The Effect of a Semi-Active Driving Assistance System on the Driver of a Four-Wheeled Personal Mobility Vehicle

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***Abstract*—Personal Mobility Vehicles (PMVs) have been recently attracted considerable interest as next-generation vehicles for individual use. However, when a PMV is allowed to be used in pedestrian areas, it should be friendly to its driver and surrounding pedestrians. In this paper, we proposed a semi-active driving assistance system for a four-wheeled PMV that detects the personal space of nearby pedestrians, informs the driver about the vehicle's invasion of pedestrian's personal space, and cooperates with the driver in avoiding pedestrians. To evaluate the effectiveness of the proposed assistance system, an experiment was conducted under the condition that the PMV encountered pedestrians and steering angle gain changed, and questionnaires of drivers' feeling were used as an evaluation index. The experimental results showed that the effectiveness of the proposed system has been confirmed, the drivers felt more comfortable when driving PMV with the assistance system.**

***Index Terms*—assistance system, four-wheeled vehicle, pedestrian, personal space, steering gain**

I. Introduction

In the context of the energy crisis and environmental pollution, Personal Mobility Vehicles (PMVs), which are suitable for individual use, have attracted significant attention as alternatives for personal transportation. Such vehicles are expected to be friendly to human and the environment, compact and convenient for personal short-distance trips in urban spaces, such as pedestrian streets, and shopping malls [1]–[2]. Moreover, a PMV can be used as an alternative transporter for people with disabilities [3]. Consequently, many types of two-wheeled PMVs have been recently proposed, such as Segway [4] and Winglet [5]. However, injuries related to operating the PMV have been arisen [6]. It is thus necessary to ensure the safety and comfort of drivers and surrounding pedestrians when PMVs are allowed to be used in pedestrian flows. There has been considerable interest in the psychological effects of PMVs on surrounding pedestrians when PMVs move in pedestrian areas. Jeong *et al*. evaluated users' feelings when driving a self-balancing PMV with a pedal driving mechanism [7]. Butler et al. examined the interactions between people and mobile personal robots by focusing on the psychological effects of robot behavior patterns during task performance [8]. Murakami et al. proposed an intelligent wheelchair that can avoid collisions with pedestrians [9]. In previous studies, we evaluated Personal Space (PS) of pedestrians encountering PMVs [10] and investigated the effects of a PMV on multiple pedestrians using personal space [11]. Furthermore, feelings of pedestrians and the driver of a two-wheeled PMV was analyzed [12].

Alternatively, four-wheeled PMVs like Scooter Q3-Chariot [13], which can keep its balance better, have been recently introduced as safer PMVs. However, such vehicles have large sizes and use mechanical steering systems, they are thus inconvenient to use in pedestrian areas. Therefore, this study proposes a compact four-wheeled PMV equipped with an electric driving system and develops a semi-active driving assistance system considering psychological factors in order to enhance the safety and comfort for drivers and nearby pedestrians in the presence of PMVs.

The remaining of this paper is organized as follows. Section 2 outlines the development of a four-wheeled PMV equipped with a semi-active driving assistance system using the concept of personal space. Section 3 describes experiments on the measurement of avoidance difficulty levels of PMV drivers. Experimental results are presented and discussed in Section 4. Finally, Section 5 provides conclusions and future work.

II. Personal Mobility Vehicle with a Semi-Active Driving Assistance System

In this study, we developed a four-wheeled PMV equipped with a semi-active driving assistance system. The proposed assistance system was derived from the concept of Personal Space (PS), which is the space surrounding a pedestrian in which invasion by others induces a psychological strain. Most people may assess their PS and feel uncomfortable or fearful when their PS

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is encroached on [14]. Front and side PSs are frontal and lateral distances between two heads when one starts avoiding the other [15], as shown in Fig. 1.

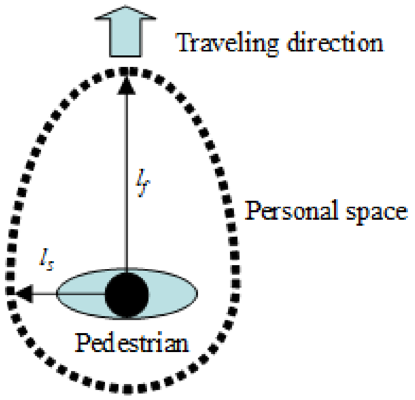


Figure 1. Personal space of a pedestrian.

