A Driving Assistance System for a Manual Wheelchair using Servo Brakes

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Abstract: We propose a novel intelligent wheelchair based on the passive robotics. Our proposed assistive wheelchair consists of a frame, casters, wheels and servo brakes. Our wheelchair system estimates the trajectory its user wants using the characteristic of the row motion and realizes the estimated tracks by controlling a torque of its servo brake. Our system requires no actuators, and its mechanism is simple and low cost. There is no risk by malfunction of servomotors and patients can use it intuitively because they use our wheelchair passively with their own intentional force. Our key ideas are two topics. One is the development of a passive-type assistive wheelchair which is suitable for practical use. The other key topic is a novel driving assistance algorithm with estimation of its user's intention. For realizing this estimation, we use a minimum jerk trajectory model, which expresses a typical human movement. Our proposed system compares a beginning part of row motion by the user and this trajectory model, and estimates a whole row motion which will be operated. Using our proposed system, the user can drive our wheelchair with a natural feeling. We test our proposed assistance system by the experiments with our prototype and verify its effectiveness.

1 INTRODUCTION

Wheelchairs are widely used by many people who are mobility impaired in daily activities. However, many accidents often occur to wheelchair users and its risk is serious. More than 80% of wheelchair accidents are caused by environmental problems (National Consumer Affairs Center of Japan, 2002). Especially, an inclination of sidewalk has high risk for a wheelchair user. In Japan, it is permitted to incline a sidewalk up to 5deg (Fig.1) (Japan Institute of Construction Engineering, 2008). This inclination leads a wheelchair user to run out from the sideway to the roadway and it causes the accident between a wheelchair user and a car. Therefore, a driving assistance system for a wheelchair is important.

In previous works, a lot of assistive technologies for wheelchairs are developed. In general, many handicapped people traditionally use power wheelchairs (Yamaha Motor Co., Ltd., 2012) and previous researchers have tried to realizing assistance functions by adding wheels with actuators and controlling them based on the robot technology such as motion control technology (Miller and Slack, 1995), sensing technology and computational intelligence (Katevas et al., 1997) (Murakami et al., 2001). These intelligent wheelchairs provide many functions, such as a suitable motion, an obstacle avoidance and a navigation; thus, they provide a maneuverable system. However, many wheelchair users have an upper body strength and dexterity to operate a manual wheelchair. For these wheelchair users, its cost is too expensive and is not acceptable.

On the other hand, a manual wheelchair without servomotors, which consists of a frame, wheels, casters and hand brakes, is commercially available and widely used. Its mechanism is simple and low cost. There is no risk by malfunction of servomotors and patients can use it intuitively because they use these wheelchairs passively with their own intentional force. Of course, these wheelchairs cannot assist to drive dynamically as powered wheelchairs and there is still a risk on a slope such as Fig.1. Thus, there is no well-adapted wheelchair assistance system for healthy users who have an

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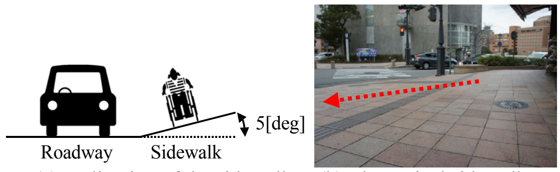
upper body strength.



(a) Inclination of the sidewalk (b) The typical sidewalk

Figure 1: Risks of the sidewalk.

Therefore, in this paper, we propose a passive-type assistive wheelchair with servo brakes. We use a concept of passive robotics. This system moves passively based on external force without actuators. Our system uses servo brakes, which can change brake torque, and realizes the desired motion using servo brakes according to the applied force and reference tracks. For realizing a natural assistance according to its user's intention, we develop a novel driving assistance scheme for a wheelchair with the estimation of the direction which its user wants to go.

This paper is organized as follows: we introduce a mechanical design and controller of our system in section 2; we propose a driving assistance scheme with the estimation of the user's intention in section 3; we show experimental results using our prototype in section 4; section 5 is conclusion of this paper.

