Identification of Intelligent Controls in Developing Anti-Lock Braking System

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Abstract— This paper presents about the development of an Antilock Braking System (ABS) using quarter vehicle model and a control structure is developed to represents an ABS and conventional braking model. Different type of controllers is proposed to develop the ABS model. Antilock braking system (ABS) is an important part in vehicle system to produce additional safety for driver. This system is known as one of the automobile's active safety. In general, Antilock braking systems have been developed to reduce tendency for wheel lock and improve vehicle control during sudden braking especially on slippery road surfaces. In this paper, to deal with the strong nonlinearity in the design of ABS controller, an intelligent controller has been identified. The controllers such as PID and Fuzzy Logic are proposed to control the stopping distance and longitudinal slip of the wheel. Comparison results between these two controllers generated using Matlab SIMULINK.

Keywords-Antilock Braking System, quarter vehicle model, PID controller, Fuzzy logic controller, Matlab Simulink

I. INTRODUCTION

Antilock braking system is an electronically controlled system which was designed to control a vehicle's steering during heavy braking. ABS also designed to stabilize the vehicle during sudden braking moments by preventing wheel from locking. ABS is recognized as one of an important contribution to road safety. Initially, the invention of ABS is to reduce the stopping distance of airplanes. But, this technology is now becomes one of the high priorities for ground vehicle because of its capability to help the drivers to stop the vehicle in a shorter distance in the safest way. ABS is to manipulate the wheel slip so that a maximum friction force is obtained and the steering stability is maintained. This is to allow the vehicle to stop in the shortest distance possible while maintaining the directional control. It is well known that the friction coefficient is a nonlinear function of the slip. The ideal goal of the control design is to regulate the wheel velocity. The

ABS function is based on the regulating wheel speed of a vehicle and maintaining the longitudinal slip of the vehicle. When braking force is applied to a rolling wheel, the slip conditions occurred. The wheel circumferential velocity (Vw) will be less than the vehicle velocity (Vv). Slip (λ) is defined as the difference between vehicle velocity and wheel circumferential velocity, normalized to vehicle velocity. The longitudinal slip can be defined as:

$$\lambda = \frac{v_V - v_w}{v_V}$$

The lateral coefficient of friction approaches at zero slip and start to decrease once the wheel slip increases. The lateral stability, steering ability and the direction of the vehicle provides lateral friction. The longitudinal coefficient of friction is zero at zero slip. If braking force is not quickly reduced at this point, the reduction in road force leads to a rapid increase in slip and eventual lockup.
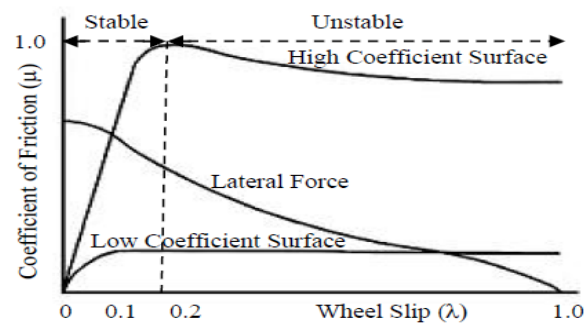

Figure 1: Coefficient of friction vs wheel slip [Mirzaei *at el.* (2005)]

Most control strategies for ABS define their main objective as maintaining slip near a value of 0.2 throughout the braking trajectory. Base on the Figure 1, before reaching the wheel slip, s= 0.2, the coefficient of friction is in stable condition. Where else, after the s=0.2, the coefficient of friction become unstable. This condition will cause the wheel to sleep during sudden braking. The development of ABS in automotive industry is to control wheel slip

according to the desired level. Various type of intelligent control has been developed to implement in the ABS control. The benchmark control, PID controller, is the conventional controller used before developing the high performance controller. But, there are a lot more advance controllers such as sliding mode, MRAC PID, fuzzy, fuzzy-neural, fuzzy-sliding mode, fuzzy-neural sliding mode, and hybrid controllers. This paper represents comparison between conventional controller PID and Fuzzy Logic Controller only.

