Journal of Signal Processing, Vol.24, No.4, pp.199-202, July 2020

SELECTED PAPER AT NCSP'20

Human-Friendly Safe Driving Support System of Electric Wheelchair for Drift Suppression

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Abstract

This paper describes a safe driving support system that reduces drift in the downhill direction when an electric wheelchair crosses a slope. To solve this drift problem, we propose a safe driving support system that controls a wheelchair based on the slip condition of drift, which is calculated from the roll angle, yaw angle, and wheelchair speed. Experimental results obtained using the developed electric wheelchair verify the usefulness of the proposed system.

1. Introduction

At present, the proportion of people over 60 in Japan is about 27.7% [1], and the number of disabled people unable to use their legs has been increasing. Electric wheelchairs are attracting attention as a means of transportation for such people, with sales of about 20,000 units every year [2]. 180 to 200 accidents involving electric wheelchair occur every year in Japan [3]. The main causes of accidents are incorrect operation, difficult road conditions, and poor maintenance. Matsuo et al. focused on incorrect operation and proposed a safe driving support system that avoids obstacles even if an incorrect operation is performed [4]. In this study, we focus on the unintended motion of a wheelchair caused by slope. A joystick-type electric wheelchair can be easily rotated on a slope against the driver's intention because the front wheels are free casters, different from the handle-type mobility scooter [5]. Therefore, there is a strong need for the research and development driving support system of an electric wheelchair for safe of a driving on a slope.

In this paper, we focus on drift, which is one of the causes of accidents on a slope, and propose a safe driving support system that reduces drift. To propose a safe driving support system, some experiments are performed to express the magnitude of drift by a mathematical formula using the motion state of the wheelchair: the roll angle, yaw angle, and speed command value. These motion states are measured by an acceleration gyro sensor mounted on the drive wheel. In the proposed safe driving support system, either wheel is decelerated when drift is detected. The usefulness of the proposed system is investigated experimentally using the developed electric wheelchair on a slope.

2. Developed Electric Wheelchair

Figure 1 shows the developed electric wheelchair. It is 0.82 m long, 0.62 m wide and 1.1 m high. To recognize the motion state of the electric wheelchair, the acceleration gyro sensors are mounted above the left and right rear wheels, and a laser range finder (LRF) is mounted on the front of the vehicle, as shown in Fig. 1. Also, a joystick is mounted to operate the wheelchair. The two wheels are independently driven by brushless DC servo motors (300 W, 24 V) to achieve the desired running speed and steering angle.

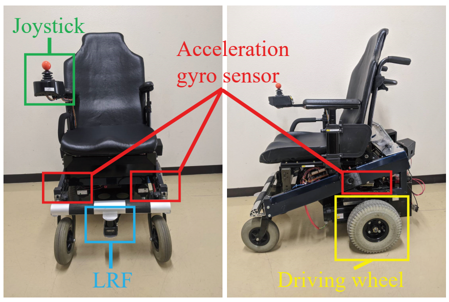


Figure 1: Developed electric wheelchair

Figure 2 shows the hardware configuration of the developed electric wheelchair. The main computer (Tinker board) generates a speed command value by considering the operation input by the joystick, the obstacle information provided by the LRF, and the motion state measured by the acceleration gyro sensor. The speed command value is given to the motor drivers through the interface board (SH7125). The motor drivers output three-phase AC and drive the motors. The mechanical angle θ of the motor is measured by the resolver and transmitted as a digital signal to the left and right microcomputers (SH7125) through an R/D converter. The motors are controlled by speed commands from the main computer using PI control. Here, the maximum speed of the electric wheelchair is limited to 1.06 m/s, which is lower than the walking speed of a human.

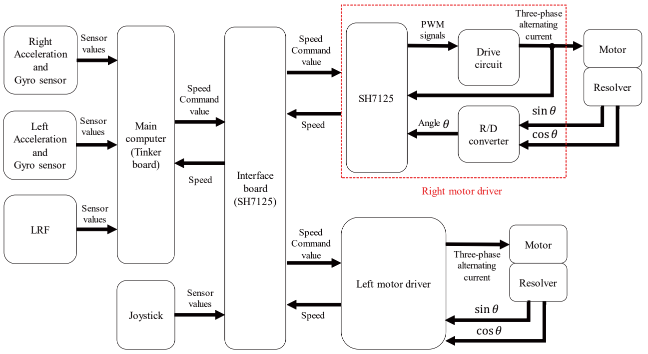


Figure 2: Hardware configuration of the electric wheelchair

3. Proposed Safe Driving Support System

A safe driving support system is proposed to reduce the drift of the electric wheelchair. This system controls the wheel speed on the basis of the slip condition of drift detected using the acceleration and gyro sensors. A six-axis motion sensor (MPU6050) measures three accelerations (a_x, a_y, and a_z) and three angular velocities (ω_x, ω_y, and ω_z) as shown in Fig. 3. To reduce the noise, the values measured by the left and right motion sensors are averaged and used for slip detection.

