Electric wheelchair control using head pose free eye-gaze tracker

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Presented is a wheelchair control using a head pose free eye-gaze estimation. The direction of the wheelchair is computed from a user's eye-gaze pointing. The eye-gaze estimation system includes a 3D orientation sensor to take into account the head pose. Therefore, the user can change his or her pose with comfort during navigation. In experiments, its performance was evaluated in comparison with a manual keyboard control.

Introduction: Intelligent wheelchairs have been being developed for a long time to support paralysed people with several disability levels. In many cases, the eye muscles of paralysed people are one of the few controllable muscles that still function well. Therefore, using the eye-gaze as an interface for paralysed or physically disabled people has been of interest [1]. Additionally, some applications to wheelchair control have also been attempted. Some cases implemented eye-gaze tracking using electrooculography, however they required the attachment of surface electrodes around the eyes [1, 2]. In some cases, optical eye-gaze tracking was studied [3–5]. They required a user to maintain the head in a static position. Therefore, further investigation on more practical and convenient approaches should be progressed. In this Letter we present the wheelchair navigation control with a simple eye-gaze tracker (EGT)-based interface.The user's head pose is taken into account to determine the direction of the wheelchair. Therefore, the user can take comfortable head poses during navigation instead of sticking to an erect pose. Even when the head pose is changed unintentionally or intentionally during navigation, the wheelchair is robustly controllable by the EGT.

System design: The overall system consists mainly of two parts: an electrical wheelchair and an EGT. The wheelchair was built by adding two DC motors to a commercial wheelchair. The motors rotate the left and right wheels, respectively, through chains, as shown in Fig. 1. A PWM motor-controller receives commands from a laptop computer to actuate the motors. A low-cost EGT was built by combining a glasses frame, an infrared camera with two LEDs on both sides and a 3D orientation sensor (MTx, Xsens, Inc.) attached to a side of the frame (see Fig. 1*b*).

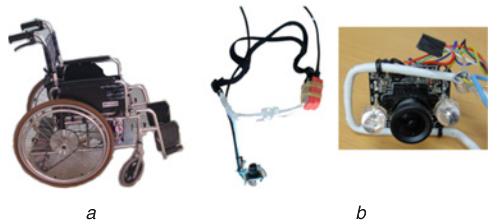


Fig. 1 *Wheelchair and EGT*

a Wheelchair
b EGT

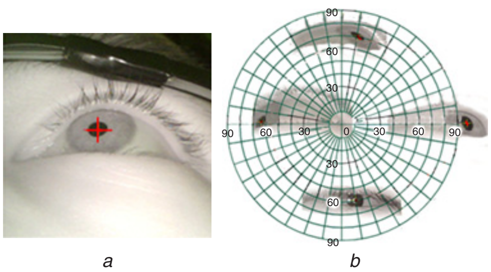


Fig. 2 *Pupil's centre detected by EGT, and examples of eye-gaze angles from EGT*

a Pupil's centre detected by EGT
b Examples of eye-gaze angles from EGT

Eye-gaze point estimation: Under infrared-light boosted by the LEDs, the pupil is clearly distinct from the white and the iris (Fig. 2*a*). An auto-adjust algorithm for time-varying illumination is applied [6]. Detection of the pupil's centre position from the infrared camera image enables the estimation of eye rotation angle. It is known that the human right eye can rotate to the left approximately up to 60°, to the right up to 90°, upward up to 46°, and downward up to 67°, respectively [7]. From a user, five eye-gaze points, leftmost, rightmost, uppermost, lowermost, and centre, are collected, on the camera image. Considering them, $(p_{x,i}, p_{y,i})$, $i = 1, 2, \ldots, 5$, the eye rotation angle (ψ, θ) of the eye with respect to the head is roughly estimated using the regression (Fig. 2*b*). The coefficients, w_i's, are regressively obtained from the data points using the following equations: $i = 1, 2, \ldots, 5$,

$$\psi = w_1 + w_2 p_{x,i} + w_3 p_{x,i}^2,$$
$$\theta = w_4 + w_5 p_{y,i} + w_6 p_{y,i}^2$$

Wheelchair control: The eye-gaze angle (ψ, θ) is described with respect to the head-co-ordinate $(O_h; X_h Y_h Z_h)$ attached to the eye as shown in Fig. 3*a*. A unit vector $\vec{e}_h$ is defined. The vector is towards a spot where a user glances with respect to $(O_h; X_h Y_h Z_h)$. Let $\vec{e}_h = [\mathrm{x}_h, \mathrm{y}_h, \mathrm{z}_h]^T$ with respect to $(O_h; X_h Y_h Z_h)$, then it can be expressed by (ψ, θ). Assuming the eye ball is spherical and the origin of $(O_h; X_h Y_h Z_h)$ is at its centre,

$$\mathrm{x}_h = \frac{\|\vec{e}_h\|}{A} = \frac{1}{A}, \mathrm{y}_h = \frac{\|\vec{e}_h\| tan\psi}{A} = \frac{tan\psi}{A},$$
$$\mathrm{z}_h = \frac{\|\vec{e}_h\| tan\theta}{A} = \frac{tan\theta}{A}$$

where $A = 1 + \tan^2\theta + \tan^2\psi$.

