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# A New Type of Omnidirectional Wheelchair Robot for Walking Support and Power Assistance

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***Abstract*— Up to now, many robotic aids for the elderly's walking support or the disabled's walking rehabilitation are reported, and numerous electrical-powered wheelchairs are developed. In this paper, a new kind of omnidirectional wheelchair typed robot is developed. The robot not only can accomplish the walking support or walking rehabilitation as the elderly or the disabled walk, but also can realize the power assistance for a caregiver when he/she pushes the robot to move. The basic structure of the robot is described, and the omnidirectional mobility of the robot is analyzed. Further, an admittance based human-machine interaction controller is introduced for power assistance. Experiments are implemented, and the experimental results show that the pushing force can be reduced and well controlled arbitrarily as designed. The development purposes of the robot for walking support and power assistance are achieved.**

## I. INTRODUCTION

In the aged society, the number of the elderly person needing for aids has been continuously increasing while the number of young people willing to be engaged in care or nursing is continuously decreasing. Therefore, it is necessary to develop technologies not only to help the elderly to walk by themselves, but also to lessen the caregivers' burden to stimulate their willingness to engage in their jobs.

Currently various robotic aids for helping the elderly's walking has developed. The Guidecane [1] is an "electronic travel aid" (ETA) that assists blind people who do not require physical support. To provide the frail blind with independent mobility, the PAM-AID [2] is developed, in which, the blind considered were not cognitively disabled. To aid the elderly and the disabled to allow them living independently and supported in their private homes, an home assistant robot [3] is developed for intelligent walking support and manipulation tasks such as fetching and carrying tasks. Mainly for the elderly's walking support, a robotic power-assisted walking support system is developed [4]. The system is to support the elderly needing help in standing up from the bed, walking around, sitting down for rehabilitation. A system called PAMM (Personal Aid for Mobility and Monitoring) [5] for a robotic aid to provide walking mobility assistance and monitoring for the elderly is developed.

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Meanwhile, a number of intelligent wheelchair-type aids are being designed for people who cannot walk and have extremely poor dexterity ([6]-[12]). Users control the aid using voice or breath-activated interfaces, or three channel joysticks. These devices are well suited for people who have little or no mobility, but they are not appropriate for the elderly with significant cognitive problems. Consequently, the facilities are generally reluctant to permit the elderly residents to use powered wheelchairs. Hence, the better solution is that the facility staff (the caregiver) pushes the wheelchair to move. Some technologies for the caregiver's power assistance are proposed ([13]-[15]).

The omnidirectional mobility is necessary to completely yield the user's (here refer to the elderly/disabled, or the caregiver) intentions of walking speed and direction. In order to obtain the smooth motion and high payload capability, research has been done in recent years to develop omnidirectional mobility not with the special tires but with the conventional rubber or pneumatic tires.

An omnidirectional and holonomic vehicle with two offset steered driving wheels and two free casters is proposed [16], in which, interferences of motions between the driving wheel axis and the steering axis occurs because of the setting of the wheel actuator on the chassis, but is compensated by an actuator control. To overcome the interference between the driving wheel axis and steering axis, an omnidirectional mobile robot platform using active dual-wheel caster mechanisms is developed [17], in which, the kinematic model of the active dual-wheel caster mechanism is derived and a holonomic and omnidirectional motion of the mobile robot using two such assembly mechanisms is realized. An omnidirectional platform and vehicle design using active split offset casters (ASOC) is also developed [18]. Its structure is very similar to [17], but particular attention is paid to the system performance on uneven floors.

However, up to now, the wheelchair typed robot that can be used either for the elderly/disabled's walking support or for the caregiver's power assistance has not been reported yet. In this study, we develop such kind of omnidirectional robot.

## II. THE ROBOT OBJECTIVE AND SYSTEM DESIGN

The developed new type of omnidirectional mobile robot for the elderly's walking support, the disabled's rehabilitation, and the caregiver's power assistance, is shown in Fig. 1. Its structure is illustrated in Fig. 2.