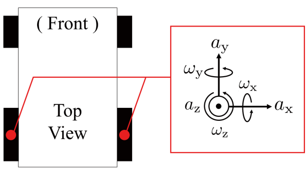


Figure 3: Axes of the sensor coordinate

3.1 Angle of electric wheelchair

The yaw angle θ_z and roll angle θ_x of the vehicle are defined as shown in Fig. 4. To detect a direction change due to slip caused by drift, the yaw angle of the electric wheelchair, θ_z, is calculated as:

$$\theta_z = \sum_{i=1}^{n} \omega_z^i \cdot \Delta t \tag{1}$$

where n is the number of measurements, ω_z^i is the angular velocity in the z direction at the ith sampling, and Δt is the sampling period (50 ms). This calculation is performed only when the wheelchair is moving. To detect body tilt, the roll angle of the electric wheelchair, θ_x, is calculated as:

$$\theta_x = \sin^{-1}\left(\frac{-a_x \cdot \cos\theta_z}{g}\right) \tag{2}$$

where g is the gravitational acceleration ($9.8\ \mathrm{m/s^2}$).

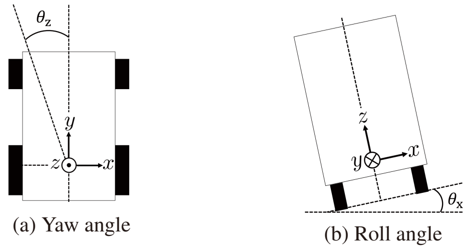


Figure 4: Roll and yaw angles of the wheelchair

3.2 Index of drift suppression

To detect drift, an index of drift suppression, α, is introduced. α is assumed to be a function of v, θ_x and θ_z, and is expressed as

$$\alpha = (\beta v + \gamma|\theta_x| + \delta)\,|\theta_z| = A\,|\theta_z| \tag{3}$$

where β, γ and δ are constant parameters, v is the wheelchair moving speed, and A is a variable coefficient of drift that depends on v and θ_x. These parameters are estimated from experiments by trial and error. Then, α is limited to $0 \leq \alpha \leq 1$.

3.3 Speed command

The proposed safe driving support system suppresses drift by reducing the wheel speed on the upside. By dividing the cases according to the inclination θ_x and slip angle θ_z, the speed command of each motor is decided as follows:

- In the case of $(\theta_x > 0^\circ \wedge \theta_z < 0^\circ)$

$$\begin{cases} N_{\mathrm{refR}} = Y \\ N_{\mathrm{refL}} = (1-\alpha)\,Y \end{cases} \tag{4}$$

- In the case of $(\theta_x < 0^\circ \wedge \theta_z > 0^\circ)$

$$\begin{cases} N_{\mathrm{refR}} = (1-\alpha)\,Y \\ N_{\mathrm{refL}} = Y \end{cases} \tag{5}$$

where N_{refL} and N_{refR} are the speed commands for the left and right drive wheels, respectively, and Y is the preset speed command decided by the joystick input.

4. Experiments

4.1 Experimental environment and conditions

Experiments were carried out on three slopes with tilt angles of 10°, 6°, and 2° as shown in Fig. 5. In each environment, experiments were conducted at a preset speed for a constant time of $Y = 1.06$ m/s for 2.83 s, 0.80 m/s for 3.77 s, and 0.53 m/s for 5.66 s, all of which correspond to a distance of 3.0 m because the shortest slope (that in Fig. 5(a)) is 3.6 m long.

(a) Slope of 10 ° (b) Slope of 6 ° (c) Slope of 2 °

Figure 5: Test environments used in experiments

4.2 Decision of coefficient of drift

To determine the appropriate coefficient A of Eq. (3) for the drift, some experiments are performed on the three slopes with different fixed coefficient A values. Figure 6 shows the transition of the yaw angle θ_z at a speed of 0.53 m/s on the slope of 10 ° with $A = 0.02$, 0.03, and 0.04. From Fig. 6, the amount of overshoot and the steady-state value are different on the setting of A. Here, steady-state value was defined as the value at a distance of 3.0 m ahead. Table 1 shows the amount of overshoot and the steady-state value of the yaw angle θ_z for all values of A. From these results, overshoot occurs when $A \geq 0.03$, and the steady-state value becomes minimum when $A = 0.03$. Therefore, the appropriate value of A for the 10 ° slope was determined as 0.03. In the same way, the value of A was determined for each experimental condition as shown in Table 2.