Our previous study [16] determined the PSs of a four-wheeled PMV and of a pedestrian encountering the PMV, which were used as input parameters for the proposed assistance system.

TABLE I. PSS OF THE PMV AND A PEDESTRIAN

Parameters	Pedestrian	PMV
Front PS (m)	4.8	4.4
Side PS (m)	0.82	0.75

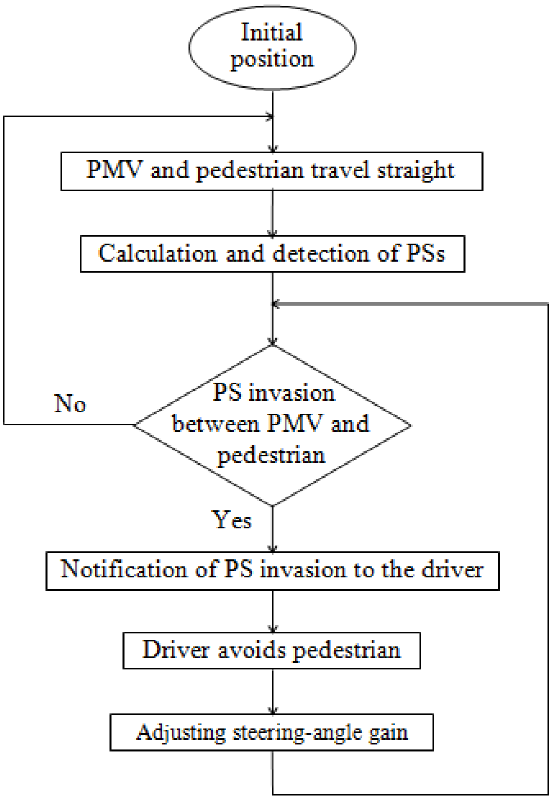


Figure 2. Flowchart of the behavior of a PMV with the semi-active assistance system

Fig. 2 is the flowchart of the behavior of the PMV equipped with the assistance system. Initially, the PMV and a pedestrian travel in straight lines from their initial positions, and once the PMV enters the PS of the pedestrian, the assistance system will notify the PMV driver about the invasion using a micro-vibration motor and a light-emitting diode (LED), the driver himself avoids the pedestrian. Moreover, during the process of avoidance, the proposed assistance system will cooperate with the driver in avoiding the pedestrian.

As shown in Fig. 3, the proposed PMV is driven by two rear wheels 5 using two electric motors, and the front wheels 4 were equipped with Omni wheels, which are able to roll freely in two directions. The Omni wheel can roll like a normal wheel or roll laterally using the wheels along its circumference. Moreover, the vehicle can move forward and backward via acting operation mode switch 13, turn via turning handlebar 8, and change the speed via adjusting speed control switch 12. The vehicle is controlled by an electronic controller 1.

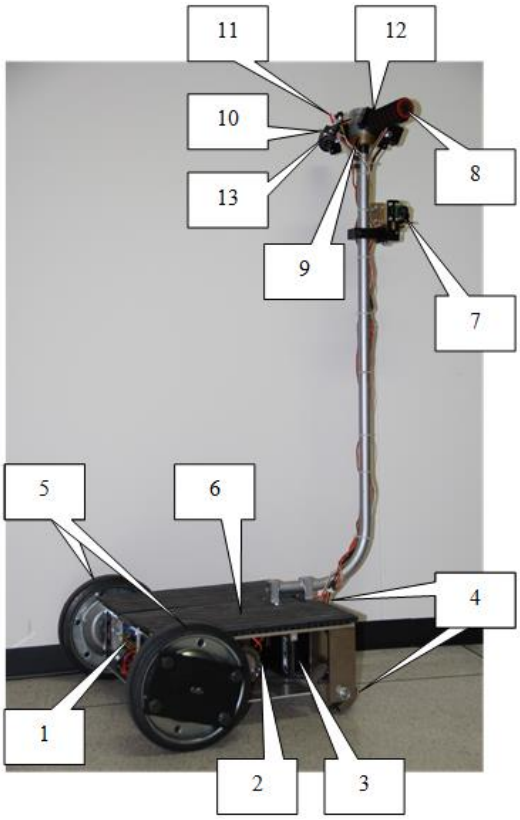


Figure 3. PMV with the assistance system: 1. Controller; 2. Motor; 3. Battery; 4. Front wheel (Omni wheel); 5. Rear wheel; 6. Platform; 7. Range sensors; 8. Handlebar;9. Steering angle sensor; 10. Vibration motor; 11. LED; 12. Speed control switch; 13. Operation mode switch.