2 PASSIVE-TYPE ASSISTIVE WHEELCHAIR

2.1 Passive System

A passive system realizes a reference motion using servo brakes with external force applied by its user. The passive robotics system requires no actuator and its mechanism is simple, therefore, the system will be low cost (Goswani et al., 1990) (Rentschler et al., 2003). In the research area of the assistive robotics, the passive robotics concept has been used for the walker and its performance is useful (Hirata et al., 2007).

This characteristic is especially suitable for a wheelchair assistance system for healthy users who have enough upper body strength to operate a manual wheelchair. Therefore, we adapt this concept for our wheelchair driving assistance system.

2.2 System Configuration

Fig. 2(a) shows our prototype. Our proposed wheelchair utilizes a powder brake, which is one of a servo brake. A powder brake is widely used in industrial purposes and its cost is low comparing with the other servo brakes. We choose the powder brake as Fig.2(b) (ZKG-YN50, Mitsubishi Electric Corp.), which can generate enough brake torque for stopping 4km/h moving wheelchair with a 100kgf user by 1sec.

Our prototype is based on a normal wheelchair (BM22-42SB, Kawamura Cycle Co. Ltd.) and our system has compatibility with a general wheelchair, which fulfills these standards (ISO7193, 7176/5). This means the user can built our system into their wheelchair without a special construction.

Fig.3 shows its controller. Our wheelchair has two powder brakes with the tension controller on each wheel. Our system can measure the rotational velocity using encoders on each wheel. All devices including the batteries are equipped in its body and can continue to work more than 24 hours without an external power supply.

(a) Overview (b) Installed brake

Figure 2: Our Prototype.

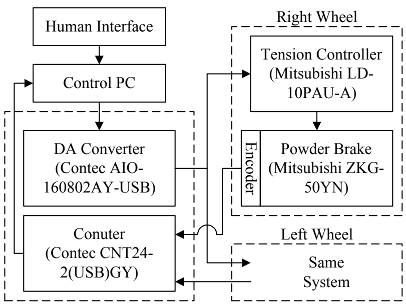


Figure 3: Our Control System.

2.3 Kinematics

Fig.4 shows a kinematic relationship of our wheelchair. The rotational radius of its trajectory R is derived as (1).

$$R = \frac{T}{2} \cdot \frac{v_R + v_L}{v_R - v_L} \quad (1)$$

where the velocity of a right wheel is v_R and one of a left wheel is v_L. The distance between the wheels is *T*. If *R* is negative, the wheelchair turns to right direction and if R is positive, it turns to left direction.

From (1), the ratio between v_R and v_L sets its turning radius and in next section, we will discuss this ratio for derivation the trajectory path.

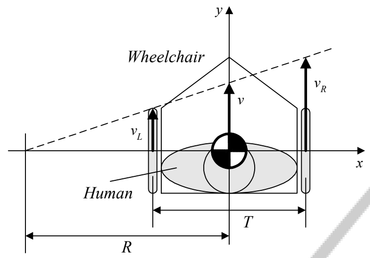


Figure 4: Kinematic model of the wheelchair.

3 DRIVING ASSISTANCE CONTROLLER

3.1 Concept of Our proposed Controller

Many previous researches on the wheelchair driving assistance control are designed for powered wheelchairs (Katsura and Ohnishi, 2004); (Sakai et al., 2010); (Takahashi et al., 2000) and they are based on traction control. However, a passive system does not generate a traction force and cannot use these methods. Thus, we develop a driving assistance control scheme which is based on a velocity control.

Usually, a movement of a wheelchair consists of two phases. In first phase, its user rows a wheelchair and accelerates it. In this phase, a movement of the wheelchair is based on its user's intention. In second phase, the wheelchair runs with inertia. In this phase, a shape of a ground such as slopes influences movement of the wheelchair easily.

