The comparison respond of braking torque control between PID and SMC controller for electric powered wheelchair descending on slope condition

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Abstract. During descending on a slope, the speed of Electric Powered Wheelchair (EPW) tends to changed rapidly. Normally, most EPW is provided with mechanical braking system which transfers human pulling force of the lever creating friction at the tire. However, the task is difficult for the users are elderly or paralyses. However, even for normal user with good strength, in fear condition they tend to give sudden braking which leads to tire locking up and skidding, eventually EPW unstable. These problems will cause accident and injuries to the users if speed does not properly control. In this paper, the automated braking torque control method was proposed in EPW as alternative to solve this problem and increase the mobility and stability especially during descending on slope in other to help the user of the EPW as their daily transportation. In this research, Proportional-Integral-Derivative and Sliding Mode Control controller are compared to determine the best response for torque braking control. The rapid change of speed can be controlled by the braking torque using proposed controllers based on the desired constant speed set by the control designer. Moreover, the sudden braking that caused tire to lock up and skid can be avoided. Furthermore, result from SMC shows this controller have good time respond to maintain the speed based on desired value when descending at slope condition by controlling the braking torque compared to the PID controller.

1. Introduction

The usage of wheelchairs is increasing every year due to the increase of disabled people and elderly. The statement of "World Population Prospects: The 2012 Revision" conducted by the UN estimates that the population of 65 years old peoples and above is 16.5% by 2060 [1]. Moreover, there are almost 200 000 disabled people use wheelchairs as transportation in daily [2]. Meanwhile in Japan, EPW sales at the end of 2008 reached 530 00 units and continues to rise due to the age and ability factor [3]. From the statement of the use of wheelchairs, elderly and disable people depend on EPW in their daily life. Therefore, the research on wheelchairs is also important in other to improve performance and safety factors.

The EPW was introduced during World War II by George Klein who worked for the National Research Council of Canada. At that time, the EPW is just only equipped with electric motors, battery and controllers [4]. Currently, EPW had been integrated with a microcontroller system to make EPW performance more stable and user-friendly since the electric motor such as fast and precise torque respond [5]. Because of structural construction such as staircase, the EPW it is difficult to move. Nowadays, EPW has become intelligent that able to move even in a critical condition [6].

Furthermore, the EPW performance is further enhanced by introducing a stable system that is able to prevent the EPW from falling backward when passing a slope [7].

As we know, Ramps or slopes are provided when in the existence of a low staircase in most of new buildings to assist wheelchair users. However, when moving down the slope, it becomes difficult for users especially elderly and disabled because they have not enough strength to pull the braking lever in order to control the speed of EPW [8]. Even for user with good strength, during descending on slope in fear condition, they tend to give exceed force which leads to sudden braking. Effect from that, the tire will lock up and cause EPW to skid. Moreover, other condition such as slippery road and small contact patch of tire can also lead to this problem.

To avoid this problem, in this paper, we proposed the automated braking control during moving down on the slope instead using human braking inputs that caused sudden braking. We also compared the output response of speed between PID and SMC controller to identify the best controller to control the braking torque.

2. Analysis of EPW model

2.1. Specification of EPW

In this analysis, an EPW was used as shown in Figure 1 and the physical specifications of the EPW are shown in table 1 below. EPW is driven by in-wheel electric motor which is the each tire can be controlled independently. This EPW also be equipped with mechanical braking system for the manual braking form user.

Figure 1. Example Electric Powered Wheelchair for analysis.

Table 1. List of specification for EPW.

