Velocity Control of a Wheelchair Using IMC-PID and IMC-PID Hybridized with Neural Network

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Abstract

This paper addresses the modelling, design, controller selection and simulations of wheelchair motion control. Where motion control of a wheelchair is modified to DC motor motion control. Therefore, DC motor is used and simulated to control the velocity of wheelchair.

PID controller has been used for this purpose. The advantage of PID controller is its feasibility but PID controller needs to adjust its proportional, integral and differential gains in order to give the better result. Even though the PID gains are well designed but still it has low robust ability as compare to other techniques.

To improve the response of the system by reducing overshoot, IMC-PID controller is designed. In IMC-PID controller, system becomes dependent on a single parameter unlike PID. The selection of that one single parameter is directly related to the robustness of the system.

Neural Network is hybridized with IMC-PID which helps the IMC-PID controller to adjust that parameter’s value and to make the system robust, adaptive and improving the system on dynamic and steady state performance.

Keywords: Velocity Control, Neural Network, IMC-PID, Wheelchair

1. Introduction

About 15-20% of every country’s population is disable. There are at least 650 million people with a kind of disability worldwide. Assistance and support are perquisites for many handicap people for participating in society. Assistive technology (i.e. wheelchair), is a potent tool to increase independence and improve involvement when suitable to the user and its surroundings especially in education and employment.

Electric powered wheelchair provides efficient mobility to motor impaired persons. It improves the potential of disable people to achieve their goals through the use of technology. Over the past 20 years, the design of powered wheelchair has been enhanced a lot, yet the control techniques needs improvement.

The structure of wheelchair control includes velocity, suspension, traction, stability and wheelchair navigation control but this paper will focus on velocity control techniques.

A lot of research has been conducted on electric power wheelchair so far. In a review paper [1], D. Ding and R.A. Cooper presents an inclusive evaluation of intelligent wheelchairs. In [2], R.A. Cooper states the importance of research on control algorithms and technologies of Electric Powered Wheelchair. Although Wheelchairs are available in different drive styles, same software is used in all the configurations, regardless of the fact that dynamics of the system varies substantially.

Numerous methodologies to assist mobility have been proposed. A high level of automation has been proposed by Taha that involves quite little user collaboration [3] and zeng offers an efficient collaborative wheelchair system which guides a user to walk on the path that has already been fed in software and user can control the speed [4]. Millan established a brain–machine interface for the severe physical disabled people [5]. Many
hybrid systems, such as Simpson [6] and Wheelesley [7] developed a Navchair which has diverse modes of operation.

Simulation and control of electric powered wheelchair is also a very significant research domain. An optimal control theory has been applied to the design and development of a control system for an EPW by K.E Brown [8]. A PID controller is developed in the technique which has auto-adaptive gains but still controller is not robust when it comes to external disturbance rejection J.B.Shung, described a model of a wheelchair which is moving on a sloping surface [9]. This computer model is proposed to enable the design of a wheelchair velocity feedback controller. He presented that wheelchair velocity feedback controller which is based on the wheelchair model and motor control circuitry [10].

EPWs are also controlled using adaptive intelligent assistance. R.Luo and T.M Chen presented a grey-fuzzy decision-making (GFD) algorithm [11]. This algorithm is based on grey prediction theory and fuzzy logic theory.

Today, many control systems, with the remarkable exclusion of wheelchairs, elucidate uncertainties and perturbations. For example, robust control approaches are functional for similar differential drive mobile robots in [12], [13] and [14].

1.1. Statement of the Problem

As discussed earlier, Speed is the most common control variable, purposely to develop a control system which enables the wheelchair a smooth and stable drive. Therefore different wheelchair speed control techniques are proposed. These techniques include PID controller, IMC-PID controller and the proposed IMC-PID controller hybridized with neural network.

The speed of a wheelchair has been controlled using PID controller before but the proposed technique of using IMC-PID controller Hybridized with Neural Network will make it robust. In IMC-PID controller, the whole system will depend upon a single parameter that is closed loop time constant $\alpha$. The proposed technique is supposed to train the network such that it will select an optimal value of closed loop time constant $\alpha$ which will further decrease the error and improve the response of the system.

1.2. Objective of the Research

The main objective of this research is to improve the step response of the wheelchair system. The response of the wheelchair using PID controller can be improved using the proposed IMC-PID controller hybridized with neural network.

The purpose of the research is to achieve a good control performance in terms of stability of the system and robustness for the system uncertainties.

2. Modelling and Design of the system

The elementary purpose of a wheelchair control system is Velocity Control. It regulates wheelchair speed for user comfort as directed by the user with the help of an input device.

In a wheelchair system, the most commonly controlled variable is Speed. The wheelchair driver applies input using a PC or joystick or analogous device. To achieve the desired velocity, a controller adjusts the voltage of the DC motor attached to the wheels.
A powered wheelchair is generally placed on a structure called, chassis, just like a mobile robot. This chassis or mobile robot is driven by four wheels. The two back wheels are free and two front drive wheels are fixed. Two separate DC motors are connected to the front fixed wheels through gear box. Both DC motors are independently powered so that desired movements of the wheelchair will be dependent on the commands given by the user to these wheels.