Using its characteristic, we propose a novel driving assistance controller for a passive-type assistive wheelchair. Our proposed scheme estimates a trajectory its user wants to go at a beginning of the first phase and controls its wheels based on the estimated result by the end of the second phase. When the user rows the wheel again, our system finishes this wheel control and restarts from the estimation process.

Our estimation scheme measures a beginning part of a row motion by the user and compares a measuring trajectory and a minimum jerk trajectory model which expresses a typical human motion (Flash and Hogan, 1985); (Seki and Tadakura, 2004). After estimation the user's intention, our system sets the reference trajectory based on this result and controls the servo brake for realizing it. Our idea does not require additional force sensors. Thus, its implementation for a general wheelchair is easy and its cost is low.

3.2 Minimum Jerk Trajectory Model

In the field of neurophysiology, previous researchers have analyzed voluntary human arm movements and demonstrated that they can be closely approximated by a minimum jerk trajectory model with characteristic velocity profile (Flash and Hogan, 1985). This model is useful for various fields of human robot interaction technologies (Seki and Tadakura, 2004) and in this study, we use this model for the estimation of a row motion by the wheelchair user.

In the minimum jerk trajectory model, the human arm movements, supporting one-dimensional movement, is expressed as the trajectories which minimize (2).

$$C_j = \int_0^{t_f} \left(\frac{d^3 x(t)}{dt^3} \right)^2 dt \tag{2}$$

where t_f is the final time of the movement and $d^3 x(t) / dt^3$ is the differential of acceleration, called jerk. C_j is an extremum when $x(t)$ is the solution of Euler-Poisson equation. The resulting equation is represented by (3).

$$\frac{d^6 x(t)}{dt^6} = 0 \tag{3}$$

This condition shows that $x(t)$ is the fifth order polynomial as (4).

$$x(t) = a_5 t^5 + a_4 t^4 + a_3 t^3 + a_2 t^2 + a_1 t + a_0 \tag{4}$$

We assume the start position is x_0 and end position is x_f. Furthermore, we assume the velocity and acceleration are zeros at the start position and the end position, then the boundary conditions are derived as (5).

$$\begin{aligned} x(0) = x_0, \quad \dot{x}(0) = 0, \quad \ddot{x}(0) = 0 \\ x(t_f) = x_f, \quad \dot{x}(t_f) = 0, \quad \ddot{x}(t_f) = 0 \end{aligned} \tag{5}$$

Appling (5) to (4), $x(t)$ is expressed as (6) and (7).

$$x(\tau) = x_0 + (x_f - x_0)(6\tau^5 - 15\tau^4 + 10\tau^3) \tag{6}$$

$$\tau = \frac{t}{t_f} \tag{7}$$

Using the minimum jerk trajectory model, we define the human arm behavior characteristic on the row movement on the wheelchair.

3.3 Estimation of the User's Intention

Using the minimum jerk trajectory model, we estimate the direction its user wants to go. For realizing the estimation, we propose a following method as show in Fig.5.

Our system measures a rotation velocity of each wheel. If the rotation velocity of a right or left wheel increases Δt continuously, our system judges the user rows the wheelchair and starts to estimate the user's motion using the minimum jerk trajectory model. Our system sets $\Delta t = 0.2$ sec experimentally and this value is derived in section 4.1.

Furthermore, our system sets the time $t = t_0$ at the moment when the rotation velocity increases. At the same time, our system measures the position (x_0), velocity ($\dot{x}_0$) and acceleration ($\ddot{x}_0$). We assume that the boundary condition of the minimum jerk trajectory model is as (8) (Seki and Tadakura, 2004). The velocity and the acceleration at $t = t_0$ are not necessarily zeros as (5) because the user may row the hand rim and accelerate the wheelchair when the wheelchair moves.

