Slip control design of electric vehicle using indirect Dahlin Adaptive Pid

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Abstract In this paper the problem to be solved is to build a slip control on a wheel that may occur in an electric car wheel. Slip is the difference in vehicle velocity and wheel tangential velocity and to be enlarged when the torque given growing. Slip can be reduced by controlling the torque of the wheel so that the wheel tangential speed does not exceed the vehicle speed. The experiment in this paper is a simulation using MATLAB Simulink and using Adaptive control. The response adaptive PID control more quickly 1.5 s than PID control and can controlled wheel tangential speed close to the vehicle velocity on a dry asphalt, wet asphalt, snow and ice surface sequent at time 2s, 4s, 10s, and 50s. The maximum acceleration of the vehicle (V) on the surface of the dry asphalt, wet asphalt, snow, and ice surface sequent at 8.9 m/s^2, 6.2 m/s^2, 2.75 m/s^2, and 0.34 m/s^2.

1. Introduction

Several control methods to control the slip in the various types of vehicles have developed enough such as Anti-lock Braking System (ABS) and Traction Control System (TCS). ABS and TCS are braking systems on the car in order to avoid locking the wheels when braking the vehicle suddenly. Likewise with slip control Model Following Control (MFC) which not need information of vehicle body velocity or acceleration sensor equipment.
Dejun Yin and Hori [1] conduct research to obtain a method control which is based on the maximum torque which allowed that slip can be limited without consider vehicle velocity. Maximum torque determined to ignore the existence of some motion resistance, such as motion wheel resistance and airflow on the vehicle.
In this paper the problem can be solved is to build slip control by reducing the value of the slip that may occur on a wheel. By building a system that has the ability to organize themselves according to the environmental conditions or adaptability. Then determine the dynamic response of electric cars with testing in various types of tracks. This experiment is simulated by using MATLAB Simulink.

2. Commercial Electric Vehicle (COMS)

This experiment simulated by using MATLAB Simulink from Dejun and Yin's electric car research [1]. The electric car is Commercial Electric Vehicle (COMS) created by TOYOTA AUTO BODY Co. Ltd., The electric car have modified and suitable for research needs. Each drive wheel is equipped by Interior Permanent Magnet Synchronous Motor (IPMSM) so that can be controlled freely.

Figure 1. Dejun Yin & Hori's electric car research [1]

Table 1. COMS Characteristic

Symbol	Definition
M	Vehicle mass (kg) (360 kg)
J_w	Wheel Inertia (kg m/s^2) (0.5 kgm^2)
r	Wheel radius (m) (0.2 m)
T	Driving torque (Nm) (100 Nm)
F_{dr}	Driving resistance (N) (230 N)
F	Driving force (N)
λ	Slip ratio
v	Vehicle velocity (m/s)
v_w	Wheel tangential velocity (m/s)
ω	Wheel rotation (rad/s)
N	Vehicle Weight (N)
μ	Friction coefficient

Characteristic of electric car which used for research refer to characteristic of Dejun Yin & Hori's electric car research [1]. See Table 1.

3. Control Design

3.1 Vehicle and Wheel Dynamic Model

Defining an equation from the motion of one wheel vehicle can be derived from Newton's second law (See Figure 2). Figure 2. show the physical quantities contained in the longitudinal motion of electric car.

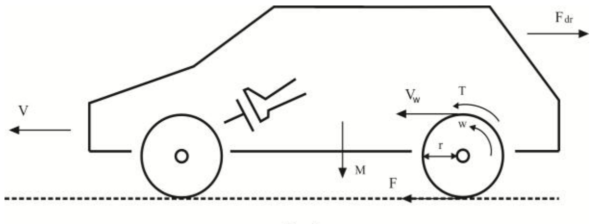

Figure 2. Model of one wheel electric car movement

The equation of motion along the longitudinal axis of the vehicle shown in equation (1) and (2) below:

$$M\dot{v} = F - F_{dr} \quad (1)$$

$$\dot{v} = \frac{F - F_{dr}}{M} \quad (2)$$

Then the linear relationship tangential velocity (v_w) with wheel rotation (ω) on a wheel model shown in equation (3) below:

$$\dot{v_w} = r\dot{\omega} \quad (3)$$

For one wheel model, the physical quantities contained in the longitudinal motion shown in Figure 3.

