A Novel Control Method for the Power-assisted Wheelchair

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Abstract

Recently, welfare system is emerging as a new application of the control theory. In the industrial application of control, precise position, velocity, force trackings and strict disturbance rejections became the main object of control. But in the case of welfare application, other factors such as smooth control is more important than precise trackings or strict disturbance rejections.

In this research, we designed a novel controller for power-assisted wheelchair while considering the comfortability of rider. Conventional power-assistance system increases power(torque) uniformly, but here we increased torque while taking jerk into consideration. This is called frequency weighted assitance.

Keyword : human sensory control, parameter control, frequency weighted assistance, extended inertia contol

1 Introduction

Motors have served as good actuators in various environment, especially in the industry. But nowadays, we use motors for human beings, such as electric powered wheelchair, power-assisted wheelchair or powered-suits, electric pet.

Controller design used in such environment should be different from that of the industrial design; the objective of this control is not faithful tracking of the reference.

As an example of this control design, we deal with power assisting control of a wheelchair. The controller used in conventional power-assisted wheelchair just increases measured human torque uniformly. Figure 1 shows the dynamics of conventional power-assisted wheelchair.

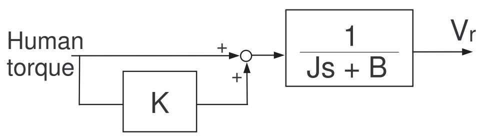

Figure 1: Conventional Power Assisting System

There are some researches on advanced control design for wheelchair. Most of them use feedforward method for power-assistance, that is, they do not feed back the velocity of the wheelchair. For example, in [1], feedback control is used for the compliance control[2] of a wheelchair. They use feedback control to change the relationship between a wheelchair and its environment, but do not use feedback control for power-assistance. In this research, we will use feedback control for the power-assistance of a wheelchair.

Jerk, especially the maximum value of jerk, is said to be strongly related to the comfortability of the rider. For the attenuation of jerk-peak, many effective methods have been proposed. However, there is no research on the control design for the comfortability of wheelchair yet.

In our proposed method, jerk-peak can be reduced by the proper choice of control parameters.

2 Power assistance using feedback control

2.1 Human torque as reference input

When designing power assisting control of wheelchair, there are some remarkable features.

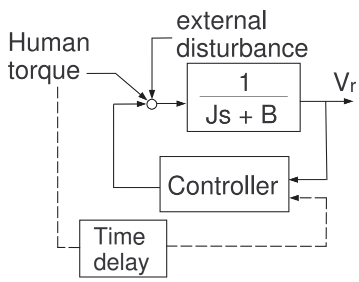

Figure 2: Characteristics of Human torque as reference input

In figure 2, human torque goes into the whole dynamics as disturbance. Any input to the plant that is not from the motor is recognized as disturbance. Human torque can be measured and used as the reference input of the controller. And, it is also a disturbance because it is different from motor torque. That is, human torque is a measurable disturbance and can be used as a reference, too.

Another remarkable point concerning human torque is about the measurement delays. Human torque is measurable, so it can be assisted by the controller, however if the measurement is delayed, human torque will be rejected by the controller, because it is a disturbance before measured. This can affect the performance of power assisting control.

Considering these features of human torque as a reference input, control design that can mask the intrinsic parameter of wheelchair is preferable for power assisting control. We call it parameter control.

2.2 Simple parameter control

The structure shown in figure 3 is the most simple structure of parameter control for a wheelchair. It can adjust the value of inertia and damping by changing the feedback gains J_A and B_A.