$$\begin{aligned} &x(t_0) = x_0, \quad \dot{x}(t_0) = \dot{x}_0, \quad \ddot{x}(t_0) = \ddot{x}_0 \\ &x(t_0 + t_f) = x_f, \quad \dot{x}(t_0 + t_f) = 0, \quad \ddot{x}(t_0 + t_f) = 0 \end{aligned} \tag{8}$$

Using this assumption, the minimum jerk trajectory model is derived as (9) and (10).

$$\begin{aligned} x(t) = x_0 &+ (x_f - x_0)(6\tau^5 - 15\tau^4 + 10\tau^3) \\ &+ \dot{x}_0 (t - t_0)(-3\tau^4 + 8\tau^3 - 6\tau^2 + 1) \\ &+ \frac{\ddot{x}_0}{2}(t - t_0)^2(-\tau^3 + 3\tau^2 - 3\tau + 1) \end{aligned} \tag{9}$$

$$\tau = \frac{t - t_0}{t_f} \tag{10}$$

In (9) and (10), unknown values are end position x_f and the final time t_f. Therefore, our system uses a pattern matching method as (11) and derives x_f and t_f which minimize $c(x_f, t_f)$. We define the x_f and t_f which leads the minimum value of $c(x_f, t_f)$ as x_{f0} and t_{f0}.

$$c(x_f, t_f) = \int_{t_0}^{t_0 + \Delta t} \left| x(x_f, t_f)(t) - x_{real}(t) \right| dt \tag{11}$$

where $x(x_f, t_f)$ is the trajectory model with the end position x_f and the final time t_f . $x_{real}(t)$ is measurable value. Thus, $x(x_{f0}, t_{f0})$ approximates the user's motion with the sufficient accuracy for estimating its trajectory. In this study, we set the candidate of these values (x_f and t_f) as (12) based on our preliminary experiment results for reducing a calculation load of our controller.

$$\begin{aligned} x_f &= \{0.05, 0.10, 0.15, \cdots, 1.50\} \\ t_f &= \{1.0, 1.1, 1.2, \cdots, 5.0\} \end{aligned} \tag{12}$$

Our system excuses this matching process on each wheel. Therefore, our system estimates x_{f0} in right wheel (x_{f0}^R) and in left wheel (x_{f0}^L), and estimates t_{f0} in right wheel (t_{f0}^R) and in left wheel (t_{f0}^L). Our system uses these values for the direction estimation its user wants to go.

In (13), we estimate the average velocity in the first phase of the wheelchair movement and we assume this velocity shows the user's intention.

$$v_R^{est} = \frac{x_{f0}^R}{t_{f0}^R}, \quad v_L^{est} = \frac{x_{f0}^L}{t_{f0}^L} \tag{13}$$

where v_R^{est} is estimated velocity of right wheel and v_L^{est} is one of left wheel.

From (13), the rotational radius R^{est} of the estimated trajectory is derived as (14). If R^{est} is negative, the wheelchair turns to right direction and if R^{est} is positive, the wheelchair turns to left direction. Furthermore, when (15) is fulfilled, our system judges that its user wants to go at straight and sets $v_R^{est} = v_L^{est}$. $v_{threshold}^{straight}$ is the threshold which is derived experimentally.

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hand, when (22) s (14)

$$\left| v_R^{est} - v_L^{est} \right| < v_{threshold}^{straight} \tag{15}$$

If the $c(x_{f0}, t_{f0}) > c_0$, our system judges the user does not row the wheelchair. In this study, we set this threshold ($c_0 = 3.0$) experimentally. This value is derived in section 4.1.

When both wheels have fulfilled this condition, our system judges the wheelchair accelerates without the user's will and stops the wheelchair with maximum brake traction for safety reason. When only one of the wheels has fulfilled this condition, our system judges the user turns with small radius. In this case, our system sets the estimated value as (16) in case of the right wheel or (17) in case of the left wheel.

$$v_R^{est} = v_R(t_0), \quad v_L^{est} = \frac{x_{f0}^L}{t_{f0}^L} \tag{16}$$

$$v_R^{est} = \frac{x_{f0}^R}{t_{f0}^R}, \quad v_L^{est} = v_L(t_0) \tag{17}$$

3.4 Wheel Control Algorithm

Based on the estimated result, our system controls its wheels with a PID controller. The control algorithm is as follows.