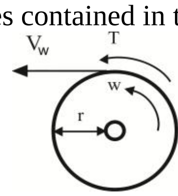

Figure 3. One wheel model

However, when the wheel touching the surface of the track with the input torque, the friction force will occur so that the vehicle body can be drove. See equation (4), (5), and (6).

$$J_w \dot{\omega} = T - Fr \quad (4)$$

$$F = \mu N \quad (5)$$

$$\dot{v_w} = \frac{r(T - rF)}{J_w} \quad (6)$$

Slip ratio (λ) is percentage of the wheel tangential velocity (v_w) with the vehicle velocity (v). Calculation of slip ratio (λ) is shown in equation (7) below:

$$\lambda = \frac{v_w - v}{v_w} \quad (7)$$

In this paper, when the vehicle slip, slip ratio can be detected friction coefficient (μ) and described into a vehicle model (See figure 4).

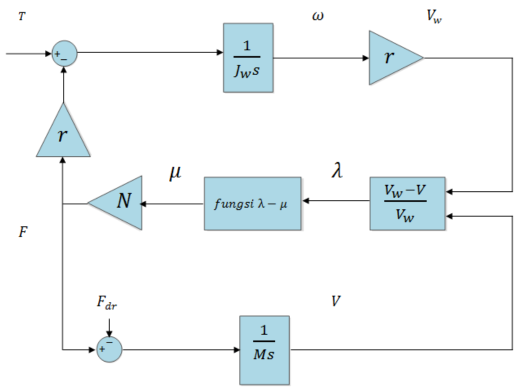

Figure 4. One wheel vehicle dynamic model [1]

The method used to detect the vehicle slip ratio becomes the value of the friction coeficient is using Magic Formula or pacejka formula discovered by Hans B. Pacejka based on experimental data [13]. The equation of *Magic formula* shown in equation (8).

$$\mu = D \, Sin \, [C \, arctan \, \{B\lambda - E(B\lambda - arctan(B\lambda))\}] \quad (8)$$

wich:

B, C, D, E = Coefficient of the tires movement to the tracks (See Table 2).

Table 2. *Magic formula* characteristic in various types of tracks [14]

Coefficient	Name	Dry asphalt	Wet asphalt	snow	ice
B	Stiffness	10	12	5	4
C	Shape	1.9	2.3	2	2
D	Peak	1	0.82	0.3	0.1
E	Curvature	0.97	1	1	1

3.2 Slip Control Design

Control design to be proposed in this paper are PID control and Adaptive PID control and then comparing the outputs. PID diagram block shown in Figure 5, then Adaptive PID shown in Figure 6.

Journal of Physics: Conference Series **776** (2016) 012097 doi:10.1088/1742-6596/776/1/012097