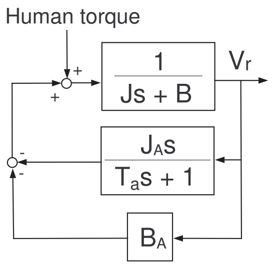

Figure 3: Simple Feedback Control

The dynamics from human torque to the velocity of the wheelchair will be like this:

$$T_{c1}(s) = \frac{1}{(J + J_A)s + (B + B_A)} \tag{1}$$

In this dynamics, the time constant $\frac{J+J_A}{B+B_A}$, and the DC gain $\frac{1}{B+B_A}$ are two important physical parameters. By changing J_A and B_A, we can change these two parameters. This is different from the conventional power assisting control shown in figure 1, which can only change the DC gain.

Note that these two physical parameters are changed in the form of "real parameter (J and B) + free parameter (J_A and B_A)". The variation in real parameter will directly affect the controlled wheelchair. If there is a sudden change in velocity due to external disturbance, it will harm the control system, because there is a direct differential feedback of velocity.

Taking these things into consideration, we will use the following control design for parameter change.

2.3 Extended Inertia Simulation Control

Hori[3] suggested an inertia control which can simulate the inertia value of motor using disturbance observer. Decreasing the inertia can function as power-assistance. In this section, we design power assisting controller using this inertia-decreasing technique. Hori's[3] inertia control only adjust inertia value in low frequency band. Adding damping factor into this control, we will have enough parameters that can adjust important physical features for power assistance in the wheelchair.

In figure 4, a controller design which includes the damping factor(B_N) is shown.

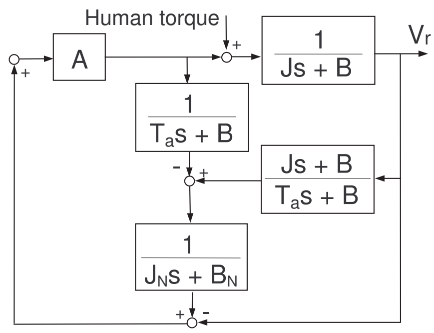

Figure 4: Extended Inertia Control

With this control system, the transfer function from human torque to velocity is:

$$T_{C2}(s) = \frac{1}{Js + B + A}\left(\frac{J_N s + B_N + A}{J_N s + B_N}\right) \tag{2}$$

In this control system the filter $\frac{J_N s+B_N+A}{J_N s+B_N}$ can be designed regardless of real parameters J, B.

3 Parameter analysis for human sensory control

In this section, time responses with step torque input will be checked, and using these time responses, we will find the physical meaning of control parameter.

Wheelchair dynamics can be simplified as:

$$P(s) = \frac{1}{\tau_b s + 1}\left(= \frac{1}{Js + B}\right) \tag{3}$$

For simplicity, DC gain, which was $\frac{1}{B}$ in previous figures, is normalized as 1 here. And the only parameter of the wheelchair will be τ_b which was $\frac{J}{B}$ in previous figures.

The dynamics of conventional power-assisted wheelchair is as follows,

$$P_{c1}(s) = \frac{K}{\tau_b s + 1}\left(= \frac{K}{Js + B}\right) \tag{4}$$

Conventional power-assisted wheelchair just increases human torque by K times. Contrary to it, the dynamics of a wheelchair controlled by the proposed method is written as equation(5).

$$\begin{aligned} P_{c2}(s) &= K' \frac{1}{\tau_{b'} s + 1} \frac{\tau_h s + 1}{\tau_l s + 1} \\ &= \frac{1}{Js + B + A}\left(\frac{J_N s + B_N + A}{J_N s + B_N}\right) \end{aligned} \tag{5}$$

This equation is same as equation (2). $K' = \frac{B_N + A}{(B+A)B_N}$, $\tau_{b'} = \frac{J}{B+A}$, $\tau_l = \frac{J_N}{B_N}$, and $\tau_h = \frac{J_N}{B_N + A}$ are the relationships between parameters. This means we can change any three of the above factors simultaneously by changing J_N, B_N, A.

3.1 Time constants and DC gain

DC gain K' is same as the assistance-ratio in the conventional power assisting control, but in the extended inertia control, it is the gain in the low frequency band. In the high frequency band, the gain will be changed.