For fitting the wheelchair to the estimated trajectory, the ratio between the velocity of the right wheel and the left wheel is same to the estimated results. Therefore, our system defines the control reference of both wheels (v_R^{ref} and v_L^{ref}) as (18).

$$v_R^{est} : v_L^{est} = v_R^{ref} : v_L^{ref} \tag{18}$$

Our system uses only servo brakes for controlling the wheelchair. Thus, when (19) is fulfilled, our system sets the control reference as (20) and (21).

$$\frac{v_R^{est}}{v_L^{est}} > \frac{v_R}{v_L} \tag{19}$$

$$\begin{cases} v_R^{ref} = v_R & (if \ v_R \le v_{\max}) \\ v_R^{ref} = v_{\max} & (if \ v_R > v_{\max}) \end{cases} \tag{20}$$

$$v_L^{ref} = \frac{v_L^{est}}{v_R^{est}} \cdot v_R^{ref} \tag{21}$$

In this case, our proposed system sets $v_R^{ref} = v_R$ and controls the left wheel. At the left wheel, $v_L > v_L^{ref}$ and our system can control the velocity with its servo brake. For safety reason, if the velocity exceeds the limitation value $v_{\max}$, our system reduces its moving speed to this limitation.

On the other hand, when (22) is fulfilled, our system sets the control reference as (23) and (24), and controls right wheel with its servo brake.

$$\frac{v_R^{est}}{v_L^{est}} < \frac{v_R}{v_L} \tag{22}$$

$$\begin{cases} v_L^{ref} = v_L & (if \ v_L \le v_{\max}) \\ v_L^{ref} = v_{\max} & (if \ v_L > v_{\max}) \end{cases} \tag{23}$$

$$v_R^{ref} = \frac{v_R^{est}}{v_L^{est}} \cdot v_L^{ref} \tag{24}$$

After setting the control references, our system uses PID controller as (25) in the left wheel or (26) in the right wheel when its velocity does not exceed the limitation. The control error integrates from t_0 and our assistance system tries to maintain the direction at the beginning of the row motion.

$$\tau_R = 0, \quad \tau_L = k_p e_L + k_i \int_{t_0} e_L dt + k_d \frac{de_L}{dt} \tag{25}$$

$$e_L = v_L^{ref} - v_L \quad \text{(if (19) is fulfilled.)}$$

$$\tau_R = k_p e_R + k_i \int_{t_0} e_R dt + k_d \frac{de_R}{dt}, \quad \tau_L = 0 \tag{26}$$

$$e_R = v_R^{ref} - v_R \quad \text{(if (22) is fulfilled.)}$$

According to (25) and (26), our system maintains the ratio between the velocity of the right wheel and the left wheel as (18). Therefore, our system with the proposed algorithm, controls the wheels only for fitting the trajectory its user wants and its velocity depends on the user's motion. Our system reduces the moving speed of the wheelchair only in case of