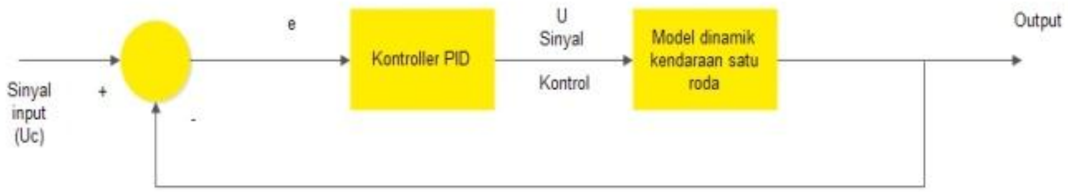

Figure 5. PID control diagram block

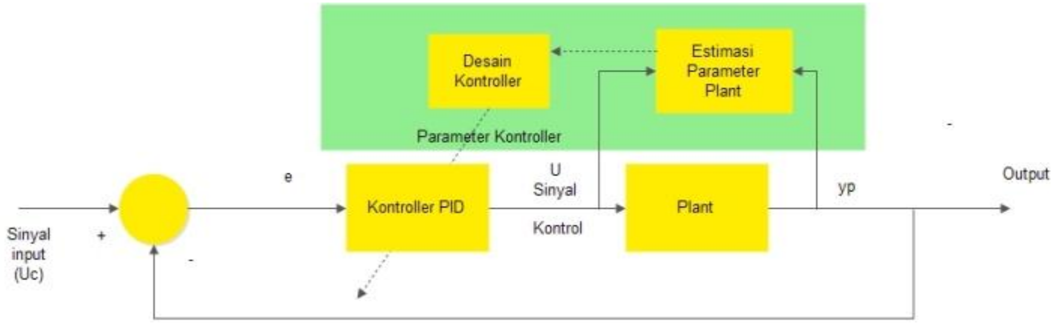

Figure 6. Adaptive PID control diagram block

In PID control design, determining the Kp, Ki, Kd parameters are using Ziegler-Nichols metode first type. Parameters obtained Kp = 198,8, Ki = 82,3, Kd = 0,3. The difference of Adaptive PID control is performed with the addition of Adaptive block from the PID control design. Adaptive block consists of block Parameter Estimation Plant and block Design Controller that serve to adjust PID controller block to generating a new K_p parameter. Generating a new Kp parameter can use the Dahlin PID Controller [12] in equation (9).

$$K_P = -\frac{(a_1+2a_2)Q}{b_1} \qquad (9)$$

Variable Q in equation (9) is defined by equation (10).

$$Q = 1 - e^{-\frac{T_0}{B}} \qquad (10)$$

where B is known as the adjustment factor which characterizes the dominant time constant of the transfer function according to changes made to the process output of a closed control loop. The smaller the value of B, the faster the response of the closed control loop [12]. Thereafter, T_0 use the settling time of the output process in a closed loop before using this type of control. In this paper, value of B is 400 and value of T_0 is 17. Parameters of a_1, a_2, and b_1 can be searched with ARMAX block in MATLAB simulink and will automatically generate parameters that adjust from environmental conditions. So we get the parameters:

a_1 = - 0,9874; a_2 = 1; b_1 = 0,006;

The next step makes MATLAB Simulink diagram block with PID control (Figure 7) and adaptive PID control (Figure 8). The tests conducted in various types of tracks. The tracks are on the surface of dry asphalt, wet asphalt, snow, and ice.

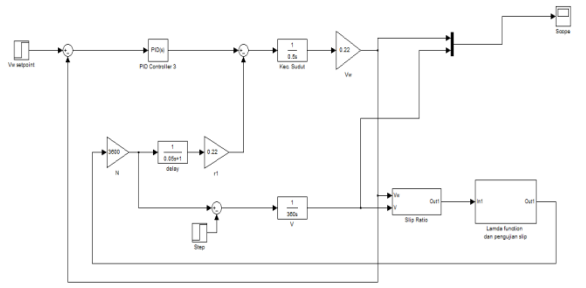

Figure 7. One wheel vehicle dynamic model with PID control diagram block in Simulink

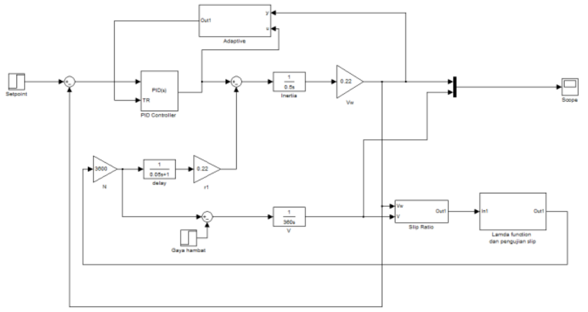

Figure 8. One wheel vehicle dynamic model with Adaptive PID control diagram block in Simulink

4. Test Results and Analysis

The next step is testing the dynamic model of the vehicle by reading the signal V (vehicle velocity) and the signal Vw (wheel tangential velocity). Setpoint using Vw by using step signal. Setpoint value in this paper is used 25 m/s by testing during 100 s. PID control test results shown in Figure 9 and Adaptive PID control testing in Figure 10. Figure 9 shows the dynamic response of vehicle speed PID control with constant input (step) experienced a constant velocity (settling time) on the surface of the dry asphalt, wet asphalt, snow and ice in a row at a time 10 s, 12 s, 20 s, and 80 s. The maximum acceleration of the vehicle (V) on the surface of the dry asphalt, wet asphalt, snow, and ice is 8.9 m/s^2, 6.2 m/s^2, 2.75 m/s^2, and 0.34 m/s^2.