In equation (2), $\tau_{b'} = \frac{J}{B+A}$,$\tau_l = \frac{J_N}{B_N}$ are two time constants. To investigate the role of these two time constants, step torque is used as input to $P_{c2}(s)$. Then, the velocity of the wheelchair will be,

$$v_r(t) = 1 - \frac{\tau_{b'} - \tau_h}{\tau_{b'} - \tau_l} e^{-\frac{1}{\tau_{b'}}t} + \frac{\tau_l - \tau_h}{\tau_{b'} - \tau_l} e^{-\frac{1}{\tau_l}t} \tag{6}$$

τ_h is set smaller then $\tau_{b'}, \tau_l$.

If $\tau_{b'} > \tau_l$ then, $e^{-\frac{1}{\tau_l}t} > e^{-\frac{1}{\tau_{b'}}t}$ and the coefficients will be $\tau_{b'} - \tau_h > \tau_l - \tau_h$. As time goes on, the coefficients $\tau_{b'} - \tau_h$ and $\tau_l - \tau_h$ play important roles, which means the first term has a larger effect on this velocity. But there also can be a period where the effect by $e^{-\frac{1}{\tau_l}t} > e^{-\frac{1}{\tau_{b'}}t}$ is larger than the effect by the coefficients; the second term has a larger effect on this velocity.

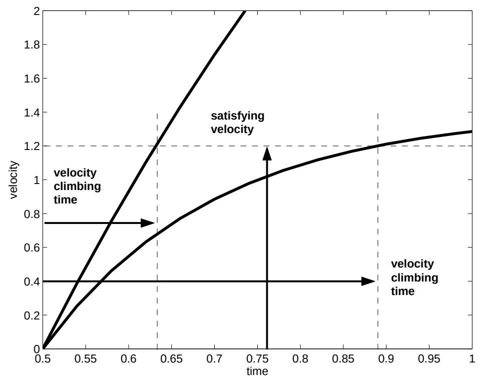

Figure 5: Important parameters in velocity (accelerating)

This analysis is required for human sensory control. When a person is riding a wheelchair, he controls the velocity. At the accelerating phase, human adds torque until the velocity reaches a certain level. We call this certain velocity level as 'satisfying velocity', and the time to reach 'satisfying velocity' as 'velocity climbing time'. In figure 5, the two velocity patterns are shown, and the satisfying velocity and climbing time are described. Decrease of this climbing time is related to the power-assistance. To decrease the velocity climbing time, DC gain K' should be high or time constants $\tau_{b'}, \tau_l$ should be small.

At the deceleration phase, the velocity damping time (described in figure 6) plays a important role in power assistance. It is related to $\tau_{b'}, \tau_l$. To increase the velocity damping time those time constants should be long.

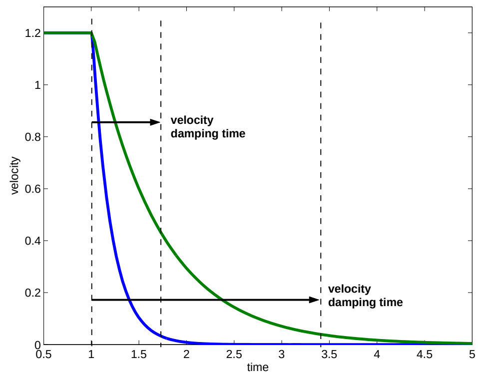

Figure 6: Important parameters in velocity (decelerating)

Proposed extended inertia control can change these parameters, so it can give good assistance.

3.2 Jerk-peak attenuation

Next, we investigate the jerk of the controlled wheelchair using step torque input.

First, if step torque is used as input to the wheelchair expressed by equation(3), the jerk will be

$$\frac{1}{\tau_b}\delta(t) - \frac{1}{\tau_b^2} e^{-\frac{1}{\tau_b}t} \tag{7}$$

The first term $\frac{1}{\tau_{b'}}\delta(t)$ is mainly concerned with the jerk-peak. If this term is too big, the human will feel unsafe.