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Fig. 1. The omnidirectional mobile robot in developing for the elderly's walking support and the caregiver's power assistance

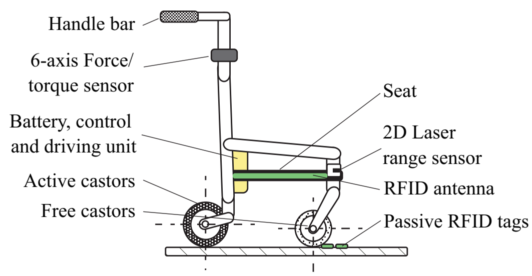


Fig. 2. The structure of the robot

### A. The Robot Objective and Functions

Different from the other intelligent aids, the robot has a handle and a seat. According to our experiences on walking support for some elderly users, their capable walking distance can be greatly enhanced with the help of the intelligent walking support devices. However, because of the muscle weakness, their knee and waist will be painful after walking some distances. At that time, they hope to have a seat for a rest. To meet such a very actual requirement, we embed a seat in the robot so that the elderly or the disabled users can take a seat for rest when necessary. On the other hand, when an elderly or disabled user is sitting in the seat of the wheelchair type aids and wants to move from one place to another, the caregiver will have to exert a force to push the wheelchair. Especially, when going up/down a slope, the caregiver's push/pull force will be considerable large. Consequently, the power assistance of the health caregivers is also necessary.

Based on the two main requirements for the walking support and the caregiving, the objectives of the robot being developed are considered as

- walking support or walking rehabilitation when an elderly or a disabled user walks while holding the robot handle;
- power assistance for the caregiver when he/she pushes the robot while an elderly or a disabled user is sitting in the seat.

To meet the above two main objectives, the robot should possess the following functions:

1) omnidirectional mobility.

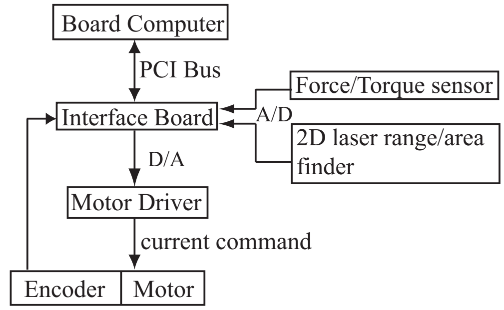


Fig. 3. The control system of the robot

2) few load feeling when the user (elderly or disabled person/caregiver) holding the handle during walking or pushing the robot.
3) guidance to destinations and obstacle avoidance via sensors and pre-determined maps.
4) adaptation to the different motion abilities of the different users.

### B. System Design

The robot shown in Fig.1, 2 is considered to be used either indoor or outdoor. It includes two active dual-wheel modules and two free casters that provides the robot omnidirectional mobility. It will be discussed in section III in detail.

A 6-axis force/torque sensor is mounted on the shaft of the handle to detect the forces and torques the user applies to the handle. With these force/torque signals, the embedded computer estimates the user's intention of walking velocity and walking direction. The robot is controlled to yield the user's intention so that the user will feel few loads to fulfill the walking support and power assistance. The detail will be explained in section IV.

The 2D laser ranger/area finder is employed to detect the obstacles. The RFID system of the RFID antenna under the seat and the passive RFID tags laid under or near the places such as the door, the corner, and the elevator, are used to identify the robot's position and orientation. They are used for the destination guidance and obstacle avoidance. Such problems are not discussed in this paper.

The control system of the robot as shown in Fig. 3 consists of a board computer running RTLinux operation system, an multi-functional interface board, two motor drivers in which each motor driver can drive two motors.

## III. Omnidirectional Mobility

As shown in Fig.4, the wheels of the robot consists of two active dual-wheel modules and two free casters. The two active dual-wheel modules enable the robot to possess omnidirectional mobility. The two free casters keep the balance of the robot.