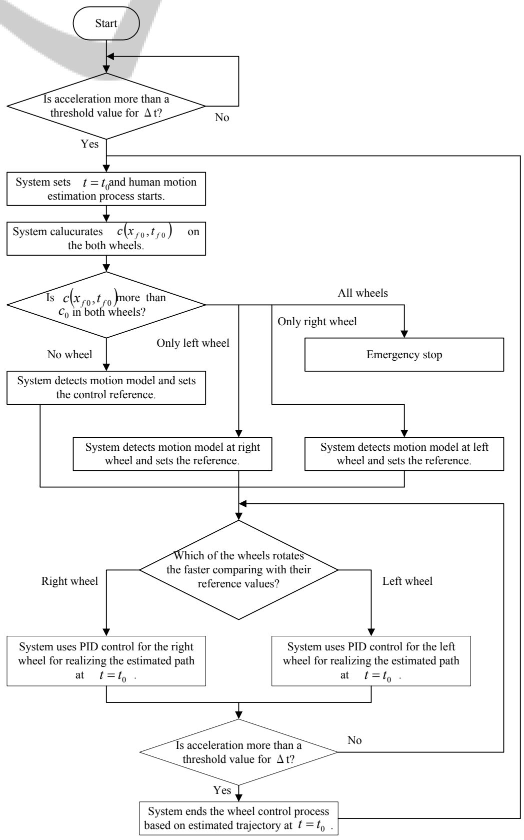


Figure 5: Estimation and control flow of our system.

the exceeding the limitation value v_{max} for safety reason.

Our system applies this control algorithm during one row motion based on its estimated trajectory, and in next row motion, our system re-estimates the user's trajectory and applies this algorithm again as Fig.5.

4 EXPERIMENTS

4.1 Parameter Derivation

Our assistance system uses two parameters, Δt is the estimation time parameter and c_0 is the pattern matching parameter which judges the row motion is done by the user or not. In this experiment, we derive the suitable values for two parameters.

4.1.1 Estimation Time Parameter

Our system estimates the row motion of the user by the measured wheel rotation velocity data during Δt seconds. Therefore, if our system sets Δt is large value, our system can use the large measuring data for estimation and the estimation accuracy will increase. However, Δt causes the time delay and Δt should be small for increasing usability.

This experiment uses 810 row motions by six subjects who use a wheelchair daily. Our proposed system estimates the whole operation from its Δt motion at the begging. Comparing between the estimated motion and the motion which extracted manually, we derive the success rate as Fig.6. From the experimental results in Fig.6, if the Δt is larger than 0.2[sec], the estimation performance is suitable. Therefore, we choose the smallest value from them and set $\Delta t = 0.2$.

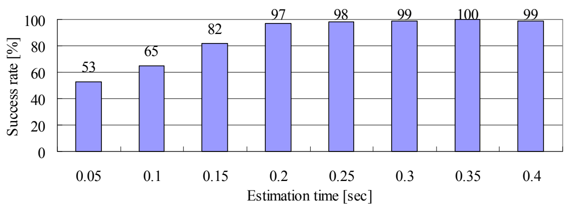


Figure 6: Success rate of each estimation time.

4.1.2 Pattern Matching Parameter

Our system judges the user has not performed any motion if the pattern matching error (11) exceeds the pattern matching parameter c_0. Therefore, this parameter is important for the safety of the user.

In this experiment, we adapt this evaluation method to the measuring data of our previous preliminary experiment in section 4.1.1. In these measuring data, the wheelchair accelerates 1100 times and 810 times are performed by the user's row motion. The experimental results are shown in Fig.7. The positive failure is the misjudgment the human motion as the acceleration by other reason and the negative error is the misjudgment the acceleration by other reason as the human motion. The negative error is more serious problem for safety reason and we choose $c_0 = 3.0$.

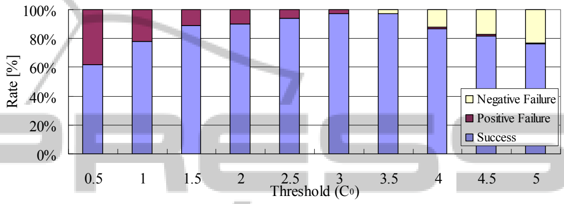


Figure 7: Success rate of each pattern matching parameter.

4.2 Field Test using our Prototype

For verifying the effectiveness of our system, we make two experiments using our prototype. In first experiment, we test the trajectory estimation performance. The other experiment, we test the performance of our wheelchair assistive system on the slope environment.

