PROPOSING A MODEL OF CENTRALIZED CONTROL SYSTEM ON PERSONAL MOBILITY VEHICLES

ĐỀ XUẤT MÔ HÌNH HỆ THỐNG ĐIỀU KHIỂN TẬP TRUNG TRÊN PHƯƠNG TIỆN DI CHUYỂN CÁ NHÂN

Vu Van Tan[1], Nguyen Quang Thinh[2,*], Nakagawa Chihiro[3]

DOI: https://doi.org/10.57001/huih5804.70

ABSTRACT

Personal Mobility Vehicle (PMV) is a term that refers to vehicles with short travel distances serving the needs of traveling in public places. Currently, scientists around the world are researching and developing many PMV models to serve different specific activities and contribute to meeting individual mobility needs. In Vietnam, there have been some studies that have begun to pay attention to the development of smart electric vehicles. However, it has not really caught up with the world's PMV technology trend. In this paper, with the main purpose of perfecting the control system for PMV in areas with high traffic volume, the authors evaluate, study on research directions and propose control methods with a system-level for various PMVs. The authors first introduce the system structure of a typical PMV. Then, a model of a centralized control system is proposed to control PMVs. The model and its system are applicable to actual PMVs in the future.

Keywords: *Personal mobility vehicle, control system, freeform control, centralized control.*

TÓM TẮT

Phương tiện di động cá nhân (Personal Mobility Vehicle: PMV) là thuật ngữ chỉ các phương tiện có cự li di chuyển ngắn phục vụ cho nhu cầu di chuyển đi lại ở nơi công cộng. Hiện nay, các nhà khoa học trên thế giới đang nghiên cứu và phát triển nhiều mô hình PMV phục vụ cho các hoạt động cụ thể khác nhau và góp phần đáp ứng các nhu cầu di chuyển cá nhân. Ở trong nước đã có một số nghiên cứu bắt đầu chú ý phát triển các phương tiện điện thông minh, nhưng vẫn chưa thực sự bắt kịp với xu hướng công nghệ PMV của thế giới. Trong bài báo này, với mục đích chính hoàn thiện hệ thống điều khiển cho PMV tại các khu vực có lưu lượng giao thông lớn, nhóm tác giả tìm hiểu, nghiên cứu về các hướng nghiên cứu trên thế giới và đề xuất phương pháp điều khiển ở cấp độ hệ thống đối với nhiều phương tiện PMV khác nhau. Trước tiên, nhóm tác giả giới thiệu về cấu trúc điều khiển cần có của PMV điển hình. Sau đó nhóm tác giả đề xuất sơ lược mô hình hệ thống điều khiển tập trung cho PMV. Mô hình này được xem xét có thể ứng dụng trên các PMV thực tế ở trong nước.

Từ khóa: *Phương tiện di động cá nhân, hệ thống điều khiển, điều khiển dạng tự do, điều khiển dạng tập trung.*

[1]Faculty of Mechanical Engineering, University of Transport and Communications, Vietnam
[2]Japan Technology Solution Joint Stock Company
[3]Faculty of Engineering, University Public Corporation Osaka, Japan
[*]Email: nqthinh@innovations-jts.com
Received: 25/9/2022
Revised: 03/11/2022
Accepted: 22/11/2022

1. INTRODUCTION

Personal Mobility Vehicle (PMV) is a term that refers to vehicles with short travel distances serving the needs of commuting in offices or public places such as airports, hospitals, schools, museums, etc., known by various names such as Personal Transporter (PT) [1- 3], Personal Vehicle (PV) [4], Personal Electric Vehicle (PEV) [5], Personal Mobility Device (PMD) [6], Personal Mobility Vehicle (PMV) [7-9] or Personal Mobility Robot (PMR) [10-12]. The PMVs are described as in Figure 1, which has a structure similar to an electric vehicle. The PMVs can be equipped with intelligent systems such as: a sensor system that recognizes the location, multiple safety sensors, analysis and calculation of the path, etc. This has helped PMV become an increasingly intelligent mobile vehicle [13-16].

(a) Whill [13] (b) U3-X [14]

(c) UNI-CUB [15] (d) 3R-C [16]

Figure 1. PMV models equipped with intelligent systems

According to experts' estimates, the PMV market is growing steadily at over 7.1% annually and the market size is predicted to grow up to USD 14,591 billion by 2027 [17]. This shows that the need to move in small areas or short ranges is increasing, and PMV is a smart mobile vehicle that has been interested in research and development in recent times.