In Fig. 4, point $O$ is the center of the robot platform. Its coordinates and velocities in the world frame $O_wX_wY_w$ are respectively $(x_w, y_w)$ and $(v_{xw}, v_{yw})$. The frame $OX_RY_R$ is attached to the robot. $\phi$ is the orientation of the robot. $\boldsymbol{V} = [v_{xw}, v_{yw}, \dot{\phi}]^T$ is the velocity vector of the robot. $\dot{x}_{wi}, \dot{y}_{wi}$ are respectively the velocity components of the joint $O_i$ in the $X_w, Y_w$ axis, and $\phi_i$ is the orientation of the module with

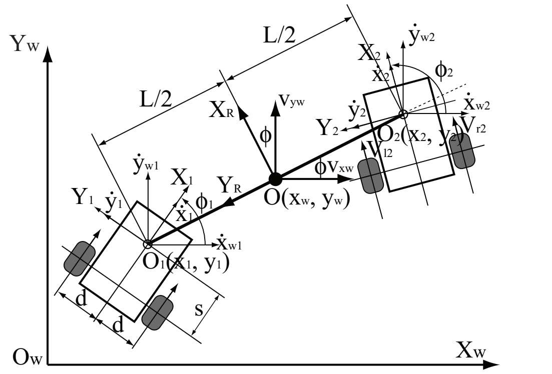


Fig. 4. Omnidirectional mobility by two active dual-wheel modules

respect to the world frame. The distance between the two joint points of two modules is $L$. $\boldsymbol{\omega} = [\omega_{r1}, \omega_{l1}, \omega_{r2}, \omega_{l2}]^T$ is the angular velocity vector of the four driving wheels of the robot.

Obviously, the linear velocities $(v_{xw}, v_{yw})$ of the robot can be given by

$$\begin{bmatrix} v_{xw} \\ v_{yw} \end{bmatrix} = \frac{1}{2} \begin{bmatrix} 1 & 0 & 1 & 0 \\ 0 & 1 & 0 & 1 \end{bmatrix} \cdot \begin{bmatrix} \dot{x}_{w1} \\ \dot{y}_{w1} \\ \dot{x}_{w2} \\ \dot{y}_{w2} \end{bmatrix} \tag{1}$$

To obtain the rotational velocity $\dot{\phi}$ of the robot, it is convenient to transform $\dot{x}_{wi}, \dot{y}_{wi}$ in the world frame to the robot frame $OX_RY_R$. The relationship is given by

$$\begin{bmatrix} \dot{x}_{Ri} \\ \dot{y}_{Ri} \end{bmatrix} = \begin{bmatrix} \cos\phi & -\sin\phi \\ \sin\phi & \cos\phi \end{bmatrix} \cdot \begin{bmatrix} \dot{x}_{wi} \\ \dot{y}_{wi} \end{bmatrix} \tag{2}$$

The rotational velocity $\dot{\phi}$ of the robot can be expressed as

$$\begin{aligned} \dot{\phi} &= \frac{\dot{x}_{R2} - \dot{x}_{R1}}{L} \\ &= \frac{1}{L}\left[(\dot{x}_{w2} - \dot{x}_{w1})\cos\phi + (\dot{y}_{w2} - \dot{y}_{w1})\sin\phi\right] \end{aligned} \tag{3}$$

Thus, the velocity vector $\boldsymbol{V}$ is expressed as:

$$\boldsymbol{V} = \begin{bmatrix} v_{xw} \\ v_{yw} \\ \dot{\phi} \end{bmatrix} = \frac{1}{2} \begin{bmatrix} 1 & 0 & 1 & 0 \\ 0 & 1 & 0 & 1 \\ -\frac{\cos\phi}{L} & -\frac{\sin\phi}{L} & \frac{\cos\phi}{L} & \frac{\sin\phi}{L} \end{bmatrix} \cdot \begin{bmatrix} \dot{x}_{w1} \\ \dot{y}_{w1} \\ \dot{x}_{w2} \\ \dot{y}_{w2} \end{bmatrix} \tag{4}$$

