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Safe Driving Support System for Electric Wheelchair Based on Time to Collision and Degree of Danger

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Abstract

This paper describes a safe driving support system of an electric wheelchair expected to be used by elderly people. However, accidents involving electric wheelchairs tend to occur when they are incorrectly operated. Improving safety and utility is a very important problem. To solve the problem, we propose a new safe driving support system, which controls a wheelchair semi autonomously based on the degree of danger. The degree of danger is calculated by fuzzy reasoning from both the manually controlled input from a joystick and the time to collision. Experimental results using our developed electric wheelchair demonstrate the high control performance of the proposed system.

1. Introduction

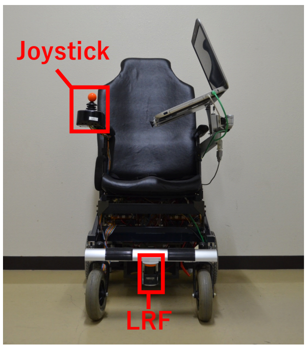
With the aging of Japan's population, electric wheelchairs are an increasingly common means of mobility for elderly people, with about 20000 units sold per year. However, accidents involving electric wheelchairs are frequent, and about 180 to 200 accidents occur per year in Japan. The main causes of accidents include incorrect operation, poor maintenance, and running poor road surfaces, with incorrect operation being the most frequent cause, accounting for 25% of the accidents. Indeed, most collisions with obstacles and pedestrians are caused by incorrect operation [1]. Therefore, the research and development of a safe driving support system for electric wheelchairs is strongly required.

In this paper, we propose a new safe driving support system controlled by considering both the operator's manually controlled input and the degree of danger of a collision, which is estimated by fuzzy reasoning. As related research, Nakatani proposed a safe driving support system using the degree of danger of collision[2]. However, this research focused on only steering control to avoid collision, and the degree of danger of collision was estimated by considering the static condition of obstacles and the electric wheelchair. Thus, the speed control performance was insufficient to ensure safety in a real environment.

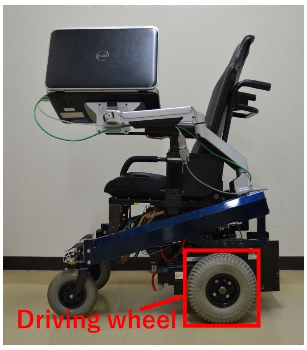
In current study, we propose system uses both time to collision as an index and the operator's control input to estimating the degree of danger of collision. This is expected to contribute to increasing the speed and the semi autonomous steering control of electric wheelchair. The time to collision is defined using the speed reference of the electric wheelchair and the distance between the electric wheelchair and obstacles. The usefulness of the proposed system is investigated on the basis of several experimental results obtained using our developed electric wheelchair.

2. Developed Electric Wheelchair

Figures 1(a) and 1(b) show the appearance of the developed electric wheelchair. The overall length 0.82 m, the width is 0.62 m, and the height is 1.1 m. To recognize environmental situations surrounding the electric wheelchair, a laser range finder (LRF) is mounted on the front of the wheelchair as shown in Fig.1(a).



(a) Front view



(b) Side view

Figure 1: Appearance of developed electric wheelchair

Figure 2 shows the hardware configuration of the developed electric wheelchair. The speed and steering angle references of the electric wheelchair are determined by manipulating a joystick. Then the two wheels are independently driven by brushless DC servo motors (300 W, 24 V) to realize arbitrary traveling speeds and steering angles. The motor driver outputs a three-phase alternating current depending on PWM signals and drives each motor. The rotation angle θ of the motor is measured by a resolver and is sent to a micro computer (SH7125) as a digital signal through an R/D converter. Each motor is controlled to track the speed command value from the micro computer. Here, the maximum speed of the electric wheelchair is limited to 1 m/s because the maximum speed has been recommended to be slower than the speed of human walking. Distance data from the LRF is sent to a laptop PC via TCP/IP communication. In the PC, the degree of danger of collision is calculated and sent to the micro computer. Finally, the micro computer calculates the speed command of each motor based on the degree of danger of collision and the operator's control input from the joystick, and then controls each motor.