Currently, scientists around the world are researching and developing many PMV models in many interesting directions to create smarter traffic solutions. It can be divided into four main problems in the current public transport system: pollution emissions, fuel consumption, traffic congestion and traffic accidents. These main problems are increasing in the current transport system, and have received increasing research attention in recent years. Research results on the combination of robotics technologies and artificial intelligence (AI) technologies, resulting in many different types of models, of which a part has been and is being commercialized in the field of personal mobility. Some typical examples include the following:

A first example, the auto-balancing technology product was named Segway Personal Transporter (Segway PT) in 2001 [18-24].

A second example, Toyota motor is a Japanese manufacturer PMV is considered to design and experimentally research PMV models with many concepts in 2003 to 2013 [25-31]. Followed by Honda Motor, this company researched and developed PMV models, that are highly appreciated in terms of design [32-35]. Manufacturer from Korea launched a multi-functional commercial PMV product in 2013 [36].

A third example, several experimental studies of PMV in real traffic environments in Tsukuba, Japan [37], and in real traffic zones in Tokyo, Japan [38].

It can be seen that these studies tend to focus only on studying control methods for each PMV as well as not paying attention to the traffic optimization of all PMV models. For research and development from the world's business blocks, it has been growing faster in terms of design and production of very practical PMV models and initially positively received by the market. For example, WHILL, a famous Japanese start-up in PMV technology, has sold thousands of PMVs in the past 5 years, and has succeeded in providing many convenient PMV-related services, such as rental at nursing homes, airport terminals, etc. This has contributed to creating a new image for Japan's modern transportation system [13].

In Vietnam, in terms of research, there are almost no in-depth studies related to PMV. However, there have been a number of technology start-ups that have begun to pay attention and begin to develop smart electric vehicles such as electric bicycles and electric motorcycles with many new features, but have not really started yet. They just keep up with the trend of PMV technology in the world, so there are still no Vietnamese branded PMV technology products.

In this study, the authors focus on how to control safely the PMV at a high level while still achieving the goal of moving all vehicles in traffic. This is an issue that the authors find important and necessary for a number of reasons as follows:

Firstly, PMV should be considered as an official entity when participating in traffic. It has the same movement function as a bicycle or motorbike, although moving at lower speed and shorter distance. At the same time, due to being involved in traffic, it is required to safely move in densely populated areas or with many traffic vehicles, which must be safely driven according to certain traffic control principles.

Secondly, PMV users always want to move safely anytime, anywhere, in the shortest time possible. It means that whether participating in traffic, or moving in an area with high traffic volume, PMV still need to move as fast and steady as possible. The current PMVs with sensor systems are controlled differently depending on the manufacturer, if moving into a crowded area, it will certainly have the problem that it is difficult to move smoothly and easily.

Thirdly, at present, PMV in developed countries has not been widely disseminated, still only providing for special customers or for special tasks. If PMV is to be used more widely, it is necessary to have a control solution everywhere, especially in densely populated areas with high traffic volume.

As analyzed above, the control of PMVs at the system level is extremely important and indispensable in the management of mobile devices in public places in the future. Researches around the world still focus a lot on the free control on each PMV, but don't really care about optimal control at the system level, which not only creates a potential accident risk between vehicles, or reduce the traffic capacity of those vehicles in crowded public areas.

2. GENERAL STRUCTURE OF THE CONTROL SYSTEM FOR PMV

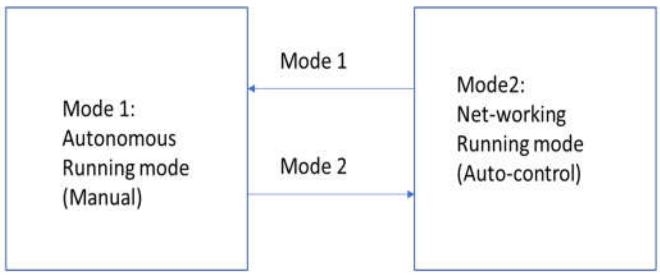
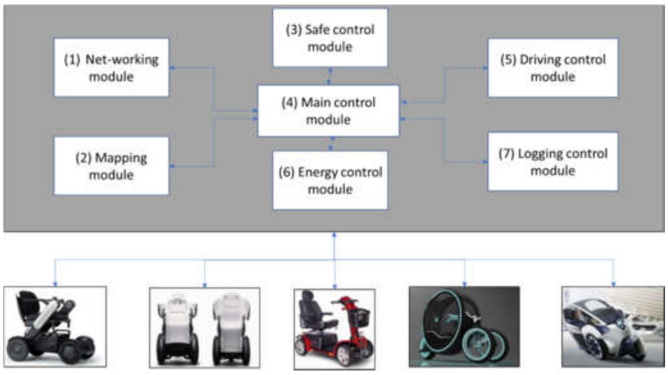