The velocity vector $[\dot{x}_{w1}, \dot{y}_{w1}, \dot{x}_{w2}, \dot{y}_{w2}]^T$ in the right side of the above expression is given by

$$\begin{bmatrix} \dot{x}_{w1} \\ \dot{y}_{w1} \\ \dot{x}_{w2} \\ \dot{y}_{w2} \end{bmatrix} = \frac{r}{2} \left[\begin{array}{c|c} A_1 & 0_{2\times2} \\ \hline 0_{2\times2} & A_2 \end{array}\right] \cdot \begin{bmatrix} \omega_{r1} \\ \omega_{l1} \\ \omega_{r2} \\ \omega_{l2} \end{bmatrix} = \boldsymbol{A} \cdot \begin{bmatrix} \omega_{r1} \\ \omega_{l1} \\ \omega_{r2} \\ \omega_{l2} \end{bmatrix} \tag{5}$$

where

$$A_i = \begin{bmatrix} \cos\phi_i - \frac{s}{d}\sin\phi_i & \cos\phi_i + \frac{s}{d}\sin\phi_i \\ \sin\phi_i + \frac{s}{d}\cos\phi_i & \sin\phi_i - \frac{s}{d}\cos\phi_i \end{bmatrix} \tag{6}$$

Note that, the omnidirectional mobility of the robot is realized by two active dual-wheel modules with a total of four motors, and its degree of freedom is three. Therefore, there should be a constraint for the redundancy. The physically constant distance between the two joint points $O_1$ and $O_2$ is used to eliminate the redundancy. It leads the following velocity constraint:

$$\dot{y}_{R1} = \dot{y}_{R2} \tag{7}$$

From (2) it means

$$0 = \dot{x}_{w1}\sin\phi - \dot{y}_{w1}\cos\phi - \dot{x}_{w2}\sin\phi + \dot{y}_{w2}\cos\phi \tag{8}$$

By combining Eqs. (4) and (8), we can get the following homogeneous expression:

$$\begin{aligned} \begin{bmatrix} \boldsymbol{V} \\ 0 \end{bmatrix} = \begin{bmatrix} v_{xw} \\ v_{yw} \\ \dot{\phi} \\ 0 \end{bmatrix} &= \frac{1}{2} \begin{bmatrix} 1 & 0 & 1 & 0 \\ 0 & 1 & 0 & 1 \\ -\frac{\cos\phi}{L} & -\frac{\sin\phi}{L} & \frac{\cos\phi}{L} & \frac{\sin\phi}{L} \\ \sin\phi & -\cos\phi & -\sin\phi & \cos\phi \end{bmatrix} \cdot \begin{bmatrix} \dot{x}_{w1} \\ \dot{y}_{w1} \\ \dot{x}_{w2} \\ \dot{y}_{w2} \end{bmatrix} \\ &= \boldsymbol{B} \cdot \begin{bmatrix} \dot{x}_{w1} \\ \dot{y}_{w1} \\ \dot{x}_{w2} \\ \dot{y}_{w2} \end{bmatrix} \end{aligned} \tag{9}$$

Consequently from Eqs. (5) and (9), we can get the following homogeneous forward kinematics of the robot:

$$\begin{bmatrix} \boldsymbol{V} \\ 0 \end{bmatrix} = \begin{bmatrix} v_{xw} \\ v_{yw} \\ \dot{\phi} \\ 0 \end{bmatrix} = \boldsymbol{B} \cdot \boldsymbol{A} \cdot \begin{bmatrix} \omega_{r1} \\ \omega_{l1} \\ \omega_{r2} \\ \omega_{l2} \end{bmatrix} = \boldsymbol{B} \cdot \boldsymbol{A} \cdot \boldsymbol{\omega} \tag{10}$$