There are some researches based on the antilock braking system such as Mirzaei [2], have developed antilock braking system for simplified vehicle/tire/road dynamics using genetic fuzzy controller. Other than that, Junwei [3] have developed antilock braking system for simplified vehicle dynamic model by using variable structure controller. Meanwhile, Ayman [4], used intelligent fuzzy control to develop the antilock braking system as well. John [5] improves the passive antilock braking system using adaptive control. In this paper, a quarter vehicle brake modeling has been developed using Matlab Simulink. This model has been given input of step with 500 Nm of brake torque to obtain the results. The quarter vehicle brake model tested using the passive braking, conventional controller PID and advance controller which is Fuzzy controller. The output results such as wheel velocity, vehicle velocity, wheel slip and stopping distance is observed.

II. Vehicle Model

Refer to the Short M. (2004). "Simulation of Vehicle Longitudinal Dynamics", the brake modeling for a single wheel with quarter vehicle mass can derive in mathematical equations. A rotating wheel allows the driver to maintain steering control under heavy braking by preventing skid and allowing the wheel to continue to interact with the road surface as directed by driver steering inputs. Locking is occurred when the wheel has no rotational speed, but still displaces either longitudinally or laterally. Whereas, under normal braking condition, the wheel has minimal rotational speed while brake is applied to avoid the wheel from skidding. Vehicle starts to slip when the wheels is locked after a heavy braking. This is because an excessive brake torque higher than or equal to the available road tractive torque.

A. Quarter Vehicle Equation

Figure 2 shows the quarter vehicle body of a vehicle. The model is represented with a wheel and quarter mass of a vehicle. Based on the quarter vehicle brake model, the equations can derived in the mathematical model. From this vehicle modeling, a control structure can be developed for the braking system of a wheel to control the wheel slip and stopping distance. [Short et al. (2004)]
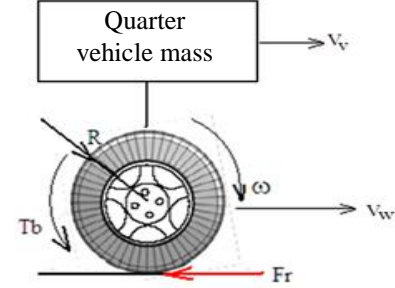

Figure 2: Longitudinal Slip in function of vehicle speed and wheel speed. [Short et al. (2004)]

$$\sum T_w = T_t - T_b \tag{2}$$

Where

$$\sum T_w = I_\omega * \alpha_\omega$$
$$T_t = F_f * R$$

$$T_t - T_b = I_\omega * \alpha_\omega \tag{3}$$
$$F_f * R - T_b = I_\omega * \alpha_\omega \tag{4}$$

Where

$$F_f = \mu_s N$$

$$\mu_s N * R - T_b = I_\omega * \alpha_\omega \tag{5}$$

Where

$$N = mg$$

$$\mu_s mg * R - T_b = I_\omega * \alpha_\omega \tag{6}$$
$$\alpha_\omega = \frac{\mu_s mg * R - T_b}{I_\omega} \tag{7}$$

Hence the longitudinal force is

$$F_f = M_v * a_v = \mu_s mg \tag{8}$$

The longitudinal speed is

$$V_v = R\omega_v \text{ (Vehicle speed)} \tag{9}$$
$$V_w = R\omega_w \text{ (Wheel speed)} \tag{10}$$

The longitudinal slip, λ, of the wheel is

$$\lambda = \frac{V_V - V_w}{V_V} \tag{11}$$

The μ_s value is obtained using the lockup table based on the experiment on normal road surface.

B. Hydraulic Brake Actuator

Hydraulic brake is a brake actuator used in the quarter vehicle brake modeling. Hydraulic brake model will produce the brake torque, T_b, during braking condition. Hydraulic brake system is current braking mechanism used in all vehicles which contains brake fluid (ethylene glycol). The hydraulic brake system consists of:

(a)   Brake pedal or lever mechanism
(b)   Pushrod or actuating rod
(c)   Master cylinder with pistons assembly
(d)   Hydraulic lines
(e)   Brake caliper assembly which is combination of brake pad, piston and a rotor.