Figure 2. Overview of the two control states for PMV

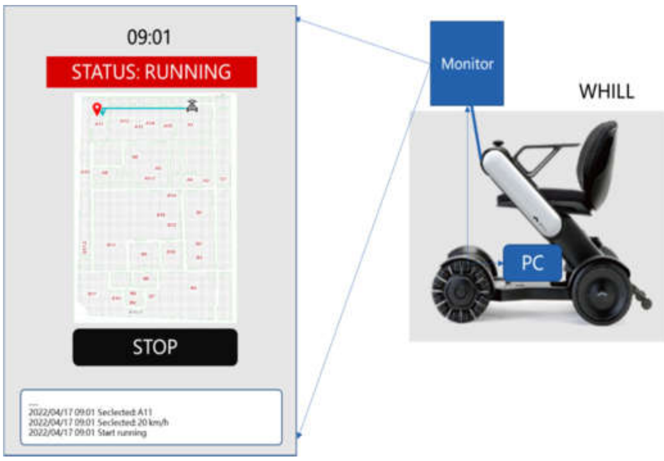
In order to improve the mobility and safety of the PMV when moving in different environments, the PMV is required to be controlled in both states: active (user actively controls the device) and passive (user switch to auto state), then PMV equipment should be designed as shown in Figure 2. In fact, most of today's PMV models are only equipped with active state (mode 1), and are control directly from the user. Therefore, centralized control system is currently facing many difficulties because it is difficult to intervene to integrate more passive states (mode 2) because many manufacturers do not provide a full API of PMVs. Therefore, in this study, the authors actively propose an open design option (Open source) for Mode 1 and Mode 2. This helps devices to integrate their own features at the system level.

3. FREEFORM CONTROL METHOD

At this moment, PMVs as shown in Figure 3(a) are equipped with different components depending on the manufacturer's design purposes, but basically include basic parts such as (1) networking module, (2) mapping module, (3) safe control module, (4) main control module, (5) Drive control module, (6) Energy control module, (7) Logging module. Figure 3(b) depicts when the PMV is running in the active control state (manual). The PMVs are equipped with software that records the map images passed to form a moving map. It is then written in memory to calculate the path when needed [13]. However, this work will require a large amount of memory resources, the processor is very expensive, increasing the cost of the PMV many times. Therefore, in this study, the authors propose a minimum configuration to maximize computer resources and operate more with the centralized control system, which will reduce the maximum cost of PMV equipment.



(a) Basic control structure on PMV models



(b) Active self-control state from the user

Figure 3. Overview of the active control state of PMV

4. PROPOSING A CENTRALIZED CONTROL MODEL

When the user changes from the active state to the passive state, the device will automatically connect to the centralized control system at that location and report the position and status continuously to the system as shown in Figure 4. The system will receive PMV power, providing map data for control work as shown in Figure 5(a). Figure 5(b, c) depicts that when the user selects a target or point, where wants to go to, the system will automatically search for the shortest and safest path from the current location to the destination. The system then sends the calculation results to each PMV and at the same time controls the traffic so that the PMVs do not collide with each other during operation.