Figure 4. Picture of an ultrasonic sensor for the experiment

The controller for the PMV is based on the LPC 1768 microcontroller covering a 32-bit, 96-MHz ARM Cortex M3 processor, 512 KB of flash memory, 32 KB of user accessible random access memory, and a variety of input/output interfaces. Moreover, in order to determine the personal space of pedestrians, three ultrasonic sensors XL-MaxSonar-EZ1 were employed. The sensor has high sensitivity and a narrow beam width, which is appropriate for detecting human [17], as shown in Fig. 4.

Furthermore, an LED and a micro-vibration motor were set up on the handle of the vehicle to inform the driver about the invasion of the vehicle. The vibration motor used in the experiment is a coin-type vibration motor [18] (Fig. 5), which operates at a high speed and generates vibration amplitude large enough so that the driver can recognize the vibration when the PMV invades the PS of a pedestrian.

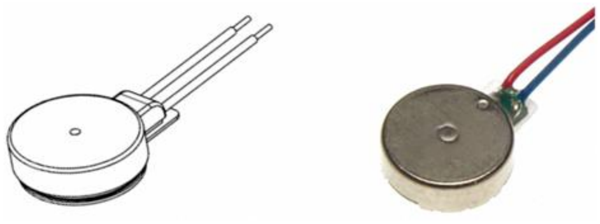


Figure 5. Picture of a vibration motor for the experiment

Additionally, in this study, the assistance system is able to assist the driver in avoiding a pedestrian faster while the PMV invade the pedestrian's PS by controlling steering gain (K_S) [16]. This gain increases with an increase in the invasion ratio of the vehicle.

III. Experiment

The experiment was conducted under the condition that 12 participants took part in driving experiments, and the PMV traveled toward 12 pedestrians, which it encountered one by one. The experimental area had a distance in the traveling direction longer than 20 m and a width large enough to allow the PMV to avoid a pedestrian, as shown in Fig. 6.

Figure 6. Picture of the experiment

Recently, personal mobility vehicles have been allowed to use by seniors in pedestrian areas at the speed lower than 6 km/h in Japan. Therefore, in this study, we assumed that the PMV travels in a pedestrian area of a Japanese road at the speed lower than 6 km/h, and we first considered the condition that the PMV travels in the opposite direction to a pedestrian. In the experiment, the PMV operated at speeds of 4 km/h (low) and 6 km/h (high), with steering angle gains K_{S1} (low) and K_{S2} (high), as shown in Fig. 7.

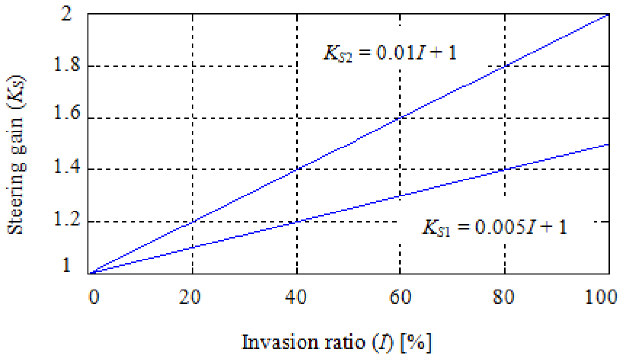


Figure 7. Steering gain according to invasion ratio

In this experiment, the drivers avoided pedestrians as soon as recognizing information on the invasion via the assistance system using a micro-vibration motor and an LED. During the process of avoidance, the semi-active driving assistance system cooperated with the driver in avoiding the pedestrian by adjusting the steering angle gain automatically according to the vehicle's invasion ratio of the pedestrian's PS. This gain increases with an increase in the invasion ratio. Meanwhile, pedestrians traveled straight from initial positions toward the PMV, and would evade the vehicle when they felt uncomfortable. Questionnaires were used to estimate the drivers' feelings of different modes of transport. After conducting the driving experiment, the drivers reported their levels of difficulty in avoiding pedestrians by completing the questionnaire sheets on a five-point scale including 1: easy, 2: slightly easy, 3: somewhat difficult, 4: mostly difficult, and 5: very difficult.