The pushrod is connected with the brake pedal mechanism which is operated by human during braking. The force given by the human (0 – 100%) will controlled the pressure in the braking mechanism. Based on this Figure 3, brake pedal mechanism, a simplified brake model can be derived. [Krishnamachari (1996)]
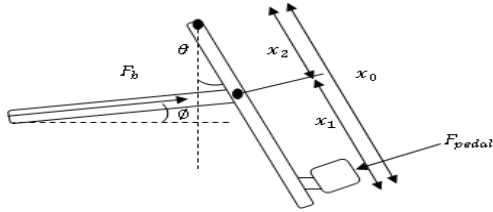
Figure 3: Brake Pedal Mechanism

The equation of the brake pedal mechanism

$$F_b = \frac{[F_{pedal} \cos\theta](x_1 + x_2)}{x_2 \cos\emptyset} \quad (12)$$

$$P_m = k_m * F_b \quad (13)$$

$$F_p = P_m * A_p \quad (14)$$

$$T_b = \mu_b * F_d * r_{eff} \quad (15)$$

Where by

μ_b = brake coefficient
r_{eff} = effective radius of disc brake
P_m = Pressure in master cylinder
F_p = Brake piston force
F_{pedal} = Brake lever/pedal force

A. Case 1: Passive Braking System without ABS

Simulation using Matlab can be developed based on the equation above. There are two conditions tested in this model which is braking without ABS and with ABS. This modeling used to differentiate the wheel speed and wheel slip of the vehicle during passive braking and with ABS braking.
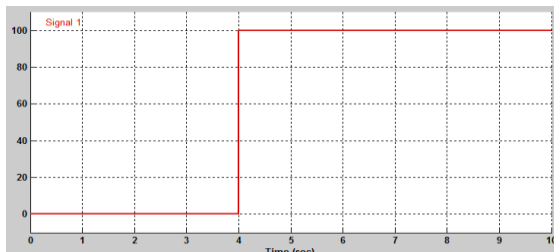
Figure 4: Signal Builder Input

Input for the human driver is given by using a signal builder. Signal builder represents the amount of braking input (in percentage) given from the human input. The simulation is tested for a vehicle without ABS function which is passive braking system. The response is obtained in a graphical method. The input of braking model without ABS is shown in Figure 4.

B. Case 2: Braking system with ABS

I.   PID Controller

PID controller is a one of the conventional controller developed to calculate the errors obtained from the actual plant model with the desired input. PID controller contained three types of parameters which is adjustable according to the errors. Every parameter functioned in different technique in order to reduce the errors from plant model. PID controller can be described as

a)   P   = proportional
b)   I   = Integral
c)   D   = Derivative

The P value represents the errors that occurred in current condition. Where else, I value represents the errors gathered from past condition and D value represents the prediction of future errors based on the changes occurred during current condition. Figure 5 shows the structure of PID controller.
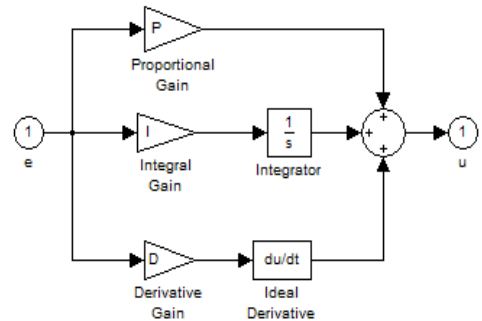
Figure 5: Control Structure of PID controller

This controller is implemented into passive braking by replacing the signal builder input. The brake actuator added with hydraulic lag in the form of transfer function to represent delay from controller to the hydraulic response. The input for the hydraulic lag is the electrical current, i.
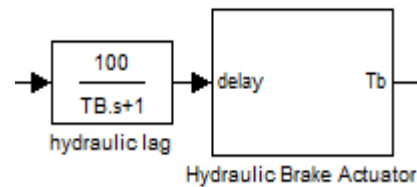
Figure 6: Hydraulic Lag Implementation

(ii) Fuzzy Logic controller

Every fuzzy controller is made up of three main components: the fuzzification, rule base, and defuzzification mechanisms. The fuzzification mechanism function is to map the controller inputs and assign a proper value μ (u) for each proper function forming the universes. Fuzzy rule base consists in assessing fuzzy rule set of the type, which has two main parts, the antecedent and the consequent.