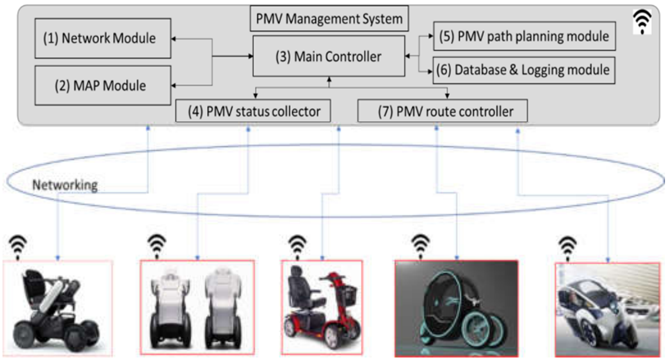
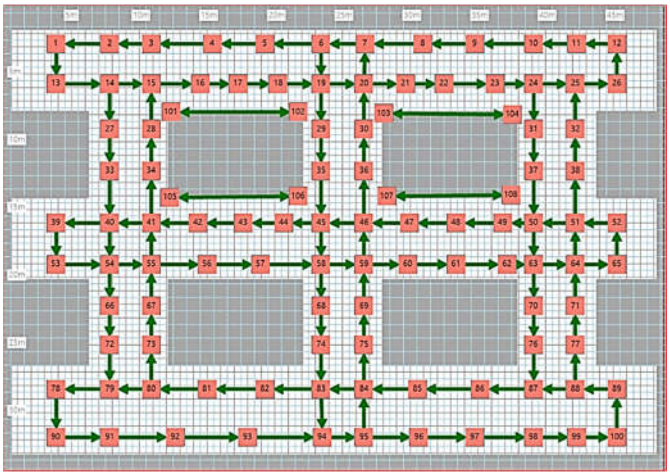
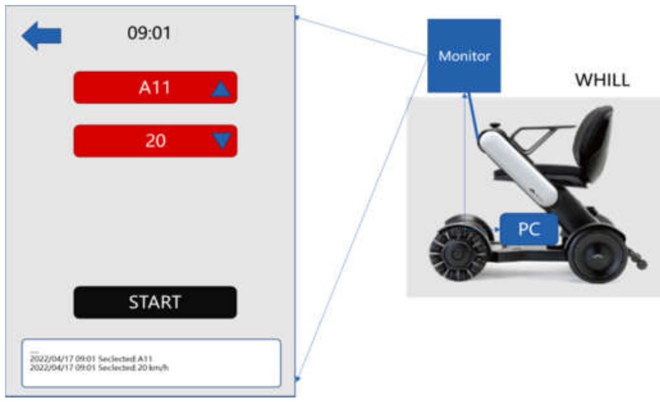


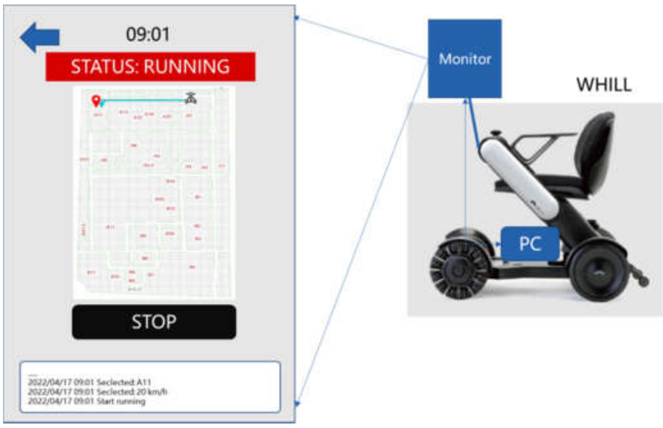
Figure 4. Overview of the centralized control state of PMV