IV. Resutls and Discussion

Fig. 8 and Fig. 9 show the results for the level of avoidance difficulty felt by 12 drivers encountering a pedestrian in the cases of the PMV with and without the assistance system. The error bar indicates the standard error. The results show that increasing the vehicle's speed increased the levels of avoidance difficulty of the drivers.

Moreover, experimental results reveal that at the low speed, the level of avoidance difficulty felt by the drivers when the PMV operated with the high steering angle gain (K_{S2}) was lower than that when the PMV operated with the lower steering angle gain (K_{S1}). This could be because, at the low speed, the drivers can maneuver the vehicle with the high gain, the PMV can get out of the PS of the pedestrian faster. In contrast, at the high speed, the proposed assistance system was more effective when the PMV operated with the low gain (K_{S1}) than when the PMV run with the higher gain (K_{S2}). This may be because, at the high speed, the drivers find it difficult to maneuver the vehicle with the high gain.

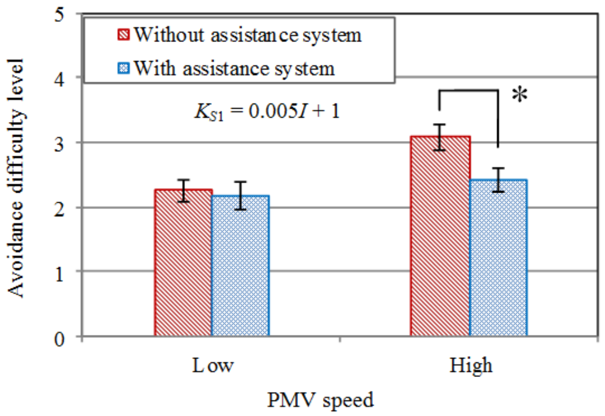


Figure 8. Avoidance difficulty levels of the drivers in accordance with the speed of PMV at a low gain (K_{S1}).

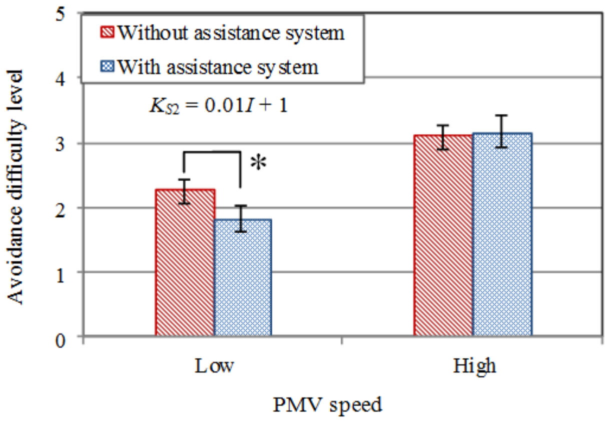


Figure 9. Avoidance difficulty levels of the drivers in accordance with the speed of PMV at a high gain (K_{S2}).

A Wilcoxon test of the five-point scale showed that there was statistically significant difference between the levels of avoidance difficulty felt by the drivers when the PMV operated with the high gain (K_{S2}) at the low speed and when the PMV operated with the low gain (K_{S1}) at the high speed ($N = 12$, $p < 0.05$).

The findings of this study show that the proposed assistance system was effective when the PMV traveled at low speed with high gain and traveled at high speed with low gain. Table II summarizes the conditions of the speed and the steering angle gain that the assistance system was effective.

TABLE II. APPROPRIATE CONDITIONS FOR THE ASSISTANCE SYSTEM

Gain / Speed	Low (K_{S1})	High (K_{S2})
Low		○
High	○	

○ indicates the condition that the assistance system was effective.

V. CONCLUSIONS

In this paper, we proposed a semi-active driving assistance system for a four-wheeled PMV using the concept of personal space and analyzed its effects on the drivers under different conditions of the velocities and steering angle gains. The present findings reveal that the effectiveness of the proposed assistance system was confirmed by the experiment. Moreover, the avoidance difficulty level of the drivers increased when the vehicle's speed increased.

This study is the first step towards developing the compact and human-friendly vehicles using personal space. Further work will continue improving the effectiveness of the assistance system by optimizing the steering angle gain in accordance with the PMV's speed and with invasion ratio. Furthermore, we will consider conducting experiments in higher pedestrian density and in different scenarios. In addition, other evaluation factors such as pedestrians' feelings will be considered in future studies.