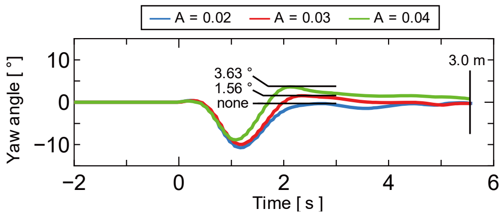


Figure 6: Yaw angle when A is fixed (10° - 0.53 m/s)

Table 1: Amount of overshoot and steady-state value

condition	A	amount of overshoot	steady-state value
10 ° 0.53 m/s	0.01	none	−0.76 °
	0.02	none	−0.28 °
	0.03	1.56 °	−0.30 °
	0.04	3.63 °	0.79 °
	0.05	6.09 °	0.91 °
	0.06	6.94 °	2.49 °
	0.07	8.01 °	4.36 °
	0.08	7.85 °	5.91 °
	0.09	9.39 °	6.04 °
	0.10	12.30 °	7.67 °

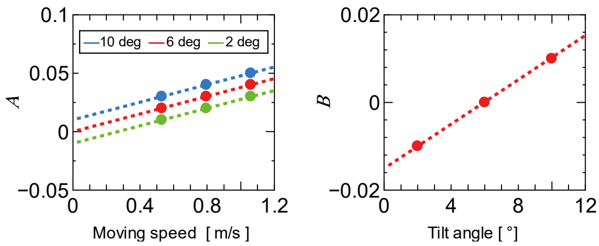
The coefficients β, γ, and δ are obtained by polynomial approximation with variables v and θ_x. Figure 7(a) shows the relationship between v and A. The approximation formula is calculated as

$$A = (3.77 \times 10^{-2})\, v + B \tag{6}$$

where B is constant depending on the tilt angle θ_x. Figure

Table 2: Appropriate coefficient A values at various tilt angles and speeds

tilt angle	moving speed	A
10 °	1.06 m/s	0.05
	0.80 m/s	0.04
	0.53 m/s	0.03
6 °	1.06 m/s	0.04
	0.80 m/s	0.03
	0.53 m/s	0.02
2 °	1.06 m/s	0.03
	0.80 m/s	0.02
	0.53 m/s	0.01



(a) Relationship between v and A (b) Relationship between θ_x and B

Figure 7: α, β, γ, and δ results

7(b) shows the relationship between θ_x and B, which is calculated as

$$B = (0.25|\theta_x| - 1.5) \times 10^{-2} \tag{7}$$

Combining Eqs. (6) and (7), the coefficients in Eq. (3) are determined as $\beta = 3.77 \times 10^{-2}$, $\gamma = 0.25 \times 10^{-2}$, and $\delta = -1.5 \times 10^{-2}$. Therefore, the index value α was determined as

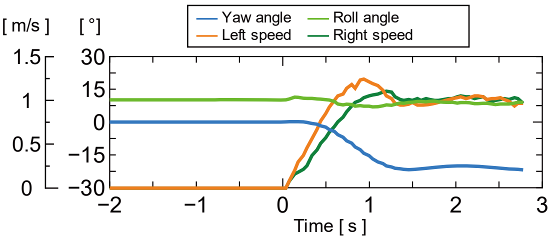
$$\alpha = (3.77v + 0.25|\theta_x| - 1.5)\, |\theta_z| \times 10^{-2} \tag{8}$$

4.3 Drift suppression

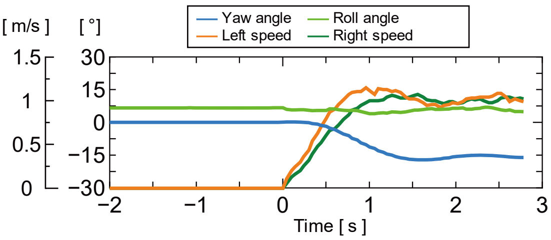
To confirm the usefulness of the proposed system, some experiments were conducted using the index α described in section 4.2 and the results were compared with experimental results obtained without the system.

Figures 8 and 9 show the experimental results obtained when running on the slopes of 10° and 6° at 1.06 m/s and 0.53 m/s without and with the system, respectively. In Figs. 8 and 9, the roll angle θ_x [°] and yaw angle θ_z [°], and left and right speeds [m/s] are shown. In Fig. 9, α is also shown.