Wheel tangential velocity (Vw) adaptive PID ; (red line)	Vehicle velocity (V) PID ; (purple line)
Vehicle velocity (V) adaptive PID ; (green line)	*Setpoint* ; ....
Wheel tangential velocity (Vw) PID ; (blue line)	

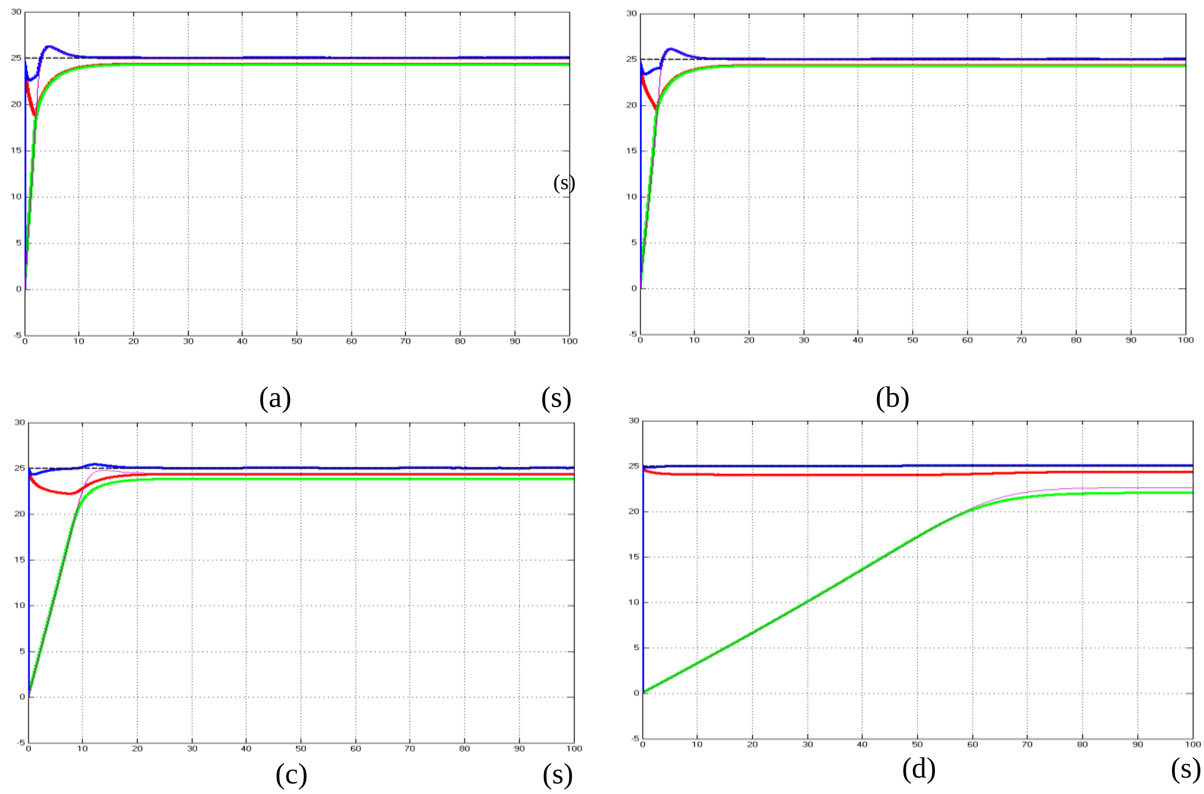

Figure 9. PID and adaptive PID testing with input step on the surface of (a) dry asphalt (b) wet asphalt (c) snow (d) ice.