IF e (t) IS …AND c(t) IS… THEN u (t)

The antecedent is before the word "THEN" and its function is to relate the controller input proper values to the consequent. Defuzzification is the procedure through which the fuzzy rule set is assessed and a non-fuzzy or analog signal is assigned. The most frequently used method is the area center, although there are methods like the first maximum or the maximum average.
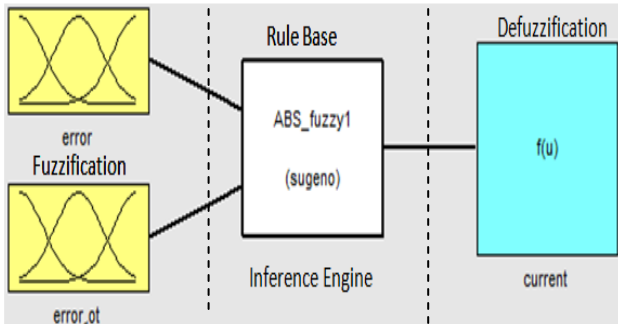

Figure 7: Fuzzy logic Control Block

In this paper, Fuzzy Logic Controller is developed based on Takagi-Sugeno-Kang (TSK) model [Mirzaei *at el.* (2005)]. There are two inputs given for this controller which is obtained from the ABS model using PID controller. PID controller function as a bench mark for fuzzy, it's a conventional controller and very easy to identify fuzzy parameters.

The maximum and minimum range inputs for fuzzy logic is defined based on the PID controllers. The output of the fuzzy logic will be the electrical current which will be the input for the hydraulic lag transfer function. The input and output variables can be divided into 3 variables which is positive (POS), negative (NEG) and zero (ZERO). Where else, output variables is positive big (PB), positive medium (PM), zero (ZE), negative medium (NM) and negative big (NM). In order to improve fuzzification speed, Gaussian function is chosen as the membership function. Figure 8 to Figure 10 shows the membership function of input and output variables.
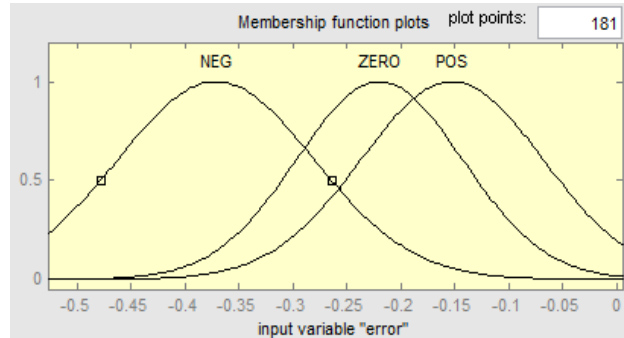

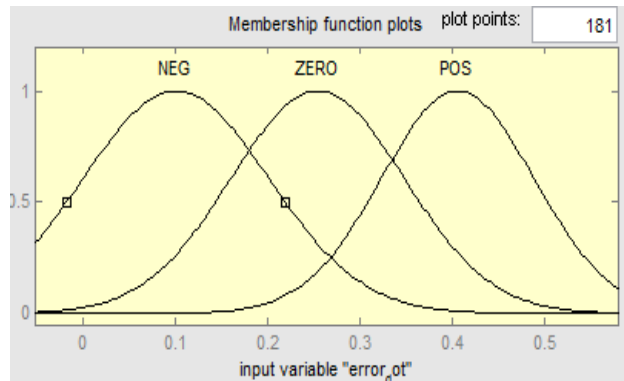Figure 8: Error input variables
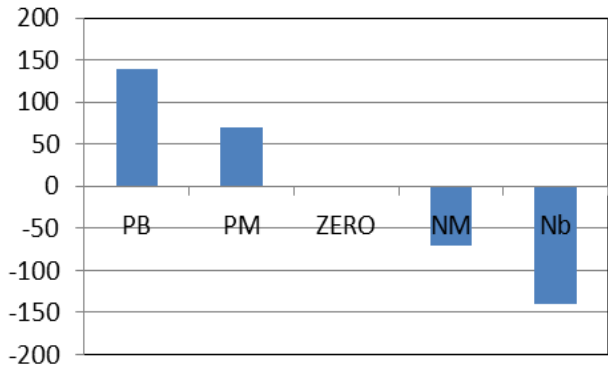

Figure 9: Error_dot input variables

Figure 10: Current Output Variable

The fuzzy logic is derived by using the mathematical model. The derivation is fuzzy logic is in exponential form. This model will include the spread, center and two inputs of Gaussian graph. The equation of Gaussian Model μ_G is:

$$\mu_G = e^{\frac{-(x-c)}{2\sigma}}$$

Where

x = input of fuzzy (error, error_dot)
c = center
σ = spread

III. SIMULATION PARAMETERS

Vehicle braking model is developed in Matlab SIMULINK using the mathematical derivation. Quarter vehicle brake model is used to develop in the SIMULINK. At the same time, the hydraulic brake actuator developed in SIMULINK. The technical specifications of the quarter vehicle test rig are listed in Table 2.

