Modification of the Personal Cart and Its Control

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Abstract
This paper describes the modification of a computer-controlled walker, which is called the "Personal Cart" in order to actively support and stabilize the walking of healthy elderly persons by their selves. The cart system consists of computers and its controlling devices. The cart has four wheels, of which the left front wheel is driven by a DC motor. Expanding the space between the front wheels increases the stability of the cart. Furthermore, its operability was improved by the connection of an axis handle to the front wheels with a joint. The cart keeps the balance even if the weight of an operator is applied to the handle of the cart as the position of an operator is near the center of gravity of the triangle that is made between the front and rear wheels. The controller, which is synthesized based on a fuzzy theory, is set in the cart system to move while maintaining a certain distance between the operator and the cart. The membership functions of the proposed fuzzy controller are changed according to the angle of slopes, in order to improve its operability. The proposed system was confirmed to be useful in reducing the workload of the operator when walking on a slope with some baggage by experimentations.

Keywords
elderly person, personal cart, walking support, QOL, gerontechnology

1. INTRODUCTION
It is said that one's walking ability begins to abate, when one becomes old. The walking ability of elderly people will weaken moreover, if they come to be confined indoors by the decline of their walking ability. Therefore, it is considered important to maintain walking ability at a certain level, so one does not become bedridden in old age. It is considered that the elderly people maintain their mental and physical health, and improve their QOL (Quality of Life) if they can communicate with the local community by going outside.

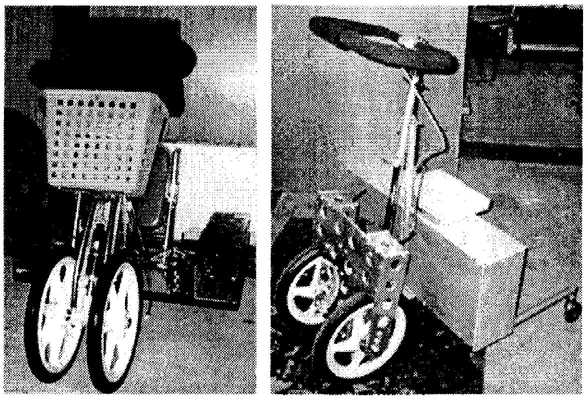
Various walkers have even been proposed for handicapped persons to assist their walking [Lacey et al. 1999, MacNamara et al., 1999; Nemoto et al., 2000 and so on]. However, it is not easy to use such walkers when going out, because they are for use in confined areas like that of a hospital. Miyawaki et al. developed a silver-car type assisting-walker controlled by analog PID controller [Miyawaki et al., 1999]. In the case of changing the characteristic of a controlled object, sufficient performance may not be able to be obtained using the PID controller if the control parameters are fixed.

We previously proposed a personal cart in order to actively support an elderly person, who is not physically handicapped in principle, in walking outside by their self [Takahara et al., 2001; Wakatsuki et al., 2002; Takahara et al., 2003]. That is, the previous personal cart functioned to pull an elderly person at their own walking pace, rather than requiring pushing by an operator. That cart was controlled based on fuzzy theory so as to move while maintaining a certain distance from an operator. However, operability on slopes was not sufficient. Especially, in cases when ambulation was started on downward slopes, the acceleration of the cart sometimes exceeded the walking pace of operator. Some persons also felt that the handling was heavy when direction was changed.

This paper describes the modified cart "Personal Cart IV" that has improved some problems with operations. Furthermore, the fuzzy controller has been redesigned in order to alleviate operator burden on slopes. The effectiveness of the system is confirmed by experiments simulating various conditions.

2. MODIFIED PERSONAL CART

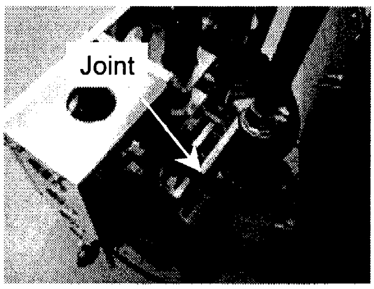
The outline of the previously developed cart "Personal Cart III" and the new modified cart "Personal Cart IV" are illustrated by Figure 1 (a) and (b), respectively.