Parameter	Symbol	Unit
Maximum Speed	v_t	20 km/h
EPW mass	m_{EPW}	24 kg
Tire mass	m_t	12 kg
Tire inertia	I_t	0.635 kg.m^2

2.2. Mathematical modeling of EPW
2.2.1 Modeling of tire speed

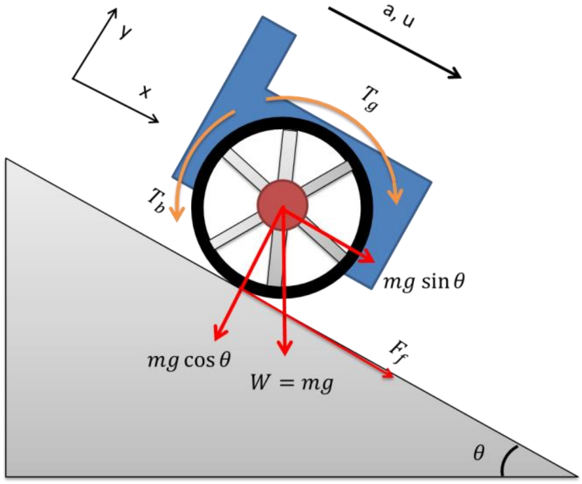

Figure 2. Dynamic body diagram of EPW during descending on the slope.

Figure 2 above shows the free rolling dynamic motion of EPW. Free rolling mean the EPW is moving without giving any external torque or forces. During descending on slope, EPW tends to move forward. This is because the existence of gravity weight ($mg\,sin\,\theta$) at x-component. The gravity weight at x-component will pull the EPW naturally. As result, the speed of EPW will increase. In this analysis, Castrol tire is neglected. When the EPW is pulled naturally by weight gravity at x-component, the torque is generated, T_g as derived as equation (1). The speed of tire is determined by using equation (2) and (3).

$$T_g = mg\sin(\theta)R \tag{1}$$

$$\dot{\omega} = \left(\frac{T_g - F_r R - T_b}{I_t}\right) \tag{2}$$

$$V_t = R\omega \tag{3}$$

Where ω is the angular speed of the tire, F_f is friction force, T_b is the applied braking torque, I_t and R is tire inertia and radius respectively. Since EPW moved at slope condition, F_f can be calculated by equation (4) where m is the tire mass and μ is the friction coefficient can be determine in equation (5) where k is depend on surface condition and ρ is slip ratio [9].

$$F_f = mg\cos(\theta)\mu \tag{4}$$

$$\begin{gathered}\mu_{driving} = -1.05k(e^{-45\rho} - e^{-0.45\rho}) \\ \mu_{braking} = 1.1k(e^{35\rho} - e^{35\rho}) \\ k = 0.8(dry) \\ k = 0.12(icy)\end{gathered} \tag{5}$$

Slip ratio can be determined by using equation (5) and (6). When the v_t > v known as driving and equation (6) is used. When v_t < v this condition known as braking and equation (7) is used.

$$\rho_{driving} = \frac{v_t - v}{v_t} \tag{6}$$

$$\rho_{braking} = \frac{v - v_t}{v} \tag{7}$$

2.3. Calculating speed of EPW

Determine the speed of EPW very important in order to know the behavior of EPW when moving in different surface condition. The EPW speed can be calculated by using Newton’s second law as shown in equation (8) where F_{fi} is force friction and subscript i to indicate left or right tire.

$$\dot{v} = \frac{\sum F_{fi}}{m_{EPW}} \tag{8}$$

3. Controller design

3.1 PID

Proportional, integral and derivative are the basic modes of PID controller, proportional mode provides a rapid adjustment of the manipulating variable, reducing error and speeds up dynamic response. Integral mode achieves zero offset. The derivative mode provides rapid correction based on the rate change of the controlled variable. The controller equation is given by equation (9)**.**

$$u(t) = k_p.e + k_i.\int e + k_d.\frac{de}{dt} \tag{9}$$

Where, e is the error between desired speed and actual speed. k_p, k_i, and k_d is the gain for proportional, integral and derivative respectively that need to be tuned in other to find the best speed response [10].