The motion of wheelchair is dependent on these two fixed wheels. These wheels can turn the wheelchair in any desired direction. These directions depends on the difference of both wheel’s rotation speed. A PC or a joystick (controlled by the user) controls the DC motor. The motor’s angular velocity is estimated by the odometers.

The average linear and angular speed of the wheelchair can be calculated as follows:

\[ v_w = \frac{v_{Right\ wheel} + v_{Left\ wheel}}{2} \]  
\[ \omega_w = \frac{v_{Right\ wheel} - v_{Left\ wheel}}{D} \]

where \( D \) = Distance between the wheels

With these kinds of drives, there are three interesting cases:
If \( v_l = v_r \) then there is a motion in forward straight line and there is effectually no rotation i.e., \( \omega \) is zero. According to formula, \( r \) becomes infinite
If \( v_l = -v_r \), then \( = 0 \), and system will rotate in its own place. Rotation about the midpoint \( P \) occurs.
If \( v_l = 0 \); Rotation about the left wheel occurs. Identical case when \( v_r = 0 \). Turning radius will have a value \( \frac{l}{2} \).

Where \( l \) = distance b/w the center of the wheels

2.1. Modelling of DC motor

The motion of the structure of the wheelchair is made easier by simplifying the system into a PMDC motor motion control. An electromechanical systems such as DC motor has electrical and mechanical components. A simplified equivalent representation of PMDC motor's electrical and mechanical components are shown in Figure 2.

We will consider the simple single degree-of-freedom case for the motion of the wheelchair structure. It will move forward and reverse. The equivalent model of the
wheelchair can be written using a basic model of a symmetric half of the structure that is constructed in Figure 3.

![Figure 2. Schematic of a Simplified Equivalent Representation of the PMDC Motor's Electro-Mechanical Components](image)

The derived equivalent transfer function of the system is given below.

\[
G_{\text{speed}}(s) = \frac{K_t}{[L_a J_{\text{equiv}}]s^2 + (R_a J_{\text{equiv}} + b_{\text{equiv}})s + (R_a b_{\text{equiv}} + K_t K_b)}
\]

(3)

![Figure 3. Representation of Symmetric Half of the System](image)

Substituting the nominal values (given in Section 4), the overall transfer function of the system becomes:

\[
G_{\text{speed}}(s) = \frac{0.3961}{0.2256s^2 + 0.3645s + 1.469}
\]

(4)

3. Control Techniques

The techniques used in this research are as follows:

i. PID controller

ii. IMC-PID controller

iii. IMC-PID Hybridized with Neural Network
There are many motor motion control approaches. Each has its advantages and disadvantages depending upon the specific type of application. The designer must select an appropriate technique which is the finest one for specific application.

3.1. PID Controller

In this system, PID controller is used to control the speed of DC motor attached to each wheel. It takes the error between the reference voltage and the output voltage of a tachometer as an input. Tachometer senses the output angular speed of DC motor and converts it into output voltage. PID controller controls the plant input and minimizes the error by changing its output depending upon the error.

PID controller has a fast response (i.e., short rise time), higher stability and no oscillations but still our system error is not reduced to zero and it has low robustivity. It is tough to select the most appropriate values for PID controller parameters. We selected these parameter’s values by hit and trial method. The PID controller transfer function is:

$$G_{PID} = k_p + \frac{k_i}{s} + s k_d$$  \hspace{1cm} (5)

3.2. IMC-PID Controller:

IMC stands for internal model control. PID controllers can be designed using IMC controller. There is only one tuning parameter, the closed loop time constant $\alpha$ in this IMC procedure. All the other control parameters such as the PID tuning parameters then becomes a function of this parameter $\alpha$. All the robustness of the closed loop system depends on the choice of the closed loop time constant $\alpha$.

If the control architecture is based on the precise model of the process, then perfect control is mathematically possible.

![Figure 4. IMC-PID Plant Model](image)

Where

$$G_{imc}(s) = \frac{C(s)}{1 - G(s)C(s)}$$

IMC based PID design involves the following steps:

1. Find the transfer function of IMC controller which includes a filter $f(s)$.

Where $s = \frac{1}{\alpha s + 1}^n$. Where $\alpha$ is the filter tuning parameter which varies the speed of the response of the closed loop system. When $\alpha$ is smaller than the time constant of the first order process the response is faster.

n=Order of filter

2. Find the equivalent standard feedback controller *i.e.*
3. Compare this equation with the standard equation of PID controller \( i.e. \)

Equation 6 refers as IMC based PID relationship because of its form \( i.e., \), which is mostly a PID controller. The major difference between IMC-PID and PID is that IMC-PID, most of the times, not required a controller to be perfect.

By comparing both equations, we get the PID gains as a function of the only tuning parameter \( i.e., \), \( \alpha \). Using this technique, the whole system depends on only a single parameter \( i.e., \), closed loop time constant \( \alpha \). We choose the preferred value for \( \alpha \). It is a trade-off between performance and robustness.

We considered model of the system to be perfect with no disturbance.