Hence, the inverse kinematics of the robot, i.e., with the given desired velocity vector $\boldsymbol{V_d}$ of the robot, the necessary driving velocity vector $\boldsymbol{\omega_d}$ of the four wheels is given by

$$\boldsymbol{\omega_d} = \begin{bmatrix} \omega_{r1} \\ \omega_{l1} \\ \omega_{r2} \\ \omega_{l2} \end{bmatrix} = \boldsymbol{A}^{-1} \cdot \boldsymbol{B}^{-1} \cdot \begin{bmatrix} v_{xw} \\ v_{yw} \\ \dot{\phi} \\ 0 \end{bmatrix} = \boldsymbol{A}^{-1} \cdot \boldsymbol{B}^{-1} \cdot \begin{bmatrix} \boldsymbol{V_d} \\ 0 \end{bmatrix} \tag{11}$$

where,

$$\boldsymbol{A}^{-1} = \frac{1}{r} \left[\begin{array}{c|c} {A_1}^{-1} & 0 \\ \hline 0 & {A_2}^{-1} \end{array}\right] \tag{12}$$

$$A_i^{-1} = \begin{bmatrix} \cos\phi_i - \frac{d}{s}\sin\phi_i & \sin\phi_i + \frac{d}{s}\cos\phi_i \\ \cos\phi_i + \frac{d}{s}\cos\phi_i & \sin\phi_i - \frac{d}{s}\cos\phi_i \end{bmatrix} \tag{13}$$

$$\boldsymbol{B}^{-1} = \begin{bmatrix} 1 & 0 & -L\cos\phi & \sin\phi \\ 0 & 1 & -L\sin\phi & -\cos\phi \\ 1 & 0 & L\cos\phi & -\sin\phi \\ 0 & 1 & L\sin\phi & \cos\phi \end{bmatrix} \tag{14}$$

Now by rewriting $\boldsymbol{B}^{-1}$ as:

$$\boldsymbol{B}^{*} = \begin{bmatrix} 1 & 0 & -L\cos\phi \\ 0 & 1 & -L\sin\phi \\ 1 & 0 & L\cos\phi \\ 0 & 1 & L\sin\phi \end{bmatrix} \tag{15}$$

We can get the following inverse kinematic equation of the robot:

$$\boldsymbol{\omega_d} = \begin{bmatrix} \omega_{r1} \\ \omega_{l1} \\ \omega_{r2} \\ \omega_{l2} \end{bmatrix} = \boldsymbol{A}^{-1} \cdot \boldsymbol{B}^{*} \cdot \begin{bmatrix} v_{xw} \\ v_{yw} \\ \dot{\phi} \end{bmatrix} = \boldsymbol{A}^{-1} \cdot \boldsymbol{B}^{*} \cdot \boldsymbol{V_d} \tag{16}$$

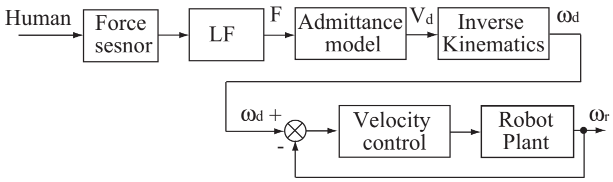


Fig. 5. Admittance based control

As discussed in section IV, $\boldsymbol{V_d}$, the desired velocity of the robot, is obtained from the introduced admittance controller, and the $\boldsymbol{\omega_d}$, each wheel's speed command, is used for velocity control.

## IV. Admittance based power assistance

Here, admittance controller is introduced in order to realize the power assistance when an old or a disabled user holding the handle to walk or a caregiver holding the handle to push the robot while a patient sitting in the seat. Admittance of a mechanical system is defined as [24]

$$\boldsymbol{G} = \frac{\boldsymbol{V}}{\boldsymbol{F}} \tag{17}$$

where, $\boldsymbol{V}$ is the velocity and $\boldsymbol{F}$ is the contact or applied force, both at the point of interaction. A large admittance corresponds to a rapid motion induced by applied forces; while a small admittance represents a slow reaction to act forces. For our situation, since user's (the elderly, the disabled, or the caregiver) walking speed doesn't change a lot, a large admittance implies relatively small forces needed to exert to the robot. This is the basic principle of power assistance. Note that almost similar approaches had been already used for the elderly's walking support ([4], [18]), since our robot can be used both by elderly or disabled person and the caregiver, the approach is extended to the caregiver's power assistance.