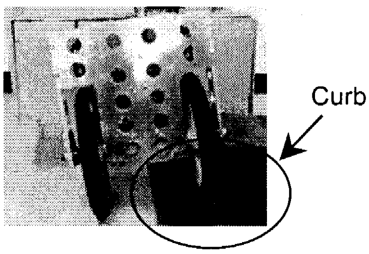
(a) Personal Cart III (b) Personal Cart IV

Fig. 1 Earlier and modified personal carts

Both carts have four wheels. The spacing between front wheels of the fourth machine is wider than the third machine. The structure of third machine looks like a three-wheeler as shown in the figure. The two front wheels are driven by a DC-motor. Therefore, one of the driven wheels is always in contact with the road surface, even when the direction changed. On the other hand, it is not easy to change direction, if both the front wheels are driven by the motor like the third machine, because the spacing of the front wheels in fourth machine is wider than the third machine. Subsequently, the new cart was modified so that only the left front wheel is driven by the DC-motor and the front wheels connected to the handle axis as in Figure 2. Accordingly, all the wheels of fourth machine are always in contact with the road surface, and therefore more stable on bumpy roads. Also, changing direction is easier, because neither of the front wheels rises when the handle is turned in this structure. The width of the new cart is 72 [cm] and the height is 95 [cm]. The height of the handle is adjustable. The diameter of the front wheel of the cart is 34 [cm], so that it can overcome curb heights up to about 10 [cm]. Therefore, the operator advances just by adding their weight to the handle, without the need to raise the front wheels to overcome a curb. The driven wheel is fixed when the brake lever in the front part of the cart is thrown down. The position of the operator is also between the front and rear wheels when using the fourth machine. Thus the operator's position is near the center of gravity in the triangle that is made with the front and rear wheels. Therefore, even when an operator applies their weight on the handle of the cart, they can still walk without losing their balance entirely.



(a) Joint between Handle Axis and Front Wheels



(b) Overcoming a Curb

Fig. 2 Joint between handle axis and front wheels

The system consists of various sensors, driving devices and two computers (Notebook Computer: PCG-FX55S/BP, SONY, One-chip Microcomputer: AKI-H8/3048F, Akizuki-Denshi). The notebook computer is a superior computer to administrate the other computers and the information from a distance sensor (WTS24, Sick), a clinometer (D5R-L02-15, OMRON) and a tachometer (Maxon Motor). The one-chip microcomputer sends the motor driver (ADS Standard, Maxon Motor) the driving data for the DC motor (RE36, Maxon Motor) according to the signals from the notebook computer. The outline of the new system is shown in Figure 3.

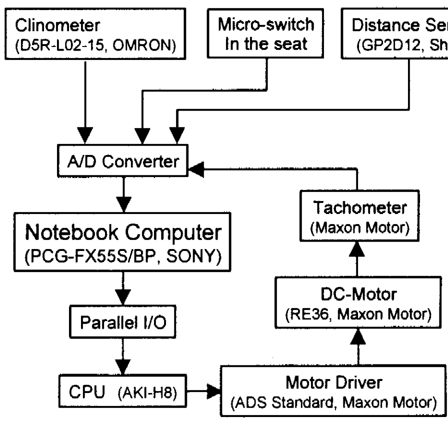


Fig. 3 Outline of the cart system

3. FUZZY CONTROLLER TO CONSIDER THE ANGLE OF SLOPES

It is considered that a supporting attendant pays attention to the distance between the supported person and themselves, and the condition of the supported person that is felt through their hands, when a supporting attendant leads a supported person by their hands. In order to let the cart lead elderly people, it is necessary to realize the action and attention of the supported person. Therefore, the distance between the cart and the operator was chosen as the index for controlling the cart.

The cart is controlled to move while maintaining the distance between the personal cart and the operator at a certain set point. By this control, the operator can ambulate while maintaining posture. Some appropriate description of the controlled object is necessary to synthesize any control system. The purpose of our modified cart was to reduce the workload of the operator, when walking on a slope with some baggage. However, it is not easy to describe the dynamic characteristics of the cart by a mathematical model that includes the changing characteristics of the driving environment, such as the condition of roads and/or baggage. Furthermore, the cart system should be a human friendly system, because it is to be used by elderly people. For these reasons our controller was synthesized based on a fuzzy theory.

The controller for the cart is composed of two subsystems for driving and for stopping [Takahara et al. 2003]. The blockdiagram of the control system is illustrated in Figure 4. The variable $x(k)$ is the distance between the personal cart and an operator as shown in Figure 5, and x_d is its desired value at stopping.