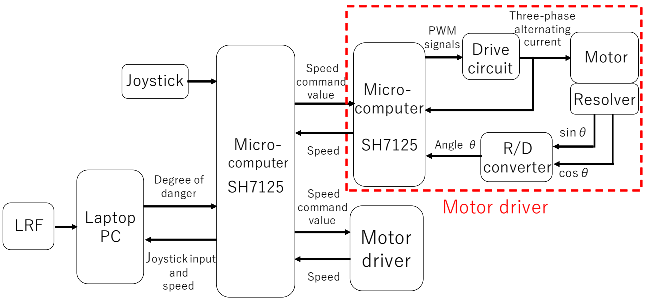


Figure 2: Hardware configuration of electric wheelchair

3. Proposed Safe Driving Support System

To realize a semi autonomous control system for the electric wheelchair, we propose a new safe driving support system as shown in Fig.3. This system controls the electric wheelchair based on the degree of danger of collision estimated by simplified fuzzy reasoning. In particular, in order to improve safety against obstacles, the time to collision is calculated using the speed reference v_{ref} instead of directly using the sensor data from the LRF. The degree of danger of collision is calculated from the time to collision and the steering angle reference θ_{ref}. Here, the speed reference v_{ref} and steering angle reference θ_{ref} are calculated from the joystick inputs $JoyX$, $JoyY$ as follows:

$$v_{ref} = \sqrt{JoyX^2 + JoyY^2} \tag{1}$$

$$\theta_{ref} = \tan^{-1} \frac{JoyY}{JoyX} \tag{2}$$

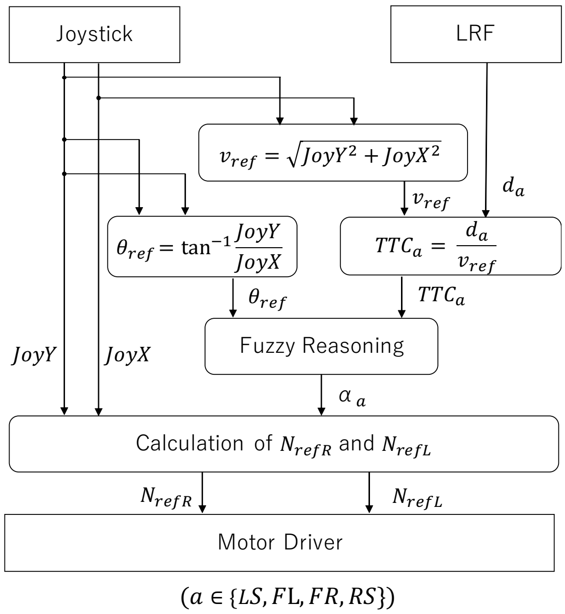


Figure 3: Safe driving support system

3.1 Index of time to collision

The time to collision index TTC_a is calculated by using the distance d_a between the electric wheelchair and the nearest obstacle in each area shown in Fig.4 and the speed reference v_{ref} as follows.

$$TTC_a = \frac{d_a}{v_{ref}} \quad (a \in \{LS, FL, FR, RS\}) \tag{3}$$

Here, a represents the LRF scanning area divided into four areas (LS (left side), FL (front left), RF (front right), and RS (right side)) as shown in Fig.4. If there are not obstacles in each area, d_a is set to 10 m, which is the maximum measurement distance of the LRF.

