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論文要旨

The technological improvement of means of transportation has helped people travel in cities more conveniently and quickly. The development of internal combustion engine vehicles, especially automobiles, is one of the greatest achievements of modern technology enabling higher mobility in daily life. However, the large number of automobiles in use around the world has caused serious problems for the environment and human life. Air pollution, global warming, and the rapid depletion of fossil fuel are now problems of paramount concern. In recent decades, the research and development activities related to transportation have emphasized the development of highly efficient, clean, and safe transportation. Fully electric, hybrid, and fuel cell vehicles have been typically proposed to replace conventional ones. For short-distance trips, personal mobility vehicles (PMVs), such as an inverted-pendulum vehicle, which are defined as single-person-use vehicles have been recently proposed. Such vehicles are environmentally-friendly, compact, and convenient to use in pedestrian areas such as walkways and shopping malls. PMVs can also be used as an alternative transporter for people with disabilities.

However, when PMVs are allowed to be used in pedestrian flows, it is important to consider the safety and comfort of not only PMV drivers but also surrounding pedestrians. Therefore, in this research, we developed an intelligent driving assistance system for PMVs focusing on nearby pedestrians' psychologies in order to enhance their safety and comfort in the presence of PMVs.

The thesis is composed of six chapters, and the contents of each chapter are as follows.

In chapter 1, a general introduction including research background, the overview of PMVs, and the objectives of the study is provided.

In chapter 2, a microscopic simulation model considering the interaction between a PMV and pedestrians was investigated, and an assistance system for the PMV was proposed using the concept of personal space (PS), which is the space in which invasion by others induces a psychological strain. By considering both the driver's and the pedestrians' PS, the PMV will decelerate and assist in avoiding a pedestrian when entering the PS of the pedestrian even though the pedestrian is outside the PS of the PMV. The simulation was examined under the condition that the PMV travelling toward 10 pedestrians for different pedestrian densities of 0.1, 0.2, 0.3, 0.4, and 0.5 people/m^2, and under different conditions of road width. To evaluate the effects of a PMV on nearby pedestrians, the invasion ratio and crossing time were introduced as evaluation indexes. The simulation results reveal that the average invasion ratio increased with increasing pedestrian density, and increasing the width of the road decreased the invasion ratio and the crossing time. The effectiveness of the assistance system was clearly confirmed. In particular, the

PMV equipped with the assistance system had invasion ratio and crossing time lower than those of the PMV without such system.

In Chapter 3, the analytical modelling of multiple PMVs travelling both with and without the assistance system was investigated in the same condition. In addition, the effects of the assistance system for PMVs was analyzed under different conditions of the width of the road, the position of a pedestrian, the avoidance angle, and the PMVs' speed. The simulation results suggest that the invasion ratio and the crossing time of pedestrians were significantly affected by the aforementioned factors. As the avoidance angle of the PMVs became smaller or as the PMVs' speed increased, the invasion ratio and the crossing time increased accordingly. Additionally, the effectiveness of the assistance system was clearly confirmed by the simulation. Similar to Chapter 2's findings, the PMVs equipped with the assistance system had invasion ratio and crossing time lower than those of PMVs without one. The findings have proved the potential application of multiple PMVs in the same pedestrian area.

In Chapter 4, the design and implementation of a passive assistance system for a PMV that supports the driver in recognizing surrounding pedestrians' psychological strain are described. The proposed assistance system includes: (1) a microcontroller: Mbed NXP LPC 1768, which has a 32-bit, 96-MHz ARM Cortex M3 processor, (2) sensors: three ultrasonic LV-MaxSonar-EZ1 sensors, which can detect nearby pedestrian from 0 to 6.45 m away, and (3) notification devices: a micro-vibration motor and a light-emitting diode (LED) that can inform the driver about the vehicle's invasion of pedestrian's PS. The experiment was conducted under different conditions of pedestrian density, and questionnaires were used to evaluate the feelings of PMV drivers and pedestrians. Experimental results suggest that the discomfort levels of pedestrians and drivers increased with increasing pedestrian density. The proposed assistance system was particularly effective for low pedestrian densities of 0.1 and 0.2 people/m^2. When the PMV operated with the assistance system, the drivers of the PMV felt more comfortable and easier in avoiding pedestrians, and the discomfort and fear levels of the pedestrians also decreased. This effectiveness corresponds to simulation results in Chapter 2. However, at higher pedestrian densities, such as 0.3, 0.4, and 0.5 people/m^2, the proposed assistance system has not been effective yet. This difference could be because the PMV driver concentrates on avoiding pedestrians using only their judgment at a high pedestrian density, and cannot react instantly to the assistance system. In addition, the passive assistance system just supports the driver in recognizing the invasion, and the driver is responsible for avoiding pedestrians; therefore, the final control results were influenced by the driver's reaction and behavior.