Table 1: Simulation parameter

Symbol	Value
I_ω	5 kg·m²·rad^{-2}
Kf	1
PBmax	1500
R	1.25 m
TB	0.01
g	9.81 m/s
μ_b	0.4
m	50 kg
h	2 m
mu	Look up table
slip	Look up table
v0	88
r_{eff}	0.15 m

V. SIMULATION RESULTS

The Figure 11 to 15 shows the comparison of input brake torque applied to the quarter vehicle brake model. The comparison is between the passive braking and ABS results where by the ABS with two type controllers. Based on the results, fuzzy controller has the optimum results compared to the PID controller. The stopping distance reduced compare to PID controller. Same goes to wheel speed and vehicle speed.
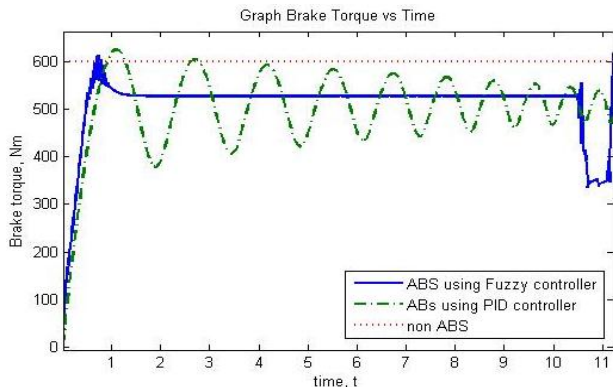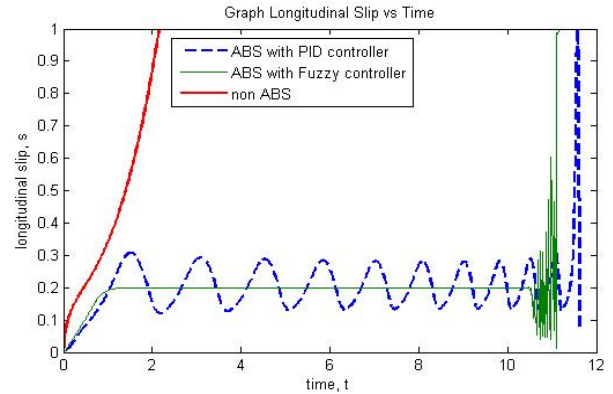

Figure 11: Brake Torque

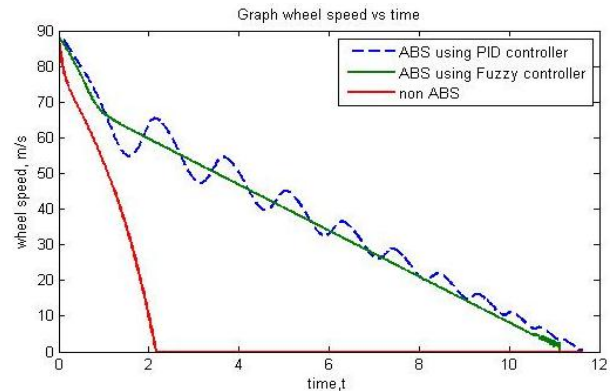
Figure 12: Longitudinal Slip
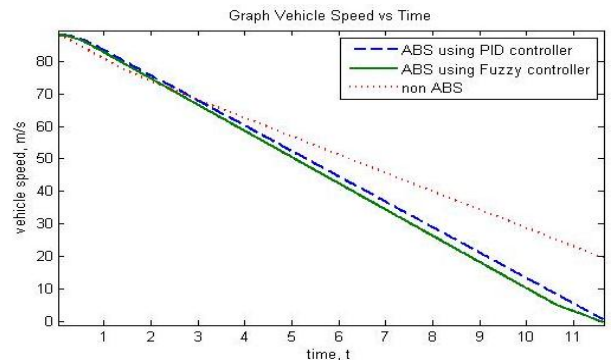