REFERENCES

[1] K. T. Ulrich, "Estimating the technology frontier for personal electric vehicles," *Transportation Research Part C: Emerging Technologies*, vol. 13, no. 5–6, pp. 448–462, 2005.

[2] Y. Suda, "Vehicle dynamics and control for sustainable transport," in *Proc. 13th Asia Pacific Vibration Conference*, Christchurch, New Zealand, 2009, pp. 1–11.

[3] B. Sawatzky, I. Denison, S. Langrish, S. Richardson, K. Hiller, and B. Slobogean, "The segway personal transporter as an alternative mobility device for people with disabilities: A pilot study," *Archives of Physical Medicine and Rehabilitation*, vol. 88, no. 11, pp. 1423–14288, 2007.

[4] Segway—The leader in personal, green transportation. [Online]. Available: http://www.segway.com/

[5] Toyota—personal mobility—Winglet. [Online]. Available: http://www.toyota.co.jp/jpn/tech/personal_mobility/winglet.html

[6] K. Boniface, M. P. Mckay, R. Lucas, A. Shaffer, and N. Sikka, "Serious injuries related to the segway ® personal transporter: A case series," *Annals of Emergency Medicine*, vol. 57, no. 4, pp. 370–374, 2011.

[7] R. Paper, S. Jeong, S. Takahara, T. Takahashi, Y. Hiroi, Yutaka, and O. Matsumoto, "Driving performance and user's evaluation of self-balancing personal mobility vehicle with a pedal driving mechanism," *International Journal of Advanced Robotic Systems*, vol. 12, no. 7, pp. 1–11, 2015.

[8] J. Butler and A. Agah, "Psychological effects of behavior patterns of a mobile personal robot," *Autonomous Robots*, vol. 10, no. 2, pp. 185–202, 2001.

[9] Y. Murakami, Y. Kuno, N. Shimada, and Y. Shirai, "Intelligent wheelchair moving among people based on their observations," in *Proc. IEEE International Conference on Systems, Man, and Cybernetics*, Tennessee, USA, 2000, pp. 1466–1471.

[10] C. Nakagawa, "Evaluation of personal space for pedestrians encountering personal mobility vehicles," in *Proc. 20th Intelligent Transport Systems World Congress*, Tokyo, Japan, 2013, pp. 1–10.

[11] T. Q. Pham, C. Nakagawa, A. Shintani, and T. Ito, "Evaluation of the effects of a personal mobility vehicle on multiple pedestrians using personal space," *IEEE Transactions on Intelligent Transportation Systems*, vol. 16, no. 4, pp. 2028–2037, 2015.

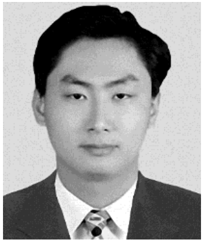
[12] T. Q. Pham, C. Nakagawa, A. Shintani, and T. Ito, "Experimental evaluation of an assistance system for the driver of a personal mobility vehicle," *Advanced Science Letters*, vol. 22, no. 9, pp. 2077–2081, 2016.

[13] Q3 Chariot - Stand & Ride Electric Personal Transporter. [Online]. Available: http://www.scootercatalog.com/q3-chariot-snr-electric-scooter.html

[14] E. T. Hall, *The Hidden Dimension*, 2nd ed., New York: Anchor Books, 1982, pp. 113-129.

[15] T. Q. Pham, C. Nakagawa, A. Shintani, and T. Ito, "Modeling and simulation of multiple personal mobility vehicles in pedestrian flows using personal space," *Journal of Advanced Simulation in Science and Engineering*, vol. 2, no. 2, pp. 255-270, 2015.

[16] T. Q. Pham, C. Nakagawa, A. Shintani, and T. Ito, "Experiment on the driver assistance system of a personal mobility vehicle considering pedestrians' psychological factors," in *Proc. JSAE Annual Spring Congrress*, Yokohama, Japan, 2016, pp. 1339–1344.
[17] Maxbotix—Ultrasonic Sensors. [Online]. Available: http://www.maxbotix.com/Ultrasonic_Sensors.htm#LV-ProxSonar-EZ
[18] Brushless vibration motor—product catalogue. [Online]. Available: http:// www.precisionmicrodrives.com



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