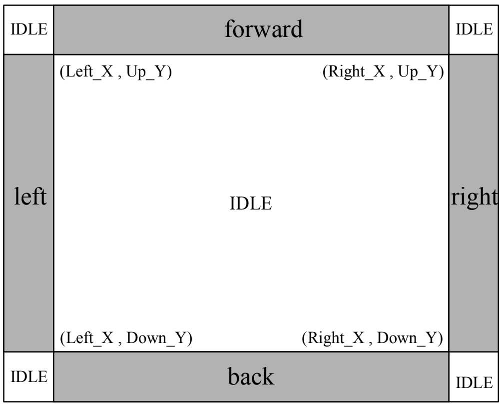

Fig. 10. Nine command zones of eye control wheelchair.

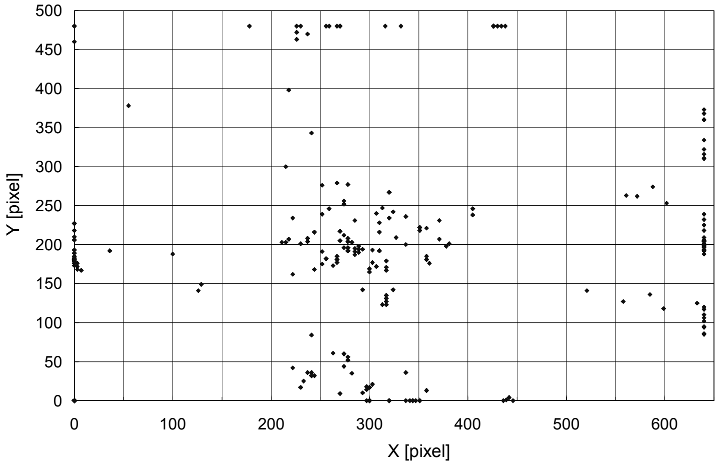

Fig. 11. Gaze point distribution of the nine zones method.

the turning right, and the left zone represents the turning left. When the pupil center falls in one of the four zone, a command is sent out. When the pupil center falls outside these four zone, it indicates a stop command.

The direction and the speed of the powered wheelchair will depend on the times and the command zone the user gazes at. The method of counting the times of gazing at the nine command zones is expressed in Tab. 1.

If the user is engaged in fixed position correction, he has no need to watch the screen of computer. By using the respective up, down, right and left eye motions, we can easily send out a control command. Figure 11 shows the gaze distribution result of the eye motion. When the eye gazes in a certain direction, the input command increases continuously in that direction until it reaches the increment value set, and the control command is sent out. Since the outputs of a pupil-tracker are nonlinear

Table 1. The method of counting and judgment.

Left region	If (sm<Left_X && Up_Y<sn<Down_Y)
	{
	L_Turn_cnt++;
	Fwd_cnt=0;
	Aft_cnt=0;
	R_Turn_cnt=0;
	}

Right region	if (Right_X<sm && Up_Y<sn<Down_Y)
	{
	R_Turn_cnt++;
	Fwd_cnt=0;
	Aft_cnt=0;
	L_Turn_cnt=0;
	}

Backward region	if (Left_X<sm<Right_X && Down_Y<sn)
	{
	Aft_cnt++;
	Fwd_cnt=0;
	R_Turn_cnt=0;
	L_Turn_cnt=0;
	}

Forward region	if (Left_X<sm<Right_X && sn<Up_Y)
	{
	Fwd_cnt++;
	Aft_cnt=0;
	R_Turn_cnt=0;
	L_Turn_cnt=0;
	}

Other regions	Fwd_cnt=0; Aft_cnt=0; R_Turn_cnt=0; L_Turn_cnt=0;

Where: sm, sn – the coordinates after transformation; Fwd_cnt – the times of gazing at the forward region; Aft_cnt – the times of gazing at the backward region; R_Turn_cnt – the times of gazing at the right region; L_Turn_cnt – the times of gazing at the left region; Right_X, Left_X, Up_Y, Down_Y – the coordinates of the nine command zones.

signals, the setting of the increment magnitude (from 1 to 10) of the control command will affect the movement of the wheelchair. If a too large increment value is set it makes difficult for the user to make fine adjustments to change direction. If the increment value is too small, even though we can make a fine adjustment, it will be waste of time to make a large angle rotation. After our practical operation test, we set the increment value to be 5 in spacious room, to allow the powered wheelchair move when smoothly followed by eye control. But we also use value 5 in school hallway, it

Table 2. Test result of the powered wheelchair with the eye-tracking device.

Item	Capacity
Maximum speed	9 km/h
Slope	10 degrees
Braking distance	Less than 1.5 m (at 9 km/h)
Across obstacle	Higher than 40 mm
Minimum radius of rotation	1 m

become quite difficult to control. To adjust the value to be 3, we can control powered wheelchair straightly move and make a right angle turning. Table 2 shows the test result of the powered wheelchair with the eye-tracking device.

5. Conclusions

Interfaces developed for powered wheelchair control, such as joystick control, head control and sip-puff control are not suitable for the people suffering from severe physical disabilities like amyotrophic lateral sclerosis (ALS), This paper proposes using the eye tracking system to control powered wheelchair.

The vision-controlled wheelchair is not easy to control. Both the ability to control eye movement and the suitability of position correction will affect the systematic control. However, research on maimed auxiliary instrument still has positive significance in providing the handicapped chance to acquire greater mobility.

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