(a) An example of pre-designed map data

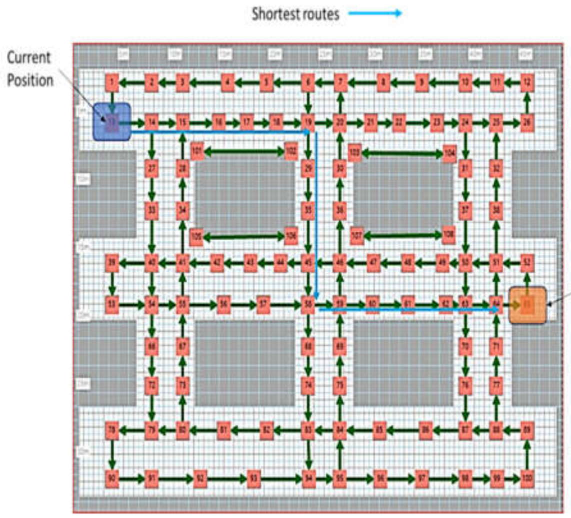


(b) Controlling the destination and speed by manually or automatically

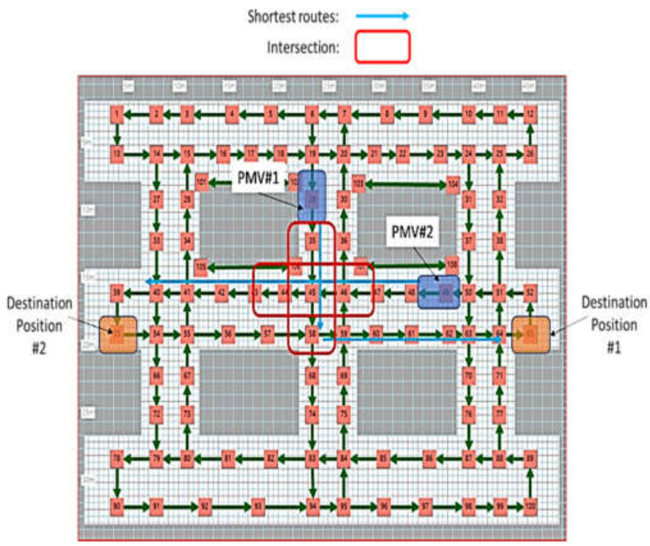


(c) The screen image simulates the location on the system

Figure 5. An example of actual operation control of PMV



(a) Choosing a finding path algorithm



(b) Traffic safety control

Figure 6. Selection of path control and traffic safety for PMV

In this applied study, the authors propose a new method to calculate and control the path of the PMV, which simplifies the design of the calculation and control for the PMV. It ensures that the PMV will not be duplicated in traffic control process. Specifically, as shown in Figure 6(a), when the user connects the PMV to the centralized control system, the PMV will regularly report the location and operating status to the system and at the same time. It requests to build the path based on a user-specified destination. Here, the system will find the path as shown in Figure 6(a) with the common finding path methods as in previous studies [39,40].

After that, the issue of traffic safety control at intersections is shown in Figure 6(b). At intersections, the authors propose a traffic control method based on the FIFO principle (First In First Out: FIFO), specifically as follows:

Step 1: All PMVs must report the current position to the centralized control system every time when a new location is detected.

Step 2: All PMVs must contact and wait for the control signal when reaching the preset intersection position.

Step 3: The PMV that received the permission signal first will be moved first, the following PMVs will have to stop at the designated point. This make sure that there is no collision even if it comes to a complete stop.

Step 4: When a PMV has left the traffic control area, the next PMV will receive the same control signal according to the FIFO principle.

5. ANALYZING THE ADVANTAGES AND DISADVANTAGES OF CENTRALIZED CONTROL SYSTEM MODEL

The advantage of the centralized control system is the stability and certainty of the system. We assume that the system runs in a completely stable network environment, and the signals and from the device to the system are completely normal. Then with the above control method, PMVs will travel with the shortest and safest path even at intersections.

The disadvantage of the system can be mentioned that, each time approaching the intersection, the control speed of the signal from the center must be fast enough to avoid PMV stopping in unnecessary cases. When the number of PMV increases large enough, the problem of calculation speed and signal processing will be difficult. When the PMV reaches the terminals of the system, it will have to update information about the network in that area, identify the safety, and receive a new control map signal there. If there is no or new map information, it is needed to update. In addition, because the information about the path is fixed for each trip, it will be difficult to find a new path in the middle of the road when there is an obstacle or other PMVs encounter an error that obstructs traffic.

The problems mentioned above need to be calculated and solved specifically in the next studies. The authors would like to stop at the scope of proposing the basic structure and control of the system, the above issues will be focused in further research.

6. CONCLUSIONS

This paper provides an overview of the PMV that is increasingly being used around the world for specific mobility purposes such as in public transport, resorts, and hospitals, nursing homes, etc. The control system structure of PMV has a great influence on the controllability and function of this type of vehicle. Based on the freeform control method being commonly applied on PMV, the authors propose a new control system model which is a collective form. This control model allows PMV to operate more safely at the level from single systems to complex systems. This helps to control and optimize for systems and improve service quality of PMV for users. In this study, the authors focused on selecting the basic model for the centralized control system. In the next studies, the research team will delve into the selection and development of control method and verification algorithms on application needs and more practical problems.

REFERENCES

[1]. B. Sawatzky, I. Denison, S. Langrish, S. Richardson, K. Hiller, B. Slobogean, 2007. *The segway personal transporter as an alternative mobility device for people with disabilities: a pilot study.* Arch. Phys. Med. Rehabil., vol. 88, no. 11, pp. 1423-8.