4.2.1 Estimation of the User's Trajectory

In this experiment, we test the proposed trajectory estimation scheme. The subject moves on the trajectory as Fig.8 and our system estimates it. We test 6 cases. In each case, six subjects who are healthy young people test our prototype ten times. Two subjects are left-handed and four subjects are right-handed. Fig.8 shows the experimental environment. We show the trajectory by drawing on the linoleum flat floor as Fig.8 and the subject moves on it using the wheelchair according to this trajectory.

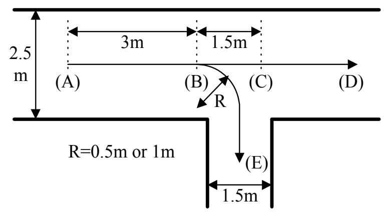
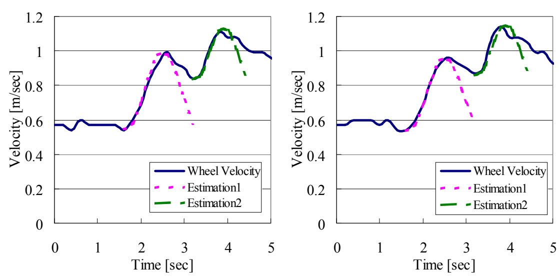


Figure 8: Experimental trajectory.

The condition of each case is as follows.

- Case1: The subject starts at (B) and goes straight. Around (C), the subject accelerates the wheelchair to (E) again. Our system estimates the trajectory at (B) and (C).
- Case2: The subject starts at (A) and goes straight at 0.6m/s. Around (B), the subject accelerates the wheelchair to the straight direction. Furthermore, around (C), the subject accelerates the wheelchair to the straight direction again. Our system estimates the trajectory at (B) and (C).
- Case3: The subject starts at (B) and turns to (E). A turning radius is 1m. Our system estimates the trajectory at (B).
- Case4: The subject starts at (A) and goes straight at 0.6m/s. Around (B), the subject turns to (E). A turning radius is 1m. Our system estimates the trajectory at (B).
- Case5: The subject starts at (B) and turns to (E). A turning radius is 0.5m. Our system estimates the trajectory at (B).
- Case6: The subject starts at (A) and goes straight at 0.6m/s. Around (B), the subject turns to (E). A turning radius is 0.5m. Our system estimates the trajectory at (B).

As the results, our system judges the straight direction in all trials in case (1) and (2). Fig.9 shows the estimated row motion in case (2). We can verify that our system succeeds to estimate the user's row motion twice in each wheel.



(a) Left wheel (b) Right wheel

Figure 9: Estimated row motion in case (2).

Fig. 10 shows estimated results by our proposed system in case (3) to (6) and Fig.11 shows the estimated row motion in case (4). In all cases, our system can estimates the turning radius with 12% error maximum and its accuracy is enough for practical use. The estimated results in case (3) are more accurate than the result in case (4). Because in case (4), the subjects turn at (B) with 0.6m/s and it is difficult for them to trace the trajectory accurately. Furthermore, the subjects operate the right wheel with the complex motion. From Fig.11(b), the subject does not row the right wheel, however, he coordinates the wheel velocity. Therefore, our system misjudges the velocity of the right wheel and in this case, estimated velocity is larger than its actual velocity.

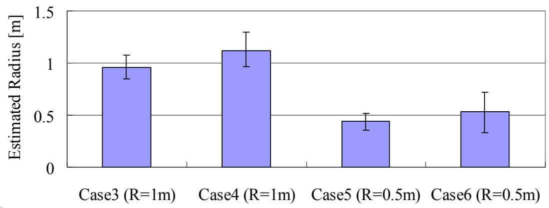
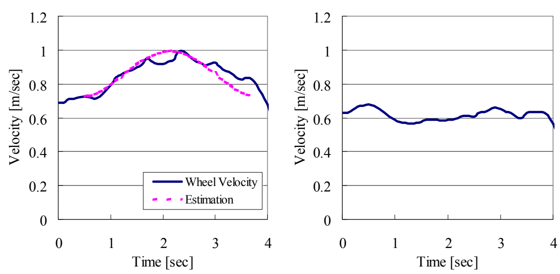


Figure 10: Estimated results in case (3) to (6).