In Chapter 5, a four-wheeled PMV equipped with a semi-active driving assistance system was developed in order to enhance the effectiveness of the passive assistance system at high pedestrian densities. The semi-active assistance system detects nearby pedestrians' PS, informs the PMV driver about the invasion of the vehicle, and cooperates with the driver in avoiding pedestrians by controlling steering gain. The experiment was conducted under different conditions of pedestrian density, steering gain, and vehicle's speed. The results show that increasing the vehicle's speed increased the levels of avoidance difficulty of the drivers as expected. Interestingly, the results reveal that, at a low speed, the proposed assistance system was more effective with a high gain, whereas at a high speed, the proposed assistance system was more effective when the PMV operated with a low gain. In addition, the levels of discomfort and fear of pedestrians and drivers increased with increasing pedestrian density. The semi-active assistance system was significantly more effective at pedestrian densities of 0.1, 0.2, 0.3, and 0.4 people/m^2 than the passive assistance system. This could be accomplished thanks to changing steering gain while invading the PS of the pedestrian. Consequently, the PMV equipped with semi-active assistance system got out of the PS of a pedestrian faster. The present findings have highlighted a potential application of the PMV considering the psychological factor of surrounding pedestrians in order to achieve a sustainable transportation system.

In Chapter 6, the results of the study in meeting the objectives of the research are summarized and assessed. Recommendations for future work to further enhance the effectiveness of the proposed system and extend its capabilities are presented.

審査結果の要旨

本論文では、パーソナルモビリティビークル（＝PMV）の駆動システムにおいて、周辺歩行者の安全性向上や心理的負担軽減を行うためのセミアクティブな駆動補助システムを提案し、理論的，実験的検証を行ったもので、以下の知見を得ている。

（１）PMV と歩行者の相互作用を考慮した数値シミュレーションモデルを構築するとともに、パーソナルスペース（＝PS）を考慮した PMV の駆動補助システムを提案した。提案した駆動補助システムは、PS の侵入率および通過時間の低減に非常に有効であることを明らかにした。

（２）複数の PMV が存在する場合において、提案した駆動補助システムは、種々の道路幅、歩行者の位置、回避角度、PMV の走行速度条件下でも有効であることを示した。この知見により、複数の PMV が歩行者領域に存在する場合でも使用可能であることを明らかにした。

（３）周辺歩行者の存在を超音波センサーにより検知し、操縦者に歩行者の PS への侵入をバイブレータと LED ライトにより知らせるパッシブな駆動補助システムを開発した。このシステムを用いた走行実験を各種歩行者密度において行い、提案したシステムは特に低密度領域において、歩行者の不快感や恐怖感の緩和に非常に有効であることを明らかにした。

（４）パッシブなシステムをもとに、PS への侵入率に依存して操縦ゲインを変化させるセミアクティブな駆動補助システムを開発し、歩行者密度がより高い場合でも歩行者の心理的負担を低減可能であることを 4 輪型 PMV により明らかにした。

以上の諸成果は、歩行者の心理的負担を軽減するための PMV 駆動補助システムの実現において重要な知見を与えるとともに、新たに提案した駆動補助システムの有効性を定量的に示したものであり、将来の PMV の実用化と産業発展に貢献するところ大である。また、申請者が自立して研究 活動を行うのに必要な能力と学識を有することを証
したものである。