Concept and Development of Personal Mobility Vehicles for Indoor Use by Persons with Walking Difficulty

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ABSTRACT

This paper presents a concept of personal mobility vehicles for indoor use by PERSONs WITH WALKING DIFFICULTY and its development approach. In recent years, many persons with walking difficulty desire to live independently in the house as long as possible. Especially, existing means of personal mobility vehicles (e.g. electric-powered wheelchairs) face a lot of problems of obstacles in the house such as there exist many steps, furniture, narrow corridors and aisles and so on. In order to live in house independently, the persons with walking difficulty try to do light working. For these purposes, a new type of mobility vehicles for such persons are required to live independently in the house. In this paper, we investigate the new concept of personal mobility vehicles for persons with walking difficulty living independently in the house and its feasibility of development. The required specifications of the proposed personal mobility vehicles are to have compact size, light weight, and omni-directionality. Furthermore, this personal mobility vehicle has the elevation seat and the softness of the seat to change the person's position for light working.

Keywords: Exemplary Paper, Human Systems Integration, Systems Engineering, Systems Modeling Language

INTRODUCTION

In recent years, people with walking difficulty who would wish to live independently in their homes as long as possible are increasing in Japan, because aging is coming along quickly in Japan. The living environment improvements for such people, barrier-free houses are effective to live. Therefore, many of the old Japanese houses have not been barrier-free, because the cost of barrier-free renovation is really high. In general, a choice of means of transportation is electric-powered wheelchairs for the people with walking difficulty. The corridors in the Japanese houses are narrow, which is from 780mm to 900mm. This breadth is too narrow for the electric-powered wheelchairs. Furthermore, the kitchens are also small. For these causes, utilization of the existing electric-powered wheelchairs is very hard for such people in Japan. In society to recognize the independent living for the people with walking difficulty in Japan, new characters of personal vehicles based on new concept are required.

The personal mobility vehicles are a novel class of transportation device emerged in the past two decades (Ulrich, 2005). A passenger is transported by the vehicle whose structure is typically open air. The first impact in the personal mobility vehicles was the Segway Series produced in 2001 (Ambrogi, 1999). This vehicle is driven by two wheels controlled so that the vehicle body does not fall down based on the control engineering. However, the existing personal vehicles including the Segways are not suitable for the persons with walking difficulty.

In this paper, we investigate the new concept of personal mobility vehicles for persons with walking difficulty living independently in the house and its feasibility of development. The required specifications of the proposed personal mobility vehicles are to have compact size, light weight, and omni-directionality. Furthermore, this personal mobility vehicle has the elevation seat and the softness of the seat to change the person’s position for light working.

CONCEPT OF PERSONAL VEHICLE FOR PARSONS WITH WALKING DIFFICULTY

The target users of our personal vehicle are persons with walking difficulty caused by aging or physical disorders. In order to live independently in the house, they need a mean of transportation, which pass through narrow corridors without assistance. When a person with walking difficulty wants to go to the restroom from the bed, he/she have to get up from the bed and move into the wheelchair. Then he/she go through the corridor to the restroom. These sequences of motions are difficult to do oneself.

The physical conditions of the persons with walking difficulty are infinite in varying with each individual. Therefore, the required features of the personal vehicles are individually different. The required concept of our personal mobility vehicle is as follows:

- Fascinating vehicle design
- Small vehicle size for passing through and turning in narrow way.
- Safety against overturning
- Comfortable and secure seat

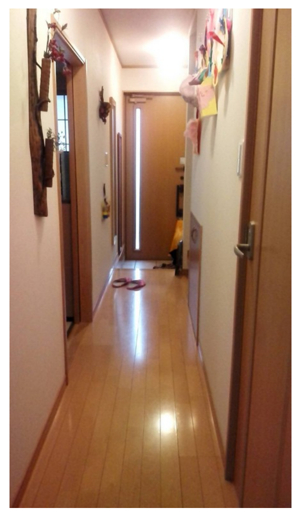

Fig. 1 Narrow corridor of Japanese house

We consider the fascinating design of the personal vehicle for the persons with walking difficulty is exceedingly important from the view point of sensibility of the user. The mission of “Design” to the users of our personal vehicles is to present the new style of the personal vehicles for the persons with walking difficulty, which is that the recognition of substitution of healthy legs is changed.