3.2 Sliding Mode Control

It is well known that SMC is one of the robust control methods to stabilize the disturbances, linear and non-linear system [11]. Figure 3 shows the block diagram of SMC. The desired angular speed in this simulation is set as 5 rad/s. This angular speed can be adjusted by user itself. Different from desired and actual angular speed know as error that used for SMC controller information **.**

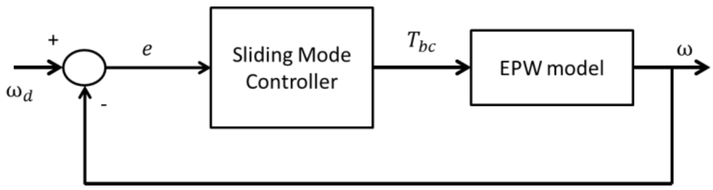

Figure 3. Block diagram of SMC.

The main objective of torque braking controller in this paper is to maintain the speed of the wheel during descending on the slope. By descending slowly, the stability of EPW will not lose. Therefore, the control objective becomes a tracking problem, and the tracking error can be defined as equation (10) where ω is the actual angular speed of tire, and ω_d is the desired angular speed of tire.

$$\omega_e = \omega - \omega_d \tag{10}$$

It is by designing the control law, the torque braking controller make its tracking error tend to zero in a finite time. Based on the above analysis, the sliding surface is taken as equation (11) where c must satisfy the Hurwitz condition, $c > 0$.

$$s = c(\omega_e = c(\ \omega - \omega_d), \text{sgn}\ (s) = \begin{cases} 1, & s > 0 \\ 0, & s = 0 \\ -1, & s < 0 \end{cases} \tag{11}$$

Differentiating the sliding surface, S with respect to time and taking the general reaching law into consideration. The purpose of reaching law is how faster the error to reach in sliding surface. It also will effect to the system responses. The equation obtained can represent as:

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$$\dot{s} = ce \doteq c(\dot{\omega} - \ \dot{\omega}_d) \leq -k\ .sgn\ (s) \tag{12}$$

where $k > 0$ is the control parameter which should be adjusted according to the number of uncertainties and disturbance. Recalling back from tire dynamic rotation in equation (1), then substitute into equation (12). The torque braking control to control the angular speed of the tire by using SMC is derived as equation (13) below.

$$T_{bc} = T_g - I\left(\frac{\dot{S}}{c} + \ \dot{\omega}_d\right) = T_g - T_f - \ \left(\frac{-k\ sgn\ (s)}{c} + \ \dot{\omega}_d\right) I_t \tag{13}$$

4. Result and discussion

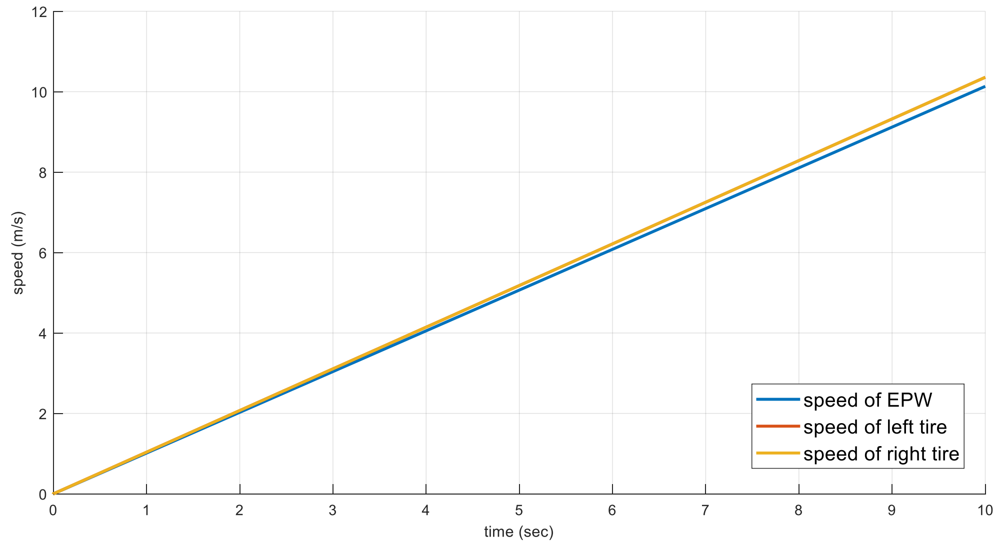

Figure 4. Speed behavior of a wheelchair during descending on slope 15º.