In this study, the admittance of the human-robot system is defined as a transfer function with the user's applied forces and torques, $\boldsymbol{F}(s)$, as input, and the robot's velocities, $\boldsymbol{V}(s)$, as the output. The time response $\boldsymbol{V_d}(t)$ of the admittance model is used as the desired velocity of the robot. Then, the desired driving speed $\boldsymbol{\omega_d}$ of each wheel is calculated from $\boldsymbol{V_d}(t)$ by the inverse kinematics equation (16), and the $\boldsymbol{\omega_d}$, as each wheel's speed command, is used for velocity control. The admittance based control process is shown in Fig.5, in which a digital LF (low-pass filter) cuts off the high frequency noises in the signals from the 6-axis force/torque sensor.

In the forward direction ($X_R$ direction in Fig.4), the admittance can be expressed as

$$G_x(s) = \frac{V_x(s)}{F_x(s)} = \frac{1}{M_x s + D_x} \tag{18}$$

where, $M_x$ and $D_x$ are respectively the virtual mass and virtual damping of the system in forward ($X_R$) direction.

The time response $V_{xd}(t)$ for a step input $F_x$ of the above transfer function is:

$$V_{xd}(t) = \frac{F_x}{D_x}(1 - e^{-t/\tau_x}) \tag{19}$$

Fig. 6. A caregiver pushes the robot while a person sitting in the seat.

where, $\tau_x$ is the time constant defined by $\tau_x = M_x/D_x$. The steady state velocity of the system is $V_{xs} = F_x/D_x$. This means that the force exerted to the robot by the user determines the velocities of the system (user and machine). In other words, when the user's steady forward walking velocity is $V_{xs}$ (this velocity usually doesn't change a lot for a user), then the necessary pushing force $F_{xs}$, or saying, the burden the user feels reacted from the robot, should be

$$F_{xs} = V_{xs} \cdot D_x \tag{20}$$

Thus, by adjusting the virtual damping coefficient $D_x$, the user will have different burden feeling. And further by altering virtual mass coefficient $M_x$ (therefore $\tau_x$ is changed), we can get the different dynamic corresponds of human-machine system. Our experiments will verify this.

## V. Experiments and discussions

In our previous research, the omnidirectional mobility of the robot is experimentally implemented, refer to [23] for the detail. Here, the developed admittance based interaction control is tested. The sampling and control period is 1 [kHz] and the robot's weight is 15[kg]. Fig. 6 shows the experimental situation, in which, one person as a caregiver is holding the robot handle to move (push) the robot forward while another person as an old or a disabled person needed to be cared, whose weight is 65[kg], is sitting in the seat.

### A. Experiment without power assistance

First, we turn off the motor drivers and carry out the experiment without power assistance. In this case, the motors are in free state and the robot is just like a traditional manual-operated wheelchair. Fig. 7. (a) and (b) respectively show the result with and without one 65[kg] person in the seat. We can find:

1) to start to move the robot, a big pushing force as large as 26[N] and 45[N] is respectively needed.
2) in steady state, the pushing force is respectively about 18[N] and 25[N]. (From this, it is clear that the rolling friction between the wheels and the floor is disproportionate to the weight of the human-machine system).
3) to stop the robot, a negative (pulling) force is needed.
4) the user's walking speed is about 0.6[m/s].