3.3. IMC-PID Hybridized with Neural Network

We use Neural Network to calculate the most appropriate value of closed loop time constant \( \alpha \) of the system. \( \alpha \) is an adjustable parameter, which determines the robustness and dynamic performance of the system. If \( \alpha \) is small, the will have better dynamic performance but poor robustness. It’s a tradeoff between robustness and dynamic performance.

\[
G_{imc}(s) = \frac{C(s)}{1 - \hat{G}(s)C(s)}
\]  
(6)

According to above figure, neural network is taking error and its delayed values as input and estimating the proper value of closed loop time constant.

The error values are fed to the Neural Network as input data. The weights of the NN are adjusted by the back propagation arithmetic to minimize the control error.

Output of Neural Network is then fed back into IMC-PID controller to update the controller. The output is then send to IMC-PID controller which further controls the plant. Controlled output has given to plant.

The schematic diagram of neural network architecture is given below:
Input of neural network can be written as:

\[ I(k) = \{e(k), e(k - 1), e(k - 2)\} \] (8)

There is only one hidden layer which can be represented as:

\[ H_j(k) = f(\sum_{i=1}^{3} W_{ij}(k) \ast I_i(k)) \] (9)

Output of neural network:

\[ \alpha(k) = f(\sum_{j=1}^{6} W_j(k)H_j(k)) \] (10)

where \( 0 < \alpha(k) < 1 \)

**4. Simulation and Results**

Topic comprises of design parameters and the results of all three controllers. The comparison of the controller is also described at the end.

**4.1. Design Parameters**

Design requirements of the wheelchair are given below:

\[ V_{in}=12, \; R_a=0.1557, \; L_a=0.82, \; K_b=1.185, \; K_e=1.1882, \; n=3, \; f_m=0.271, \; b_m=0.271, \; \angle=180, \; r=0.075; \; k_{pot} = \frac{V_{in}}{\text{angle}}; \; k_{tach} = \frac{V_{in}}{\text{desired angular speed}}; \]

\[ \text{Desired angular velocity } \omega = \frac{\text{Desired linear speed}}{r} \]

Chair height=0.920;  chair width=0.580;  Distance b/w wheels=0.40;
Desired linear speed of wheelchair = 0.55 m/s
Desired linear speed of right wheel=0.5 m/s
Desired linear speed of left wheel=0.6 m/s
4.2. Velocity Control using PID Controller

The graph of Wheelchair’s linear speed using PID controller is given below. Values for PID gains are given below:

\[ k_p = 36.55 \; ; \; k_i = 8.73 \; ; \; k_d = 8.33; \]

System attains its final value 0.52 m/s but according to calculations, it should be 0.55 m/s. System has 5.8579% of overshoot and settling time is 86.6461.

![Figure 7. Step Response of the System using PID Controller](image)

4.3. Velocity Control using IMC-PID Controller

After proper calculations, the transfer function of \( G_{imc} \) turns out to be the following equation

\[ G_{imc} = \frac{0.2256s^2 + 0.3645s + 1.469}{0.099s^2 + 0.3961s + 0} \]  \hspace{1cm} (11)

Where \( \alpha \) is taken as 0.5.

![Figure 8. Linear Speed of Wheelchair using IMC-PID Controller](image)
4.4. Velocity Control using IMC-PID hybridized with NN Controller

Figure 9 shows the results of IMC-PID controller hybridized with Neural Network. Desired results has been achieved using this technique. Neural Network toolbox has been used for the simulations.

![Linear Speed using IMC-PID hybridized With Neural Network](image)

**Figure 9. Linear Speed Using IMC-PID hybridized with Neural Network**

4.5. Comparison

Table 1 shows the comparison of all three controllers. This comparison shows that rise time of the proposed controller (IMC-PID hybridized with NN) is better than IMC-PID and settling time comes far before the other controller’s settling time. Similarly overshoot has been reduced to approximately zero.

<table>
<thead>
<tr>
<th>Characteristics</th>
<th>PID</th>
<th>IMC-PID</th>
<th>IMC-PID hybridized with NN</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rise time</td>
<td>5.1812</td>
<td>4.3367</td>
<td>5.1424</td>
</tr>
<tr>
<td>Settling time</td>
<td>30.45</td>
<td>16.5605</td>
<td>19.908</td>
</tr>
<tr>
<td>Overshoot</td>
<td>5.85%</td>
<td>1.65%</td>
<td>0.6638%</td>
</tr>
<tr>
<td>Final value (speed)</td>
<td>0.52 m/s</td>
<td>0.55 m/s</td>
<td>0.55 m/s</td>
</tr>
</tbody>
</table>

Table 1. Comparison of all Three Techniques
5. Conclusion

Analysis and evaluation of all three control strategies show that each has its own advantages. Using PID controller with proper gain values, almost desired response in desired time was attained. To achieve the fast response with minimum overshoot and steady state error, IMC-PID technique has been applied. A robust technique of intelligent controller has been introduced to the velocity control algorithm. IMC-PID is hybridized with Neural Network to make it robust with all improved desired requirement.

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References


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