Figure 4 shown the changes of speed when the EPW is release from the top of slope. In this analysis, the slope is set as 15º more than standard slope recommended for building slope[12]. These conditions also known as free rolling. From the plot shows the speed of left and right tire and also speed of EPW which indicate red, yellow and blue respectively gradually increase. At 10 second, the speed of EPW was recorded almost 10 m/s.

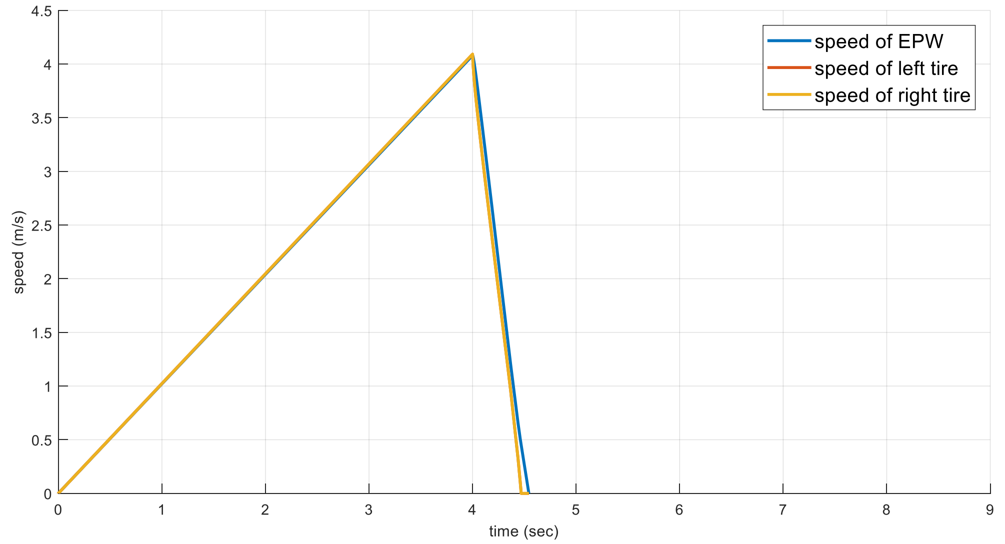

Figure 5. Applied sudden braking at dry condition.