In the case of conventional power-assisted wheelchair, jerk will be,

$$K\frac{1}{\tau_b}\delta(t) - K\frac{1}{\tau_b^2} e^{-\frac{1}{\tau_b}t} \tag{8}$$

K is the assist-ratio which is higher than 1. It means that jerk will be increased by K times, too. By this simulation, we can verify that the conventional power assisting control is not good for comfortability. In real experiments, where people really manipulated the conventional power-assisted wheelchair, many people said they felt unsafe.

In the case of proposed power assisting control, jerk will be like as follows.

$$K'\left(\frac{\tau_h}{\tau_{b'}\tau_l}\delta(t) + \frac{\tau_h - \tau_{b'}}{\tau_{b'}^2(\tau_{b'} - \tau_l)} e^{-\frac{t}{\tau_{b'}}} + \frac{\tau_h - \tau_l}{\tau_l^2(\tau_l - \tau_{b'})} e^{-\frac{t}{\tau_l}}\right) \tag{9}$$

Comparing with equation (8), the jerk-peak is changed from $K\frac{1}{\tau_{b'}}\delta(t)$ to $K'\frac{\tau_h}{\tau_{b'}\tau_l}\delta(t)$. If $K' = K$ and $\frac{\tau_h}{\tau_l} < 1$, then the jerk-peak will be reduced. This means that the jerk-peak can be reduced without any loss in DC gain.

The criterion $\frac{\tau_h}{\tau_l} < 1$ means that the gain at high frequency must be lowered to reduce the jerk-peak. In the low frequency, high assistance-ratio is adequate for good assistance performance, and in the high frequency, low assistance-ratio is adequate for the attenuation of the jerk-peak.

Figure 7 shows a jerk pattern when low pass filtered step torque is used as input. Two factors in this figure are important for power assisting control design. First is the peak value of jerk, second is the time span while jerk has a nonzero value.

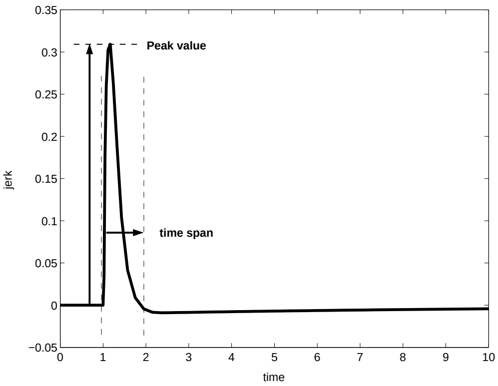

Figure 7: Important parameters in jerk

The peak value is related with how a person feels while accelerating, and the time span is related with the 'velocity climbing time'. Small peak value is good for the comfortability of rider, but a too small peak makes the 'velocity climbing time' longer and worsens the power assistance. But if we have sufficient time span by setting adequate time constants $\tau_{b'}, \tau_l$, the power-assistance will be improved.

4 Conclusion and future work

The potential of extended inertia control as a feedback control designed for power assisting control was explained. Taking the characteristic of human torque in power assisting control into consideration, parameter control is preferred. The extended inertia control is a good example of this parameter control.

Unlike the conventional control methods, proposed control method is a frequency weighted power-assistance. It has different gains in different frequency bands. Owing to this characteristic, we can reduce the jerk-peak accordingly.

Experiments will be done by the commercial power-assisted wheelchair JW-II (Figure 8). We are planning to use this experiments to evaluate the relationship between the control parameters and human sensory system. The results can help make the proper choice of parameters.

As we said in the introduction, the control design method used in the environment for human beings should be different from that for the industrial application. It is not established yet what performance is needed, or what

Figure 8: Experimental Equipment

a good performance is. These things must be researched for the next.

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