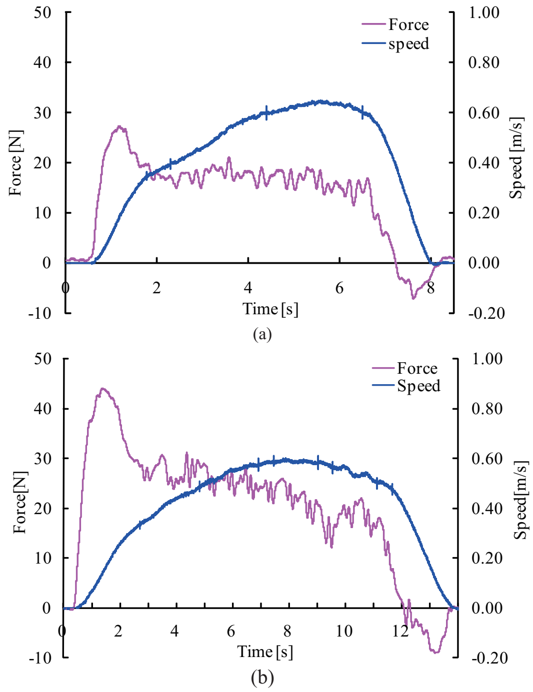


Fig. 7. Experimental results without assistance: (a) no person in the seat; (b) one 65[kg] person sitting in the seat

## B. Experiments with power assistance as $D_x = 20$[N·s/m]

In this case, we set $D_x = 20$[N·s/m]. According to eq.(20), since the user's walking speed is around 0.6[m/s], then the pushing force would be controlled at about $F_x = V_{xs} \cdot D_x = 12$[N], no matter what the load (the person sitting in the seat or not) is. The experimental result of no person sitting in the seat with parameter $\tau_x = 0.3$[s] is shown in Fig.8.(a); while in (b) and (c) one 65[kg] person is sitting in the seat but with different $\tau_x = 0.5$[s] and $\tau_x = 1.1$[s]. These results indicate that the pushing forces are controlled to about 12[N] when the steady walking speed is about 0.6[m/s] as we planned. Meanwhile, almost no pulling (negative) force is needed to stop the robot, which can be directly interpreted by eq.(19) or (20). Therefore, the purpose of power assistance is achieved.

The results of Fig.8.(b) and (c) show that the user's burden (pushing force) in steady state is halved to about 12[N] from 25[N] (refer to Fig.7.(b)). Note that different from the result in Fig.8.(b), Fig.8.(c) shows that an about 25[N] big pushing force occurs at the start to move the robot. This can be explained as follows. The parameter $\tau_x$ used in Fig.8.(c) is 1.1[s]. This means, the virtual mass coefficient $M_x(= \tau_x \cdot D_x)$ is set to be 22[kg]. While $\tau_x$ in Fig.8.(b) is 0.5[s], thus $M_x$ is 10[kg]. Since mass is a metric of inertia, the more the inertia of an object is, the bigger the force to move the object is.

Generally, a small $\tau_x$ or $M_x$ is helpful for smoothly starting to move the robot. But a too small $\tau_x$ or $M_x$ will make the system too sensitive to the exerted force. This will lead to the user fearful to use the robot.

## C. Experiments with power assistance as $D_x$=10, 40[N·s/m]

To further testify the effect of the parameter $D_x$ to the walking, we also did the experiments with different $D_x$ when a 65[kg] person sitting in the seat. The result with $D_x = 10$[N·s/m] and $\tau_x = 0.10$[s] ($M_x = 1.0$[kg]) is shown in Fig. 9. It shows that during the middle phase from time 6.0[s] to 10[s], the average walking speed is about 0.73[m/s], and the pushing force is about 7.5[N]. Note that the walking speed in this case is faster than in the above cases, since in walking the user feels very light (the pushing force, or saying the burden, of the user, is smaller).