For achieving safety of the personal vehicle in operation by users, we introduce the robotics technology for guidance, stabilization and collision avoidance of the vehicle moving in the house. There are a lot of forms of obstacles on/in the passageways of the house. The vehicle using in such space must avoid these obstacles during moving.

Fig. 1 shows an example of narrow corridors in a Japanese house. In this case, the width of this corridor is 750mm which is not sufficient width for the common electric wheelchairs to pass through and to turn at this corridor. In order to use a personal vehicle in such Japanese narrow corridor, the vehicle must have small size and small turning circle. The weight of the vehicle should be lightweight, because the Japanese house has several rooms having tatami mats made with straws which are softer than the wooden floor.

In the use of the personal vehicle in the house, the safety against overturning of the vehicle with passenger is a serious problem. We introduce control strategies employed in the field of robotics for solving this problem. The overturning of the vehicle occurs when the vehicle is strongly accelerated or decelerated. The controller of the vehicle is designed for the mathematical model of the vehicle based on the observation data, such as the three-axes acceleration of the vehicle body, the three-axes angular velocity, and the angular velocities of the wheels.

The seat of the vehicle for the persons with walking difficulty should be comfortable and secure. The vehicle is considered as the means of the mobility in during almost a day. Therefore, the softness of the seat must be capable to change so that the user feels comfortable. The idea of comfortable and adjustable seat is realized by using the variable cushions.

DESIGN OF PERSONAL VEHICLE

Needs in Design---Eradicating the Recognition as "Substitution of Healthy Legs"---

The common wheelchairs shown in Fig. 2 sufficiently satisfy their purposes of mobility for the individuals with walking difficulty. Even though, there is no fundamental such that the users feel fun to operate auto automobiles or motorcycles (see Fig. 3). The impression of the wheelchair is a special tool for persons with walking difficulty, it is an icon that conveys the handicap of the body. On the other hand, glasses to correct vision are widespread in the world wide society as one of the fashion styles. Therefore, the mission of "Design" to the users of our personal vehicles is to present the new style of the personal vehicles for the persons with walking difficulty, i.e. it is how we can eradicate the recognition of substitution of healthy legs.

Fig. 2 Common (electric) wheel chair.

The structure and design of our personal vehicle is inspired by the structure and functions of the office chairs on casters. The design of the personal vehicle for the persons with walking difficulty consists of an adjustable seat attached to the polygonal frame and the drive mechanism illustrated in Fig. 4. This seat has multiple adjustable cushions whose softness can be changed depending on the state of the moving vehicle. While the vehicle is moving, the user's bony pelvis and cervical vertebra are clamped by the multiple cushions to support the user's body. The user can move as a unit consisting of the vehicle and user's body. The gas-spring and damper for adjusting the seat height of the office chair on casters becomes altered as an intelligent damper controlled by a computer, which suppresses undesirable shocks due to the motion of the vehicle and adjusts the height and tilt of the seat (see Fig. 5). Furthermore, the arm connected with the front wheel and the body frame of the vehicle can be expanded. This motion allows that the center of gravity

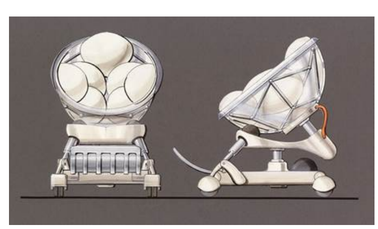

Fig. 4 Image of proposed personal vehicle.

of the vehicle can be shifted for finding the suitable body position for stable moving (see Fig. 6). Realizing the all of the above ideas, the recognition of our personal vehicle is changed from “Substitution of Healthy Legs” to “A Part of Person” and the reciprocal recognition of the healthy persons and persons with walking difficulty will be changed. Such change of value in the mind of persons with walking difficulty will be reflected in the life of them, i.e. the new personal vehicles are recognized as “new products with new values” by all people.

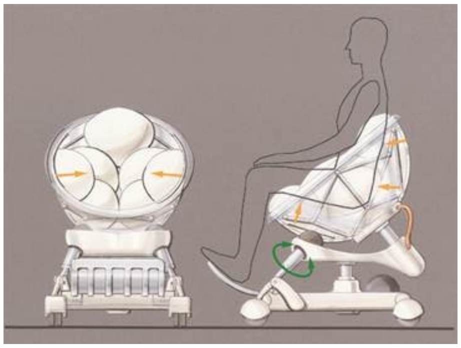

Fig. 5 Design of the seat with the softness controlled cushions.