Figure 13: Wheel Speed
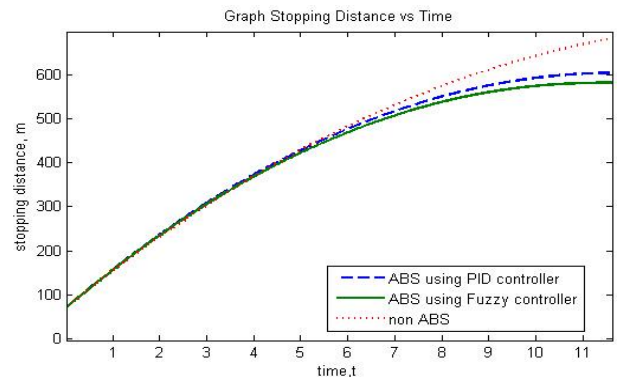

Figure 14: Vehicle Speed

Figure 15: Stopping Distance

Based on the results, quarter vehicle model using hydraulic brake model can be used to develop an antilock braking system. Active control such as PID and Fuzzy controller can reduce the stopping distance of the vehicle. PID also can control the wheel slip to maintain the slip in between 0.1 to 0.3 till the wheel fully stop. At the same time, Fuzzy controller can produce better results compare PID. The wheel slip can be controlled at the ideal slip value which is 0.2. The vehicle stopping distance using fuzzy controller is reduced compare to PID controller. Fuzzy controller shows a better performance compare to PID controller. This is because the variables to control the Fuzzy controller are more flexible compare to PID controller. The range for Fuzzy obtains from the error of the PID. Hence, the results obtained using Fuzzy is better compare to PID controller.

IV. CONCLUSION

As a conclusion, an Antilock Braking System (ABS) for quarter vehicle model can be developed using Matlab SIMULINK with using hydraulic actuator. The intelligent system can be used to control the passive braking in order to develop Antilock Braking System. The Fuzzy controller shows a better result compare to PID controller to develop the ABS for the quarter vehicle model. The stopping distance for fuzzy controller is reduced almost 30 meters. The wheel speed stops at 11.6 second compare to PID controller the wheel stops at 11.83 sec. The slip occurred is ideal at 0.2 for fuzzy controller compare to PID controller which is fluctuating in between 0.1 to 0.3.

ACKNOWLEDGEMENT

REFERENCES

[1] M. Short, M.J.Pont, and Q.Huang, "Simulation of Vehicle Longitudinal Dynamics" University of Leicester, 2004.

[2] O.T.Nyandoro, J.O.Pedro,O.A.Dahunsi and B.Dwolatzky, "Linear Slip Control Formulation for Vehicular Anti-Lock Braking System with Suspension Effects". *18th World Congress Milano,Italy*, University of the Witwatersrand, August 2011.

[3] A. Mirzaei, M. Moallem and B. Mirzaeian: "Designing a Genetic-Fuzzy Anti-Lock Brake System Controller" *IEEE International Symposium on Intelligent Control*, Limassol, Cyprus, June 2005.

[4] L. Junwei and W.Jian, "Design of Anti-Lock Braking System on Variable Control Structure" *IEEE International Conference on Intelligent Computing and Intelligent Systems* (pp. 411–415). Shandong of University Technology Shanghai, China. doi:10.1109/ICICISYS.2009.5358357, 2005.

[5] A.A.Aly, "Intelligent Fuzzy Logic Controller for Antilock Braking System with Road Surface Identifier". *IEEE International Conference on Mechatronics and Automation*, (2010).

[6] S.John, J.O.Pedro and L.T.Koczy, "Adaptive Improvement of a Passive Antilock Brake Control" University of the Witwatersrand, *IEEE Africon Conference*, Zambia, September 2011.

[7] G.F.Mauer, "A Fuzzy Logic Controller for an ABS Braking System" *IEEE Transactions of Fuzzy System*, vol,3, no.4, November 1995.

[8] R. S. Krishnamachari, "Design Model Of A Vacuum-Assisted". Michigan, Ann Arbor, (pp. 6–12). 1996.