On the dry asphalt surface (Figure 9(a)) at time 2s, the wheel tangential velocity (Vw) adaptive PID have experienced reduction of 6 m/s from setpoint and towards vehicle velocity value at 19 m/s. Then, on the wet asphalt surface (Figure 9(b)) at time 4 s, the wheel tangential velocity (Vw) adaptive PID have experienced reduction of 5 m/s from setpoint and towards vehicle velocity value at 20 m/s. This proves have adaptation process from adaptive PID control. Dynamic response on adaptive PID control and has no overshoot. On dry asphalt surface have experienced settling time at time 10 s and on wet asphalt surface have experienced settling time at time 12 s.

On the snow surface (Figure 9(c)), the wheel tangential velocity (Vw) adaptive PID have experienced reduction of 2.5 m/s from setpoint and towards vehicle velocity. Then, reduction of the wheel tangential velocity (Vw) adaptive PID on the ice surface (Figure 9 (d)) quite small around 1 m/s from setpoint, because a large setpoint (25 m/s) for slippery surfaces. Settling time from vehicle velocity (V) on the snow and ice surface is slower than dry

Asphalt surface (settling time for snow = 20 s and settling time for ice = 80 s). This proves in adaptive PID control, settling time value of vehicle velocity (V) inversely proportional to the wheel tangential velocity reduction. The acceleration of the vehicle on ice surface have smaller acceleration than on dry asphalt surface. Likewise with vehicle velocity (V) does not reach the full setpoint. This proves have a slip, because wheel tangential velocity not fully modified into vehicle velocity (V). Another reason is the frictional force on the ice surface is very small nearly zero. Measurement of slip ratio λ (t) performed during 20 s in four surfaces that are dry asphalt, wet asphalt, snow, and ice. Slip ratio (λ) range shows the number 0 to 1. Slip ratio (λ) = 0, it shows the wheel tangential velocity (Vw) is equal to vehicle velocity (V). While slip ratio (λ) = 1, it shows vehicle velocity = 0 m/s or vehicle body in stationary condition. In figure 10. The value of slip ratio (λ) with input step at time 0 s shows the slip ratio value (λ) = 1. This signify the wheel tangential velocity (Vw) that directly responds to reach setpoint value with input step. However, at the next time interval, slip ratio (λ) value close to the value 0.