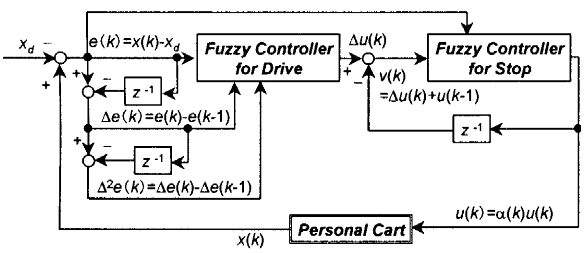


Fig. 4 Blockdiagram of the control system

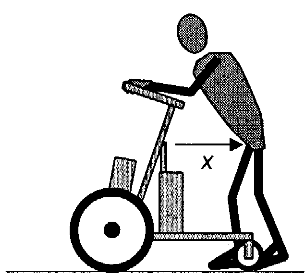
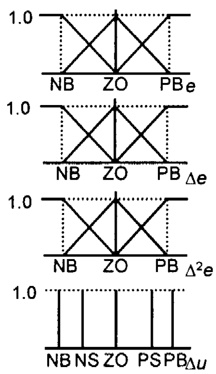
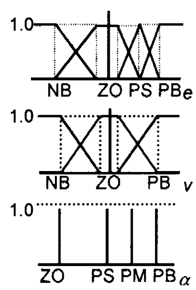


Fig. 5 Variable $x(k)$ (distance between operator and cart)

The difference from the desired distance $e(k)=x(k)-x_d$ is the relative position, its difference $\Delta e(k)=e(k)-e(k-1)$ is the relative velocity and its difference $\Delta^2 e(k)=\Delta e(k)-\Delta e(k-1)$ is the relative acceleration, which are selected as the inputs of the driving fuzzy controller, and the deviation of the setting value of the motor velocity $\Delta u(k)$ is selected as the output. The proposed control system determines $\Delta u(k)$ to reduce the values $e(k)$, $\Delta e(k)$ and $\Delta^2 e(k)$. That is, the cart decelerates when it is away from the operator and accelerates when it is close to the operator, by this fuzzy controller. The cart sometimes automatically moved back to within a certain defined distance when the operator fell behind the pace of the cart, using only the above driving controller. The controller for stopping appropriately decreased the output of the controller for driving if the cart approached too close to the operator during such backing movements to re-establish the appropriate cart-operator distance. Figure 6 shows the fuzzy membership functions and fuzzy control rules.



e(k)		Δe(k): PB	ZO	NB	Δ²e(k)
PB		NB	NB	NS	PB
		NS	NS	ZO	ZO
		ZO	ZO	ZO	NB
ZO		NS	ZO	ZO	PB
		ZO	ZO	ZO	ZO
		ZO	ZO	PS	NB
NB		ZO	ZO	ZO	PB
		ZO	PS	PS	ZO
		PS	PB	PB	NB



e(k)	v(k): PB	ZO	NB
PB	ZO	PB	PB
PS	PS	PB	PB
ZO	PM	ZO	PM
BN	PB	PB	ZO

Fig. 6 Fuzzy membership functions and fuzzy control rules

Furthermore, the membership functions are modified according to the angle of slopes as Table 1. On a downward slope, the cart must operate while holding the operator upright. Therefore, the deviations in the negative velocity of the motor on a downward slope will change less than on a flat road, while the deviations in the positive velocity will change more. In contrast, the deviations in the negative velocity of the motor on an upward

Table 1 Changes in fuzzy labels of the membership functions for the driving controller

	PB	NB
Upward Slope θ>3 [deg]	0.125θ+0.625	0.125θ-1.375
Flat Road	1.0	-1.0
Downward Slope θ<-3 [deg]	0.075θ+1.225	0.125θ-0.625

slope will change more than on a flat road and the deviations in negative velocity will change less. Here, PS and NS are half of each value of PB and NS. The membership functions are changed in the cases of upward and downward slopes as illustrated in Figure 7.

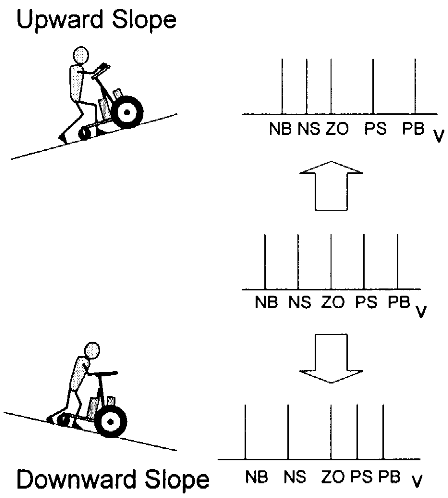


Fig. 7 Changes in fuzzy membership functions during operation on slopes

The velocity of motor is determined as the follow equation.

$$u(k) = \alpha(k)\, v(k)$$

Here, $v(k)$ is the velocity of motor, which is calculated by the driving controller and $\alpha(k)$ is a parameter of the stopping controller.
In the next section, the effectiveness of the modified fuzzy controller is tested by experiments.