[2]. G. S. Serv, L. Miguel, S. Vera, 2012. *Prototype for a self-balanced personal transporter.* in 2012 Work. Eng. Appl., pp. 1-6.

[3]. M. Strand, T. Schamm, A. Benazza, T. Kerscher, M. Zollner, R. Dillmann, 2009. *Control of an autonomous personal transporter towards moving targets.* in Proc. of IEEE Work. Adv. Robot. its Soc. Impacts, pp. 18-23.

[4]. S. Ajisaka, T. Kubota, H. Hashimoto, 2013. *Human balance control ability for affinitive personal vehicle.* in Proc. of the 10th Int. Conf. Ubiquitous Robot. Ambient Intell., pp. 503-508.

[5]. K. Ulrich, 2005. *Estimating the technology frontier for personal electric vehicles*. Transp. Res. Part C Emerg. Technol., vol. 13, no. 5-6, pp. 448-462.

[6]. L. D. Ballard, 2012. *Human-scaled personal mobility device performance characteristics.* Georgia Institute of Technology, Tech. Rep.

[7]. S. Nakajima, T. Fujikawa, 2012. *Proposal for personal mobility vehicle supported by mobility support system*. in Proc. of IEEE Int. Electr. Veh. Conf., pp. 1-6.

[8]. R. Ando, A. Li, 2012. *An analysis on users' evaluation for self-balancing two-wheeled personal mobility vehicles.* in Proc. of the 15th Int. IEEE Conf. Intell. Transp. Syst., no. 9, pp. 1525-1530.

[9]. J. Masood, M. Zoppi, R. Molfino, 2012. *Investigation of personal mobility vehicle stability and maneuverability under various road scenarios*. in Proc. of IEEE/RSJ Int. Conf. Intell. Robot. Syst., pp. 4859-4864.

[10]. N. Tomokuni, M. Shino, 2012. *Wheeled inverted-pendulum-type personal mobility robot with collaborative control of seat slider and leg wheels*. in Proc. of IEEE/RSJ Int. Conf. Intell. Robot. Syst., pp. 5367-5372.

[11]. N. Hirose, R. Tajima, K. Sukigara, Y. Tsusaka, 2013. *Posture stabilization for a personal mobility robot using feedback compensation with an unstable pole.* in Proc. of IEEE Int. Conf. Mechatronics, pp. 804-809.

[12]. T. Ienaga, Y. Senta, D. Arita, Y. Kimuro, K. Murakami, T. Hasegawa, 2010. *A method for event handling on robot town platform and a sharable personal mobility robot.* in Proc. of Int. Conf. Broadband, Wirel. Comput. Commun. Appl., pp. 749-754.

[13]. Whill Co. Ltd. *Whill Model C2.* [Online]. Available: https://whill.inc/jp/

[14]. Honda Motor Co. Ltd. *The U3-X challenge: Mobility that unites rider and vehicle.* [Online]. Available: http://world.honda.com/U3-X/BackStory/index.html

[15]. Honda Motors Co. Ltd. *UNI-CUB (in Japanese).* [Online]. Available: http://www.honda.co.jp/UNI-CUB/

[16]. Honda Motors Co. Ltd. *Overview of exhibited car at Geneva Motor Show (in Japanese).* [Online]. Available: http://www.honda.co.jp/news/2010/4100224.html

[17]. Research and Markets. *Personal Mobility Devices Market by Product and End User - Global Opportunity Analysis and Industry Forecast, 2020-2027*. [Online]. Available: https://www.globenewswire.com/en/news-release/2021/06/21/2250273/28124/en/Global-Personal-Mobility-Devices-Market-2020-to-2027-by-Product-and-End-user.html

[18]. N. Tomokuni, M. Shino, 2012. *Wheeled inverted-pendulum-type personal mobility robot with collaborative control of seat slider and leg wheels.* in Proc. of IEEE/RSJ Int. Conf. Intell. Robot. Syst., pp. 5367-5372.