The estimated results in case (5) and (6), there is same tendency in case (3) and (4). In both cases, the radius is 0.5m and the estimated results in case (5) are more accurate than the result in case (6). The disturbance of the estimated results in case (6) is large because for realizing the reference radius (0.5m), the subject should fix the right wheel and it causes the complex motion at (B) point.

The estimated error by left-handed subjects and right-handed subjects are almost same. However, left-handed subjects turn at about 0.57m/s and right-handed subjects turn about 0.52m/s in case (4). This may mean right turn motion is easy for left-handed person and in our future work, we should discuss a dominant hand of the wheelchair user.



(a) Left wheel (b) Right wheel

Figure 11: Estimated row motion at right direction in case (4). In the right wheel, our system detects there is no row motion by the subject.

4.2.2 Running Test on the Slope

In this experiment, we test the performance of our system in a typical high-risk situation to a wheelchair user. The subject goes straight using a wheelchair on a test load, which has 8deg inclination, with our assistance scheme. Furthermore, for verifying its effectiveness, the subjects do this experiment without our system. In each case, six subjects who are healthy young people test our prototype with an eye mask for removing the influences by visual information.

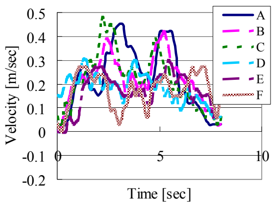
As the result, the user can go straight with our system as Fig.12(b). On the other hand, without our assistance system, it is difficult to go straight by the inclination as Fig.12(a). Fig.13 shows the difference between the velocities of right and left wheel during the experiment. When the difference is zero, the wheelchair goes straight and when the difference is the positive value, the wheelchair turns to the right direction (the gravity direction) as Fig.12(a). From Fig.13, the wheelchair goes straight with our assistance. Fig.14 shows the average value of Fig.13. In Fig.14(b), the maximum velocity difference is almost same and we can verify that our controller controls the wheels to realize the straight direction.

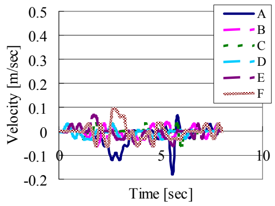
From these results, we can verify our system can assist to fit the trajectory which its user wants.

(a) Without assistance

(b) With assistance

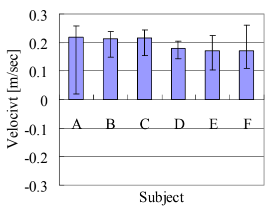
Figure 12: Test run on the slope (Subject A).

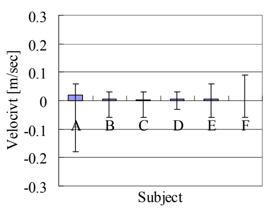




(a) Without assistance (b) With assistance

Figure 13: The velocity difference between a right and a left wheel. Positive value means the wheelchair turns to the right direction (The gravity direction).





(a) Without assistance (b) With assistance

Figure 14: The average value of the difference between the velocities of a right and a left wheel. Positive value means the wheelchair turns to the right direction (The gravity direction).

5 CONCLUSIONS

In this paper, we develop a novel assistance control for a passive-type wheelchair for healthy users who have enough upper body strength. For realizing the assistive wheel control, we develop the estimation scheme for the user's intention and our system controls its wheels based on the estimated results. Using our system, the user can move with the wheelchair easily to the direction he wants.

In our future work, we will improve the user's motion estimation scheme. In the experiments in section 4.2.1, the errors of the estimated trajectory tend to be large when the subject changes the motion rapidly. From our experiments, these motions are characteristic and we will classify them considering with the character of the wheelchair movement during these motions.

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