4. EXPERIMENTS

The sampling interval was set at 10 [ms]. The desired value x_d was set at 50 [cm] on flat and inclining road surfaces, at 45 [cm] on declines, respectively. The value of x_d is a reference value to make the cart move while maintaining an appropriate interval from an operator, as the selected values of membership functions influence the motion of cart.

The absolute value of dead zone, where the unsteadying influence of the operator's clothes and body causes small fluctuations in the cart-operator distance, is set at 5 [cm] in order to reduce the sensitivity of distance detection for smoother operation.

The control experiments of the cart were performed in accordance with the course shown in Figure 8. The slope of this course is shown with half-tone dot meshing in the figure and the subject was instructed to stop on the slope. The average angle of slope was 6.0 [deg]. The flat part of the course was paved with asphalt and the slope was paved with concrete.

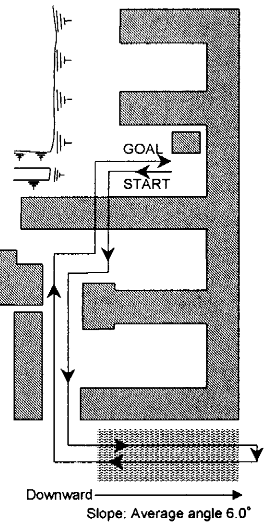


Fig. 8 Simplified illustration of the experimental road course with flat sections and a slope (average angle 6.0°)

Figure 9 shows an example of control results obtained using the modified fuzzy controller, which shows the influence of slope angle. The subject was a 68 year-old woman. Distance between the operator and cart, cart velocity and angle of road are illustrated in (a), (b) and (c) of Figure 8, respectively. In the figures, the part of data recorded on the slopes is shown with half-tone dot meshing with respect to the angle of slope in (c).

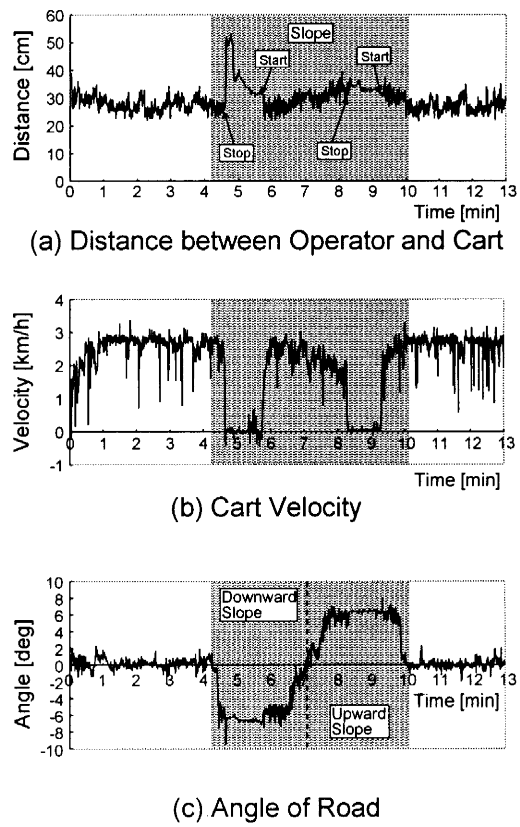
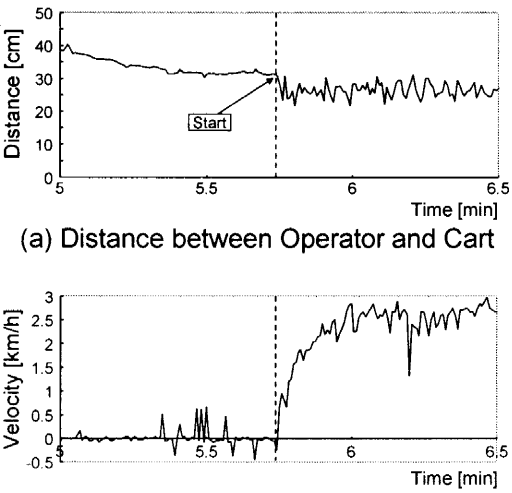