[19]. Segway Inc. *Segway Company Milestones.* [Online]. Available: http: //www.segway.com/about-segway/segway-milestones.php

[20]. Segway Inc. *Project P.U.M.A.* [Online]. Available: http://www.segway.com/ puma/

[21]. General Motors. *GM Unveils EN-V Concept A Vision for Future Urban Mobility*. [Online]. Available: http://media.gm.com/content/autoshows/Shanghai/2010/ public/cn/en/env/news.html

[22]. S.C. Lin, C.C. Tsai, H.C. Huang, 2011. *Adaptive robust self-balancing and steering of a two-wheeled human transportation vehicle*. J. Intell. Robot. Syst., vol. 62, pp. 103-123.

[23]. N. Hatao, R. Hanai, K. Yamazaki, M. Inaba, 2009. *Real-time navigation for a personal mobility in an environment with pedestrians.* in Proc. of the 18th IEEE Int. Symp. Robot Hum. Interact. Commun., pp. 619-626.

[24]. L. J. Pinto, D.H. Kim, J. Y. Lee, C.S. Han, 2012. *Development of a Segway robot for an intelligent transport system.* in Proc. of IEEE/SICE Int. Symp. Syst. Integr., pp. 710-715.

[25]. Toyota Motor Corp.*Toyota Personal Mobility.* [Online]. Available: http: //www.toyota-global.com/innovation/personal mobility/

[26]. Toyota Motor Corp. *Toyota exhibited a new concept of fuel cell hybrid vehicles and personal mobility at the Tokyo Motor Show (in Japanese)*. [Online]. Available: http://www.toyota.co.jp/jp/news/03/Oct/nt03 082.html

[27]. Toyota Motor Corp. *Toyota presents a new concept fuel cell hybrid vehicles, personal mobility at the Tokyo Motor Show (in Japanese).* [Online]. Available: http://www.toyota.co.jp/jp/news/05/Oct/nt05 060.html

[28]. Toyota Motor Corp. *Toyota i-Real.* [Online]. Available: http://www.toyota-global.com/innovation/personal mobility/i-real.html

[29]. Toyota Motor Corp. *Toyota develops personal transport assistance robot 'Winglet'.* [Online]. Available: http://www.toyota.co.jp/en/news/08/0801 1.html

[30]. Toyota Motor Corp. *Toyota i-Road (in Japanese).* [Online]. Available: http://www.toyota.co.jp/jpn/tokyoms2013/iroad/

[31]. Toyota Motor Corp. *Toyota personal mobility.* [Online]. Available: http: //www.toyota-global.com/events/motorshow/2013/geneva/booth/pmobility.html

[32]. Honda Motor Co. Ltd. *The U3-X challenge: Mobility that unites rider and vehicle*. [Online]. Available: http://world.honda.com/U3-X/BackStory/index.html

[33]. Honda Motors Co. Ltd. *U3-X.* [Online]. Available: http://www.honda.co.jp/ robotics/u3x/

[34]. Honda Motors Co. Ltd. *UNI-CUB (in Japanese).* [Online]. Available: http://www.honda.co.jp/UNI-CUB/

[35]. Honda Motors Co. Ltd. *Overview of exhibited car at Geneva Motor Show (in Japanese).* [Online]. Available: http://www.honda.co.jp/news/2010/4100224.html

[36]. T. Hayashi. *Hyundai Unveils 'E4U' Personal Mobility Vehicle.* [Online]. Available: http://techon.nikkeibp.co.jp/english/NEWS EN/20130402/274491/

[37]. City of Tsukuba. *Robot Demonstration Zone Promotion Council.* [Online]. Available: http://www.rt-tsukuba.jp/council/

[38]. Toyota Motor Corp. *Sustainability Report 2010.*

[39]. Silvester Dian Handy Permana, Ketut Bayu Yogha Bintoro, Budi Arifitama, Ade Syahputra, 2018. *Comparative Analysis of Pathfinding Algorithms A *, Dijkstra, and BFS on Maze Runner Game.* International Journal Of Information System & Technology Vol. 1, No. 2, pp. 1-8.

[40]. S.K. Gopikrishman, 2011. *Path Planning Algorithms: A comparative study*. Conference: National Conference on Space Transportation Systems (STS - 2011).

THÔNG TIN TÁC GIẢ

Vũ Văn Tấn[1], Nguyễn Quang Thịnh[2], Nakagawa Chihiro[3]

[1]Khoa Cơ khí, Trường Đại học Giao thông Vận tải

[2]Công ty cổ phần Giải pháp Công nghệ Nhật Bản

[3]Khoa Kỹ thuật, Trường Đại học công lập Osaka, Nhật Bản