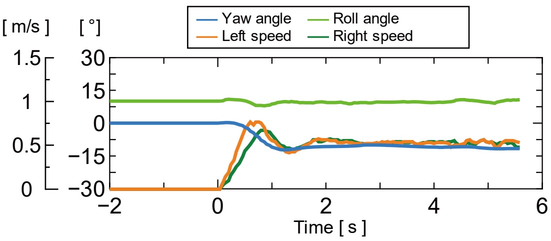
As shown in Figs. 8(a) and 8(b), immediately after the operation started, the speed of the left wheel was faster than that of the right wheel, indicating that drift occurred. After the drift occurred, the yaw angle θ_z ranged from $-5°$ to $-20°$ according to the roll angle θ_x and speed command v. It was confirmed from Fig. 8 that the change in the yaw angle θ_z due to drift has a linear relationship with both the tilt angle θ_x and the speed command v. The results also show that the assumption of Eq. (3) and the determination of the coefficients are correct. As shown in Figs. 9(a) and 9(b), the index α increased and the speed of the left wheel decreased after the



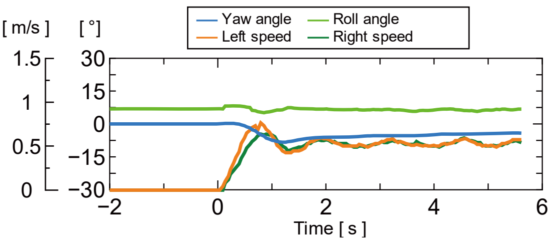
(a) 10 ° - 1.06 m/s



(b) 6 ° - 1.06 m/s

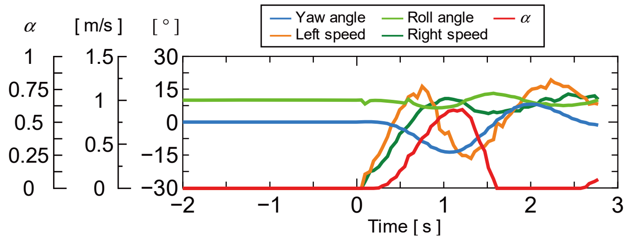


(c) 10 ° - 0.53 m/s

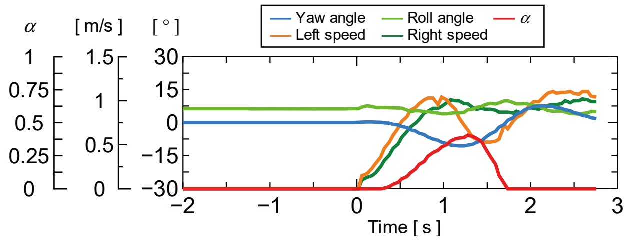


(d) 6 ° - 0.53 m/s

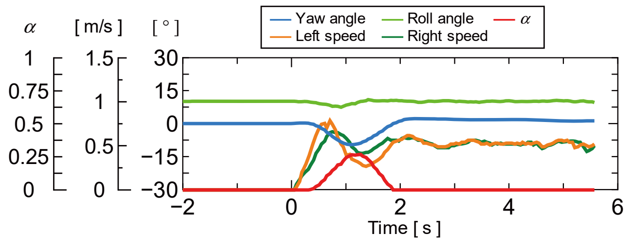
Figure 8: Experimental results without system



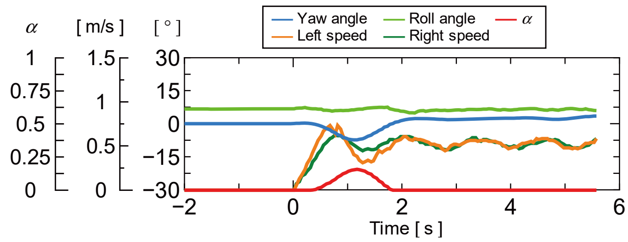
(a) 10 ° - 1.06 m/s



(b) 6 ° - 1.06 m/s



(c) 10 ° - 0.53 m/s



(d) 6 ° - 0.53 m/s

Figure 9: Experimental results with system

drift. As a result, the yaw angle θ_z of the vehicle tended to increase and was controlled to $\theta_z \approx 0$ for all results. Moreover, because the right wheel was lower than the left wheel, the wheelchair may cross the slope. Therefore, we confirmed that the proposed system can reduce drift.

5. Conclusions

In this paper, we proposed a safe driving support system to reduce drift that is based on the roll and yaw angles of the body and the speed command value of the wheelchair. From the experimental results, the proposed system can detect the occurrence of drift and reduce it.

A future task is to develop a system that considers the driver's weight to further reduce drift.

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