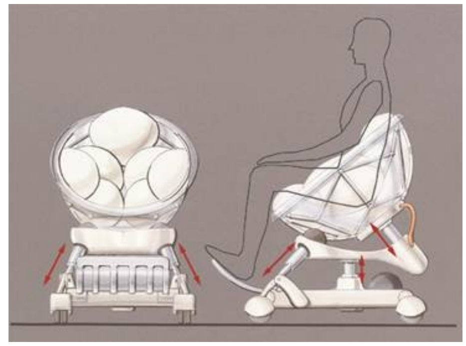

Fig. 6 Variable parts of the vehicle.

MODELING AND CONTROL OF PERSONAL VEHICLE

In order to develop the controller for the proposed personal vehicle for the persons with walking difficulty, the dynamics of the vehicle is required. Especially, the control strategy for avoiding the overturning of the vehicle is emphasized. In this paper, we show an example of simple position controller and its numerical simulation. In this paper, we consider the simplified model of the personal vehicle for the persons with walking difficulty illustrated in Fig. 7, where we just consider the motion of the proposed vehicle in the vertical plane.

This simplified model of the proposed personal vehicle has two traction wheels driven by the control torques $\tau_1(t)$ and $\tau_2(t)$, respectively (see Fig.7). The radius of each wheel is denoted by r; the wheelbase, d_b; the mass of the vehicle body, m_b; and the inertia of the body J_b; the mass and inertia of each wheel, m_w and J_w. The rotational angles of the front and rear wheels are represented by $\theta_1(t)$ and $\theta_2(t)$, respectively. The position of the center of the rear wheel is denoted by $x(t)$. The distance between the mass center of the body, G, and the center of the rear wheel P_2 is described by l. $\varphi(t)$ denotes the angle between the vertical axis and the line $\overline{P_2G}$, which means the inclination of the vehicle body (see Fig.8). When the vehicle’s wheels contact on the ground, the inclination angle $\varphi(t)=\varphi_0$. $f_w(t)$ denotes the reaction force from the ground.

The dynamics of the motion of the personal vehicle considered in this paper is derived by using the Hamilton’s principle. The derive dynamics of the vehicle is given by the following equations (Li, 2005; Nakamura, 2009):

$$\left(m_b+2m_w+2\frac{J_w}{r^2}\right)\ddot{x}(t)+\left\{m_b l\sin\varphi(t)+m_w d_b\cos\left(\varphi_0-\varphi(t)\right)\right\}\dot{\varphi}^2(t)+\left\{m_b l\cos\varphi(t)+m_w d_b\sin\left(\varphi_0-\varphi\right.\right.$$

$$¿\frac{b_1}{r}\tau_1(t)+\frac{b_2}{r}\tau_2(t)b \quad (1)$$

$$\left\{ m_b l \cos\varphi(t) + m_w d_b \sin(\varphi_0 - \varphi(t)) + \frac{J_w}{r} \right\} \ddot{x}$$
$$- m_b g l \sin\varphi(t) - m_w g d_b \cos(\varphi_0 - \varphi($$

The equation (2) is used in the case that the front wheel is lifting from the ground, i.e. $\varphi(t) > \varphi_0$. The reaction force acting at the bottom of the wheels due to the contract with the ground is modeled by the Hertzian contact force theory (Johnson, 1999).

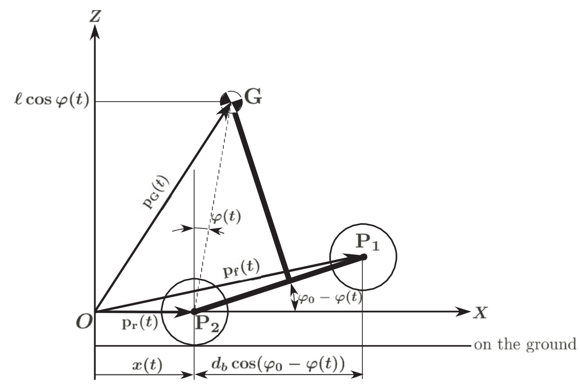

Fig. 8 Personal vehicle in the case of lifting the front wheel.