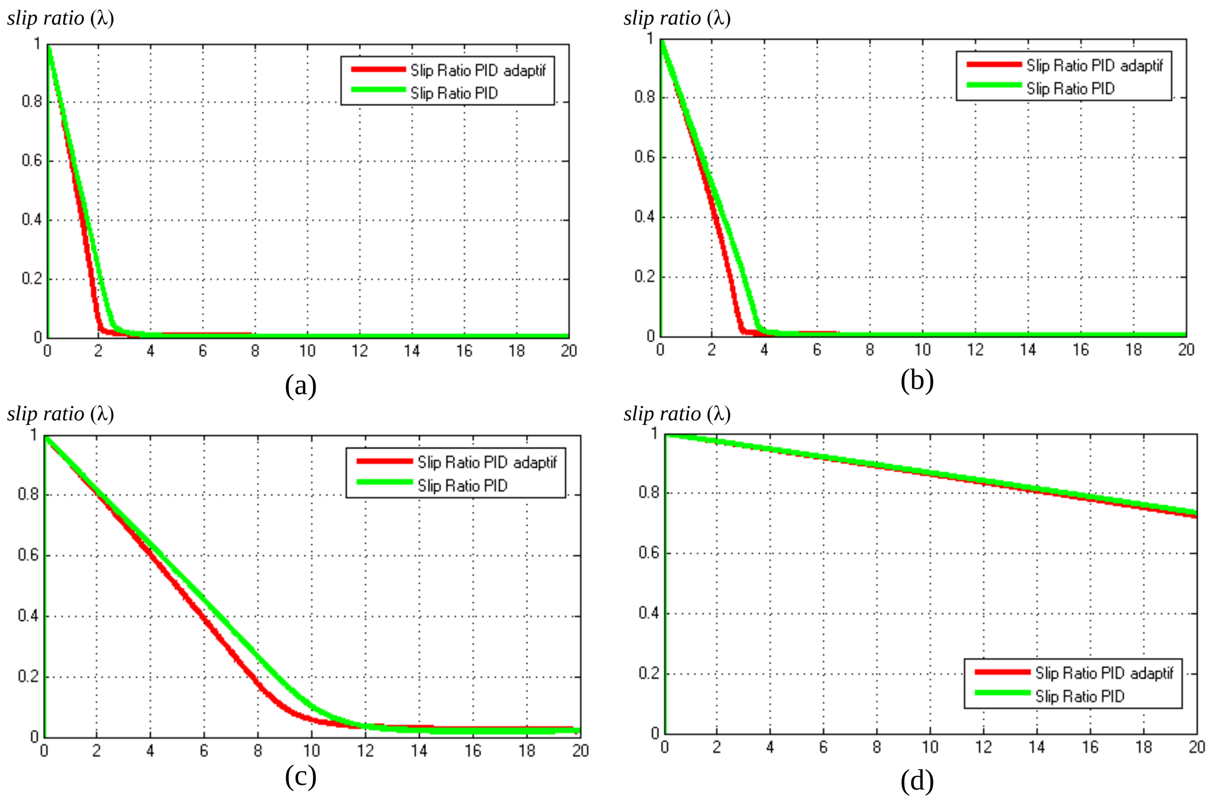

Figure 10. Responds of slip ratio with PID and adaptive PID control with input step on the surface of (a) dry asphalt (b) wet asphalt (c) snow, and (d) ice

Testing on the dry asphalt surface (figure 10(a)) at time 2 s, slip ratio (λ) in PID control shows number at 0.2. But, slip ratio (λ) in adaptive PID control shows number at 0.01. Thus, there is a reduction (reduction) slip ratio (λ) on dry asphalt surface by 0.19. On the other of tracks, there is a reduction (reduction) slip ratio (λ) on wet asphalt, snow, and ice surface sequent at number 0.1, 0.05, and 0.005. On the wet surface (figure 10(b)), respond of slip ratio (λ) value close to the value 0 at time 4 s slower than respond of slip ratio (λ) on dry asphalt surface. On the snow surface (figure 10(c)), respond of slip ratio (λ) value close to the value 0 at time 10 s and on ice surface (figure 10(d)) at 50 s.

The respond of the adaptive PID control close to the value 0 more quickly than PID control. On the dry asphalt surface adaptive PID 0.5 s more quickly than PID control. On the wet asphalt surface 1 s more quickly and on the snow surface 4 s. So the role of adaptation (adaptive PID) works on the slip control.

5. Conclusion

From the results of this simulation**,** it could be conclude as follows:

1. Dynamic response of vehicle speed control PID and Adaptive PID with step input of 25 m / s experiencing constant velocity (settling time) on the dry asphalt, wet asphalt, snow, and ice surface sequent at time 10 s, 12 s, 20 s, and 80 s.
2. The simulation results prove the PID control vehicle speed maximum acceleration of vehicles on dry asphalt surface, wet asphalt, snow, and ice sequent at 8,9 m/s^2, 6,2 m/s^2, 2.75 m/s^2, and 0.34 m/s^2.
3. Wheel tangential velocity (Vw) on the adaptive PID control is reduced to the velocity of setpoint and the value of the vehicle velocity (V). This proves have adaptation process from adaptive PID control and has no overshoot. Velocity reduction from setpoint and towards vehicle velocity value (V) on the dry asphalt, wet asphalt, snow, and ice surface sequent at time 2 s, 4 s, 10, and 50 s.
4. The role of adaptation (adaptive PID) works on the slip control with the reduced of slip ratio (λ) value. Reduction of slip ratio on dry asphalt surface at 0.19. Then on the wet asphalt, snow, and ice surface sequent at 0.1, 0.05, and 0.005

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