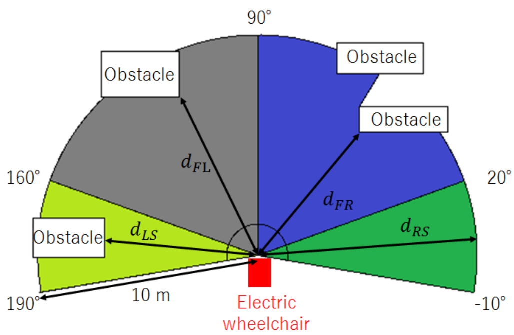


Figure 4: Definition of scanning area of LRF

3.2 Degree of danger of collision

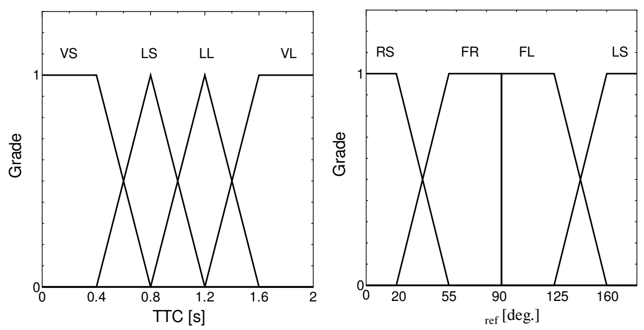
The degree of danger of collision in each area α_a is calculated by simplified fuzzy reasoning using the steering angle reference θ_{ref} and the calculated time to collision index TCC_a as inputs. The procedure of the simplified fuzzy reasoning in the system is briefly described as follows. First, input variables TCC_a and θ_{ref} are converted into suitable linguistic variables which may be regarded as labels of fuzzy sets. In this paper, the following linguistic variables for each input variable are used: VS(very short), LS(little short), LL(little long), and VL(very long) for TCC_a, LS (left side), FL (front left), FR (front right), and RS (right side) for θ_{ref}. Fuzzy sets are defined by assigning the grade of the membership functions shown in Figs.5(a) and 5(b). Here, the boundary of VS is set to 0.4 s, which is the time required to safely stop an electric wheelchair running at 1 m/s. Because the minimum reaction time of elderly people is about 1.2 s [2], the boundary of VL is set to 1.6 s. The boundaries of VS and LS are set to be equally spaced. In addition, the boundaries of FL and FR are set depending on LRF scanning area in Fig.4 and the boundaries of RS and LS set to be equally spaced. For each input variable, two fuzzy sets are selected, and the grade for the selected fuzzy rules is given by

$$\mu_a^{(ij)} = \mu_a^{(i)} \cdot \mu_a^{(j)} \quad (a \in \{LS, FL, FR, RS\}) \tag{4}$$

where $\mu_a^{(i)}$ and $\mu_a^{(j)}$ correspond to the grade for each input variable obtained from Figs.5(a) and 5(b) respectively. Finally, as a result of these process, the output of the simplified fuzzy reasoning, which is the danger of degree of collision α_a for each area, is obtained as

$$\alpha_a = \frac{\sum \mu_a^{(ij)} W_a^{(ij)}}{\sum \mu_a^{(ij)}} \quad (a \in \{LS, FL, FR, RS\}) \tag{5}$$

where $W_a^{(ij)}$ are the obtained parameters of the fuzzy rules listed in Tables 1-4.



(a) TCC_a (b) θ_{ref}

Figure 5: Membership functions

Table 1: $W_{RF}^{(ij)}$

		TTC			
		VS	LS	LL	VL
θ_{ref}	RS	1.0	0.5	0.2	0.0
	FR	1.0	0.8	0.4	0.0
	FL	1.0	0.2	0.0	0.0
	SL	1.0	0.0	0.0	0.0

Table 2: $W_{LF}^{(ij)}$

		TTC			
		VS	LS	LL	VL
θ_{ref}	RS	1.0	0.0	0.0	0.0
	FR	1.0	0.2	0.0	0.0
	FL	1.0	0.8	0.4	0.0
	LS	1.0	0.5	0.2	0.0

Table 3: $W_{RS}^{(ij)}$

		TTC			
		VS	LS	LL	VL
θ_{ref}	RS	1.0	0.8	0.4	0.0
	FR	1.0	0.2	0.1	0.0
	FL	1.0	0.0	0.0	0.0
	LS	1.0	0.0	0.0	0.0

Table 4: $W_{LS}^{(ij)}$

		TTC			
		VS	LS	LL	VL
θ_{ref}	RS	1.0	0.0	0.0	0.0
	FR	1.0	0.0	0.0	0.0
	FL	1.0	0.2	0.1	0.0
	LS	1.0	0.8	0.4	0.0

3.3 Speed command

The speed command for each brushless DC servo motor is decided by using the joystick inputs $JoyX$, $JoyY$ and the degree of danger of collision α_a as follows:

- In the case of $JoyX > 0$ and $JoyY > 0$,

$$N_{refR} = (1 - \alpha_{LF})JoyY - (1 - \alpha_{RS})JoyX \tag{6}$$

$$N_{refL} = (1 - \alpha_{RF})JoyY + (1 - \alpha_{RS})JoyX \tag{7}$$

- In the case of $JoyX \leq 0$ and $JoyY > 0$,

$$N_{refR} = (1 - \alpha_{LF})JoyY - (1 - \alpha_{LS})JoyX \tag{8}$$

$$N_{refL} = (1 - \alpha_{RF})JoyY + (1 - \alpha_{LS})JoyX \tag{9}$$

- In the case of $JoyY \leq 0$,

$$N_{refR} = JoyY - JoyX \tag{10}$$

$$N_{refL} = JoyY + JoyX \tag{11}$$

where N_{refR},and N_{refL} are the speed commands for the right and left driving wheels respectively. Thus, the proposed safe driving support system can only avoid obstacles located in front of the electric wheelchair. Therefore, in the case of $JoyY \leq 0$, the speed command is not changed with changes in the degree of danger of collision.