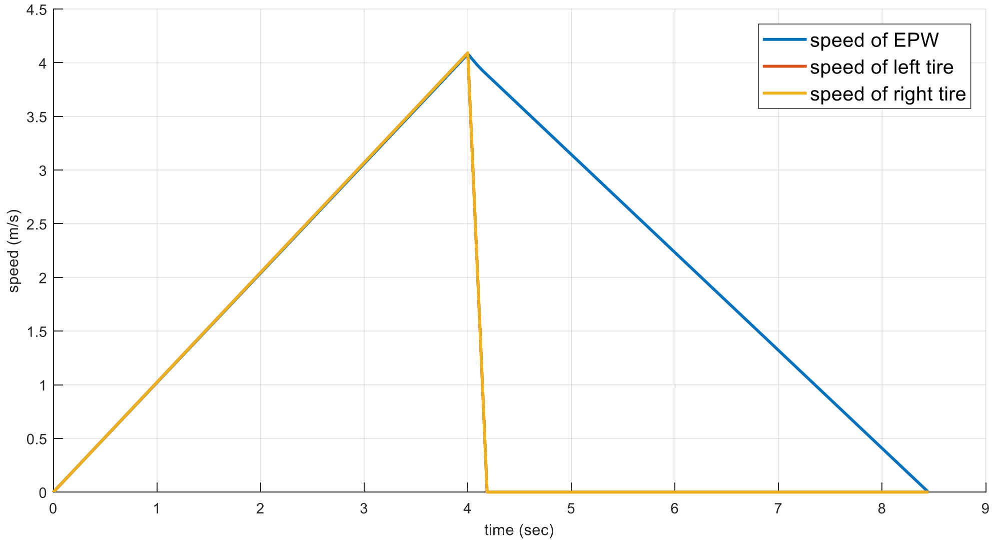

Figure 6. Applied sudden braking at icy condition.

When sudden braking was applied at t=4 sec second in dry condition ($\boldsymbol{k = 0.8}$), from the Figure 5, the speed of left and right tire which indicated with red and yellow line respectively are stopped abruptly at 4.5 seconds and EPW still moved slightly and stopped at 4.7 second. Next, when sudden braking was applied at the low adhesive surface condition ($\boldsymbol{k = 0.12}$), the tires are suddenly locked at 4.2 second. However, EPW kept sliding ad stopped at 8.4 seconds as shown in Figure 6. This is shown that by when sudden braking is dangerous to apply especially at slippery condition.

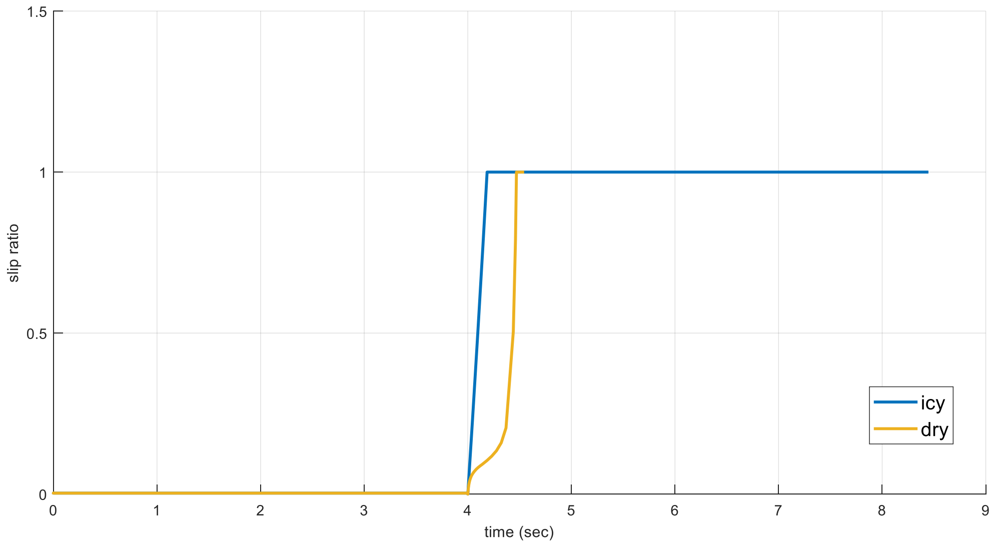

Figure 7. Slip ratio during braking in dry condition**.**

Slip ratio plotted in Figure 7 also can be used to identify the slip behavior for the EPW. The yellow and blue plot indicted as the slip ratio during braking in dry and icy condition respectively. When the EPW is acceleration (t < 4 seconds) the slip ratio was recorded as 0.08. That means the EPW does not slip. After a sudden braking is given at t = 4 for dry condition, the slip ratio became 1 at $\boldsymbol{t = 4.5}$ seconds and EPW stopped at t = 4.7 seconds. When sudden braking was applied at icy condition, the slip ratio became 1 at t = 4.2 seconds and EPW stopped at t = 8.4 seconds.