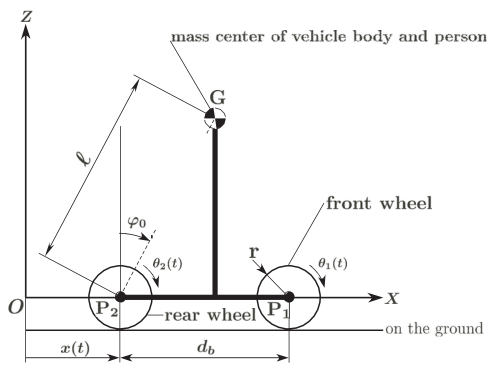

Fig. 7 Simplified model of the personal vehicle.

The controller for the vehicle is simply constructed by the PD-controller based on the position and velocity of the vehicle for the vehicle's position control. In order to avoid turnover of the vehicle, the angle and angular velocity of the vehicle from the ground are used for the control to suppress the lifting of the front wheel. The form of the PD-controller is omitted.

The collision avoidance control is achieved by introducing the robotics technology based on the contactless sensors such as ultrasonic sensors, scanning range finders, and so on. By measuring the distance to the obstacles, e.g. walls, furniture, something obstacles on the floor, and so on, in the direction of movement, the collision avoidance controller reduces the velocity of the vehicle or stop it, when the obstacles are detected.

EVALUATION OF SEATING

In order to realize the adjustable softness seat, the evaluation of the pressure on the surface of the seat should be carrying out. To control the softness of the seat, the measured data of the pressure on the surface of the seat is required. This information can be measured by introducing the sheeted pressure sensor-array installed on the surface of the seat. The example of the measured data is shown in Fig.9. The left picture shows the pressure distribution on the surface of the backrest. The right picture shows the pressure distribution on the surface of the seat. The adjustable softness seat should be controlled so that the peak of the pressure distribution becomes reduced in value.

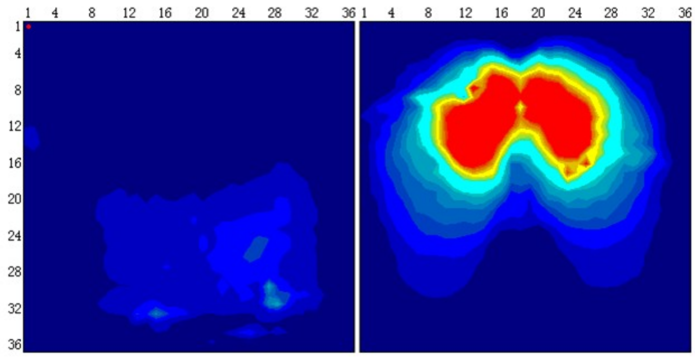

Fig. 9 Pressure distribution on the surface of the seat vehicle.

CONCLUSIONS

In this paper, the new concept of the personal vehicles for walking difficulty has been proposed for developing and designing. The concept was organized by the four elements which were the fascinating vehicle design, the safeness of the vehicle, the vehicle size, and the comfort and safety of the users. The design strategy was considered from the viewpoint of users, i.e. the persons with walking difficulty. The main approach of the design was to eradicate the recognition of substitution of healthy legs. For realizing this concept, the new design of the personal vehicle has been proposed. For the safeness of the vehicle in operation, the control and robotics technologies have been introduced to stabilize the motion of the vehicle and to avoid the obstacles in the direction of movement. In order to develop the adjustable cushions for the comfortable seat, the multiple variable softness cushions controlled by the computer is introduced based on the pressure distribution data measured by the sheeted pressure distribution sensor array.

REFERENCES

Ambrogi, R.R. et al. (1999), "*Transportation vehicles and methods*", US Patent 5,971,091

Johnson, K.L. (1999), *Contact mechanics*, Cambridge University Press, Cambridge

Li, W., Hata, N. and Hori, Y. (2005), "*Prevention of overturn of power assisted wheelchair using novel stability condition*", Industrial Electronics Society Annual Conference, 1, pp.6-12

Nakamura, A. and Murakami, T. (2009), "*A stabilization control of two wheels driven wheelchair*", Proc. of IEEE/RSJ International Conference on Intelligent Robots and Systems, pp.4863-4868

Ulrich, K. T. (2005), "*Estimating the technology frontier for personal electric vehicles*", Transportation research part C, Volume 13, Elsevier, pp. 448-462