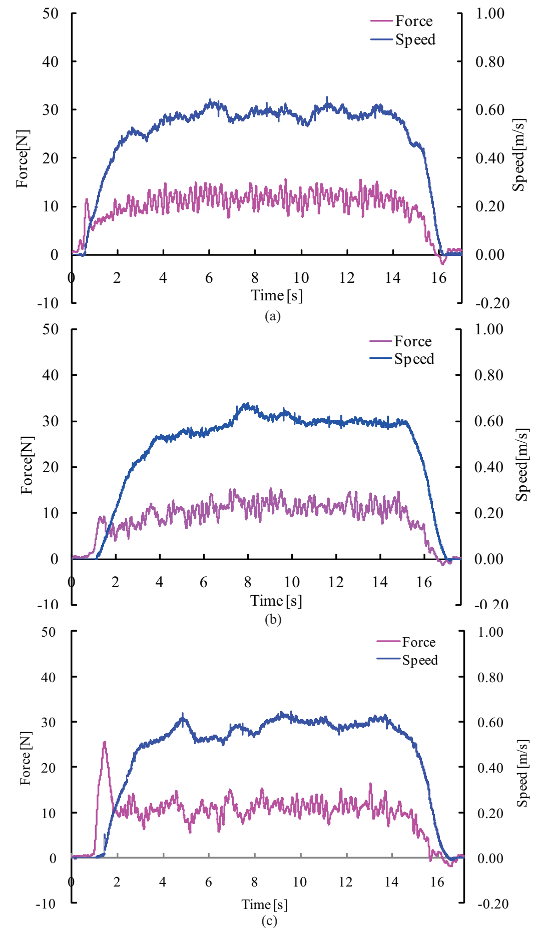


Fig. 8. Experimental result with assistance as $D_x = 20$. (a). no person in the seat ($\tau_x = 0.3$). (b) person in the seat ($\tau_x = 0.5$). (c) person in the seat ($\tau_x = 1.1$).

Contrarily, Fig.10 shows the result with a big $D_x = 40$[N ·s/m] as $\tau_x = 0.3$[s] ($M_x = 12$[kg]). The pushing force is about 22[N] as the walking speed is about 0.53[m/s]. Note that this walking speed is lower than other cases, since the user feels somewhat heavy in walking.

All of the experimental results demonstrate that the developed admittance based controller has well performance for controlling the pushing force (the user's burden). According to different applications such as the elderly's walking support, the disabled's walking rehabilitation, or the caregiver's power assistance, the virtual mass and damping coefficients can be arbitrarily adjusted so that the user will have different burden feelings, and further his/her walking speed can be indirectly changed.

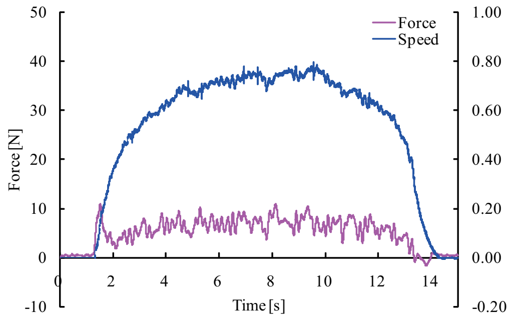


Fig. 9. Experimental result with power assistance as $D_x = 10$ and $\tau_x = 0.10$ while a 65[kg] person sitting in the seat.

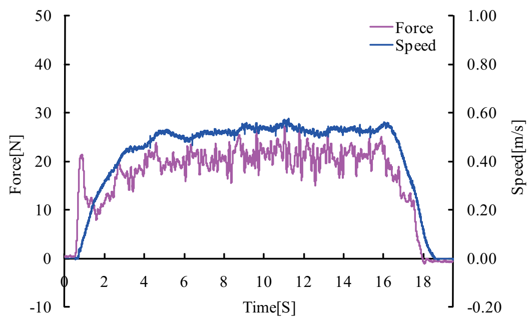


Fig. 10. Experimental result with assistance as $D_x = 40$ and $\tau_x = 0.3$ while a 65[kg] person sitting in the seat.

## VI. Conclusions

In this research, we developed a new type of omnidirectional mobile robot that not only can fulfill the walking support or walking rehabilitation as an elderly or a disabled user walks while holding the robot handle, but also can realize the power assistance for a caregiver when he/she pushes the robot to move while a patient is sitting in the seat. The omnidirectional mobility of the robot is analyzed, and an admittance based human-machine interaction controller is introduced for power assistance. The experimental results show that the pushing force can be altered arbitrarily and well controlled as we planned. The purpose for walking support and power assistance is achieved.

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