To avoid from speed became rapidly change and EPW loose stability, the speed need to be maintain in less fear condition speed for wheelchair user which follow the jerk based $v = 0.6\ m/s$ [13]. In other word, the EPW need to descend on slope slowly. In Figure 8 shows the blue line is speed responds when using PID controller. From the plotted graph, the speed is maintained as desired which is 0.6 m/s and settling time, t_s is 1.8 second. In order to archive the best time responses speed, it seems 13.9 % of overshoot was happening and this is the limitation of PID.

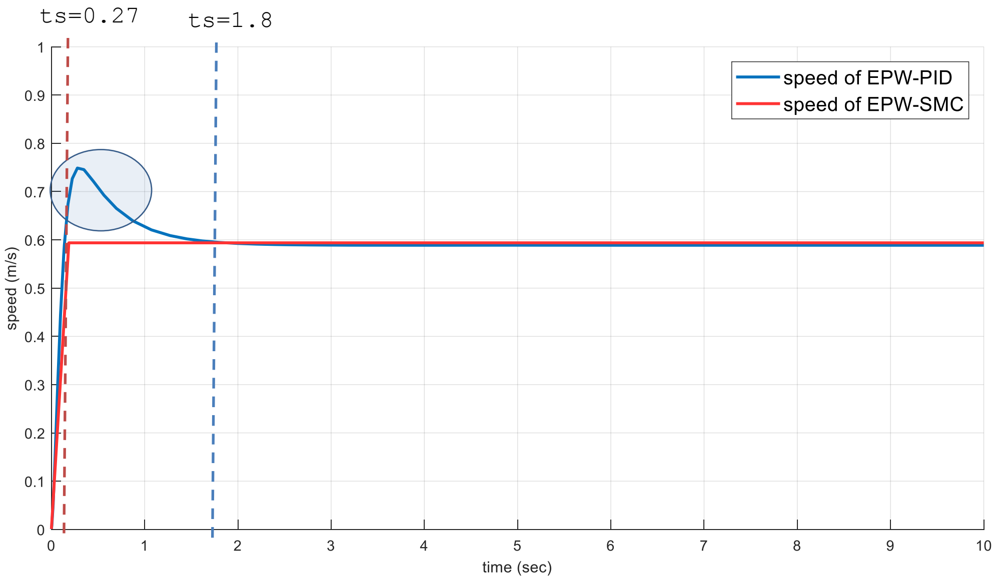

Figure 8. Time respond of Controller by using PID and SMC controller.

By using Sliding Mode Control (SMC) method control, the speed also can be maintained as desired 0.6 m/s as shown a red plot. Even the time rise for SMC and PID almost same, the different of PID and SMC can be identified in settling time and overshoot percentage. SMC gives the much faster speed response. The settling time, t_s was recorded at 0.27 second, but there is no overshoot was recorded.

Table 2. Comparison parameters between PID and SMC.

Parameter	PID	SMC
Gain	$k_p = 5.22$ $k_i = 1.01$ $k_p = 1.43$	$k = 5$ $c = 0.5$
Rise time, t_r (seconds)	0.25	0.27
Settling time, t_s (seconds)	1.8	0.27
Overshoot (%)	13.9	No

5. Conclusion

In conclusion, the proposed automated torque braking control gives the best braking control during descending on a slope by controlling the speed as desired instead using human strength that caused sudden braking and loss stability of EPW. Moreover, by using Sliding Mode Control (SMC) control technique is more effective rather than using PID controller. SMC gives the fastest speed responses without giving any overshoot value than PID. By maintaining the speed of the tire, the slip ratio also became smaller. In other words, the sudden braking problem that caused tire to lock can be eliminated and the stability of EPW during descending on the slope also enhanced.

Acknowledgements

The authors would like to thank Ministry of Higher Education Malaysia for providing Research Acculturation Grant Schemt (RAGS) under project number RDU151403. Special thanks to Universiti Malaysia Pahang for providing laboratory facilities and technical support for this research.

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