Fig. 9 Control results for controllers considering the angle of slopes

Driving the cart maintained the distance from the operator at a certain level by changing cart velocity when the operator's walking pace changed. Furthermore, control performance in both cases of walking straight and turning almost agrees. The subject stopped once and started walking up and down the slope to confirm control performance on a slope. The stopping and starting are shown with the arrows in figure (a). Although the cart velocity seems to be changing during stopping, the cart never moved. When stationary, changes in the distance between the cart and the operator were detected as a result of the operator moving her upper body or leaning on the cart, when in fact the cart-operator distance had not changed.

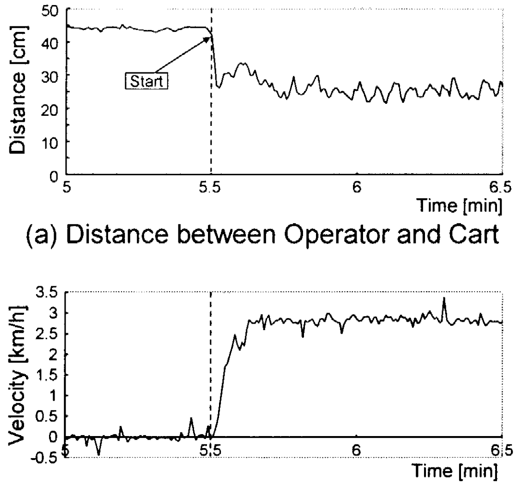
The control results from 5 to 6.5 minutes are enlarged in Figure 10. Here, the subject began to walk once again, at the time that is shown as a dotted line. For comparison, the performance of the control system without considering slope angle was confirmed for the same subject on the same course. Figure 11 shows an example of results from 5 to 6.5 minutes, using the controller set to ignore slope angles. The cart was driven maintaining the distance from the operator at a certain level and its velocity was changed according to the changing walking velocity of the operator even on the downward slope, by both controllers. The velocity of the cart in Figure 10 (b) changed more gently than in Figure 11 (b). This means that the changing membership function according to angle of slopes is effective in making the cart start while holding an operator upright. On the other hand, the modified controller made the velocity of the cart change more quickly on upward slope. These results demonstrate that an operator need not push and pull the cart, and that the cart can support the operator's weight on the cart during walking. Therefore, the modified fuzzy



(a) Distance between Operator and Cart

(b) Cart Velocity

Fig. 10 Enlarged section of the control results from 5 to 6.5 min. using fuzzy controller that considers the angle of slopes



(a) Distance between Operator and Cart

(b) Cart Velocity

Fig. 11 Enlarged section of the control results from 5 to 6.5 min. using a fuzzy controller that does not consider the angle of slopes

controller enabled the cart to support an elderly person's walking more actively.

5. CONCLUSIONS

We modified the computer-controlled walker as "Personal Cart IV" to solve some of the problems with operation of "Personal Cart III". First, the spacing between the front wheels was expanded, so that the stability of cart was increased. Only the left front wheel was driven by the DC motor, which improved operability in the case of changing directions. Connecting the axis of the handle to the front wheels with a joint always maintained the wheels of the cart in contact with the road surface, thereby stabilizing it on bumpy roads. Therefore, even in the case when an operator applies their weight on the handle of the cart, they can still walk without losing their balance entirely.

The fuzzy controllers for driving and stopping the cart were installed in the proposed cart system, in order to maintain the distance from an operator at a certain level. The membership functions were changed according to the angle of slopes, which enabled the cart to accelerate at appropriate rates according to the slope. It was experimentally confirmed to work well on roads. Although the walking pace was different by operators and changed during walking, this proposed cart system was able to correspond to various walking paces by fuzzy control system. An operator can walk without needing to push the cart on an upward slope and to pull it on a downward slope. Therefore, the workloads of an elderly person can be relieved when walking with some baggage. It is also considered to be useful for reducing the workload of an attendant that might be pushing a wheelchair mechanically operated with our fuzzy control system.

The desired value of the distance between the cart and an operator, x_d, should be chosen appropriately. We are considering a method to automatically determine appropriate x_d, according to the changes of angle of slopes, differences in physique and so on. Furthermore, we are considering safety devices that will give an operator warning of danger, informing the operator in the form of an image taken with a camera.

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(Received April 19, 2004; accepted June 10, 2004)