4. Experimental Results

In order to verify that the proposed safe driving support system for the electric wheelchair can avoid obstacles and maintain safe conditions anytime, experiments using the developed electric wheelchair were conducted. In the experiments, we prepared a test environment with some static obstacles as shown in Fig.6, where the static obstacles were arranged as shown in Fig.7(a).

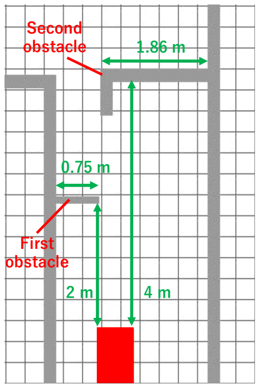
Figure 7 (b) illustrates the locus of the electric wheelchair every 0.5 s. Here, in order to confirm the safe performance against incorrect operation by the operator, the speed reference v_{ref} and steering angle reference θ_{ref} are intentionally fixed to v_{ref}= 1 m/s and θ_{ref}= 90 °, respectively. Therefore, if the safe driving support system is not installed, the electric wheelchair will collide with obstacles because the obstacles are located on a straight path. However, as shown in Fig. 7(b), the electric wheelchair can move forward while avoiding obstacles successfully.

Figures 8(a) and 8(b) respectively show the transitions of the driving wheel speed and the degree of danger of collision in each section. In section (A), the degree of danger α_{FL} increases as the wheelchair approaches the first obstacle because the first obstacle is located in the front left area at around 2 s. Then, due to the increasing α_{FL}, the right wheel decelerates at around 2 s so that the electric wheelchair turns right to avoid the first obstacle. After avoiding the first obstacle, the speed of the right wheel increases from around 3 s in section (B). Next, the electric wheelchair detects the wall to the front right and α_{FR} increases in section (B). Owing to the increasing in α_{FR}, the wall is avoided by reducing the speed of the left wheel. After avoiding the wall, the electric wheelchair goes straight and detects the second obstacle in the front area. α_{FL} and α_{FR} increase in section (C). When α_{FL} and α_{FR} reach a maximum value of 100, the electric wheelchair stops to avoid collision.

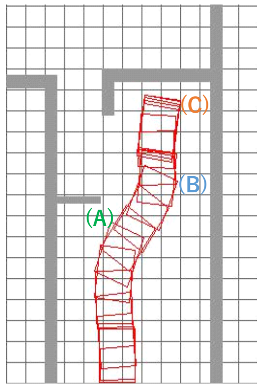
Figure 6: Test environment used in experiment

5. Conclusion

In this paper, we proposed a safe driving support system using simplified fuzzy reasoning with the operator's input from the joystick and the degree of danger of collision calculated by the time to collision index. Experimental results demonstrated that the proposed system can ensure safety in the case

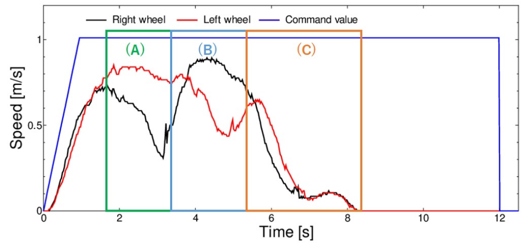


(a) Map

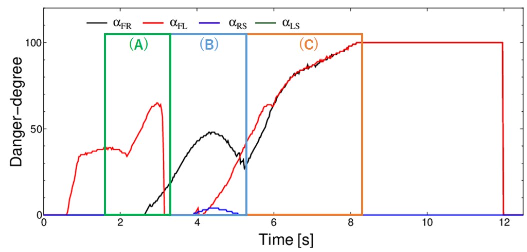


(b) Locus

Figure 7: Traveling map and locus of electric wheelchair



(a) Wheel speed



(b) Collision danger-degree

Figure 8: Transition of wheel speeds and degree of danger

of incorrect operation by the operator.

A future task is to evaluate the degree of danger of collision of side areas in various environments.

References

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