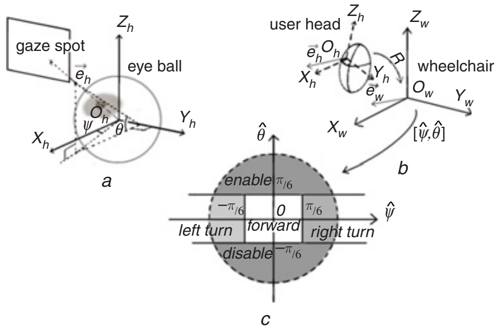


Fig. 3 *Eye-gaze angles, head-to-wheelchair transformation, and wheelchair control scheme*

a Eye-gaze angles
b Head-to-wheelchair transformation
c Wheelchair control scheme

Using the orientation sensor, the relative orientation of the head with respect to the co-ordinate $(O_w; X_w Y_w Z_w)$ fixed on the wheelchair is measured. From the measurement, the rotation matrix R is computed. The translation variation of the head position is negligible compared with the distance to a spot a user glances at. Thus, the positional description of $\vec{e}_w$ with respect to $(O_w; X_w Y_w Z_w)$ is, as shown in Fig. 3*b*, given by

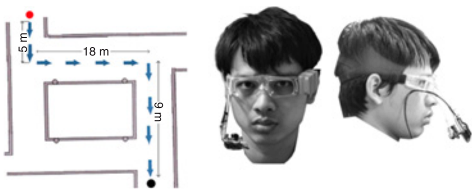
$$\vec{e}_w = \mathrm{R}\vec{e}_h$$

When $\vec{e}_w = [\mathrm{x}_w, \mathrm{y}_w, \mathrm{z}_w]^T$, a virtual eye-gaze angle $(\hat{\psi}, \hat{\theta})$ is declared to be

$$\hat{\psi} = arctan\left(\frac{\mathrm{y}_w}{\mathrm{x}_w}\right), \hat{\theta} = arctan\left(\frac{\mathrm{z}_w}{\mathrm{x}_w}\right)$$

Wheelchair control is determined by a rule on $(\hat{\psi}, \hat{\theta})$ as described in Fig. 3*c*. As long as the value is within the middle band, the wheelchair moves forward. If it stays on the side, the wheelchair makes a turn accordingly. The wheelchair continues to turn until the value returns into the middle. Therefore, the users can turn the wheelchair to any angles they desire. The wheelchair can be enabled and disabled temporarily by moving the gaze upward and downward, respectively. Adequate boundary values are empirically chosen. The eye-gaze positioning strategy aims to provide comfort to users. Rather than accurate gaze pointing, relative gaze change is effective to choose the desired movement of the wheelchair.

Experiments: To evaluate the system, experiments were held on eight healthy participants. Each subject was asked to navigate the wheelchair along a certain pathway using the EGT and the keyboard as well. Each task was repeated five times.The selected pathway was 32 m away from start to end and included left and right turns along the corridor of an indoor environment as shown in Fig. 4*a*. For each subject, the EGT regression was carried out and 15 minutes were provided for training before conducting experiments. During experiments, each subject controlled the wheelchair through the EGT and the keyboard repeatedly, to avoid a biased performance. Each subject wore the EGT equipped frame as shown in Fig. 4*b*. Each subject was allowed to change head pose if he or she desired during the EGT-based navigation. However, any other parts of the body had to be kept still. The aim here was to check whether controllability was improved by integrating the orientation sensor. The forward and turning speeds of the wheelchair were empirically set to be 0.6m/s and 0.1 rad/s, considering safety and adequate run. All trials were successfully fulfilled with neither deviation nor collision. Fig. 5 shows some snapshots during experiments. The subject took different head poses while navigating. However, the system worked normally.



a *b*

Fig. 4 *Pathway for experiments; subject equipped with EGT*

a Pathway for experiments
b Subject equipped with EGT

Fig. 5 *Snapshots from experiments*

Table 1 summarises the averaged times taken to travel the pathway in experiments. There are variations between users, probably depending on their abilities to adapt. The time ratios between the two control schemes are also shown.The ratios are at least over 0.8. which implies that the EGT-based control is only at most 20% longer than the manual keyboard control. For the best case in EGT performance, the ratio is 0.93. The two performances are comparable considering that the EGT control is adequate for physically disabled people. The averaged speed of the wheelchair was roughly in the range of 0.4–0.5 m/s.

Table 1: Averaged times taken per subject during navigation through EGT and the keyboard control and their ratios (EGT/keyboard)

Subject	1	2	3	4	5	6	7	8
EGT	63.6	70.4	77.8	82.6	87.4	78.4	68.4	74.4
Keyboard	59	61.6	63.8	68	71.8	63.8	58.2	64.2
Ratio	0.93	0.88	0.82	0.82	0.82	0.81	0.85	0.86

Conclusions: This Letter proposes the control of a wheelchair through an EGT with a 3D orientation sensor. The simple interface device provides comfortable control of wheelchair navigation. Furthermore, the detection of head pose change enables a robust and comfortable control. In comparison with the conventional keyboard control, EGT-based performance was a bit slower, but by less than a factor of 0.2. The experimental results demonstrate the potential of the system as a mobility aid for paralysed or physically disabled people.

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One or more of the Figures in this Letter are available in colour online.

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