DEVELOPMENT OF ANTILOCK BRAKING SYSTEM BASED ON VARIOUS INTELLIGENT CONTROL SYSTEM

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Abstract: This paper presents about the development of an Antilock Braking System (ABS) using quarter vehicle model and control the ABS using different type of controllers. Antilock braking system (ABS) is an important part in vehicle system to produce additional safety for drivers. 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, a variable structure controller has been designed to deal with the strong nonlinearity in the design of ABS controller. The controllers such as PID used as the inner loop controller and Fuzzy Logic as outer loop controller to develop as ABS model to control the stopping distance and longitudinal slip of the wheel.

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. It is well known that wheels will slip and lockup during severe braking or when braking on a slippery road surface. This usually causes a long stopping distance and sometimes the vehicle to lose steering stability. The main purpose of ABS is to manipulate the wheel slip so that a maximum friction force is obtained and the steering stability (also known as the lateral 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. Most control strategies for ABS define their main objective as maintaining slip near a value of 0.2 throughout the braking trajectory. This value shows a compromise between lateral stability, which is best at zero slip. For maximum deceleration, usually peaks for some value of slip between 0.1 and 0.3. The goal of ABS is to control wheel slip to a known and desired level. There are a lot of researches done base on the ABS control. Various type of intelligent control has been developed to implement in the ABS control.

Mirzaei [2] have developed antilock braking system for simplified vehicle/tire/road dynamics using genetic fuzzy controller. 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 600 Nm of brake torque to obtain the results. The quarter vehicle brake model is used to develop an ABS model in order to analyze the performance. The outer loop model is control using Fuzzy logic controller where else the inner loop control which is hydraulic brake actuator is controlled using PID controller. The output results such as wheel velocity, vehicle velocity, wheel slip and stopping distance is observed.

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 1 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)]

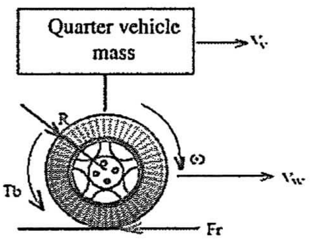

Figure 1: Longitudinal Slip in function of vehicle speed and wheel speed. [Short *et al.* (2004)]

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

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 2, brake pedal mechanism, a simplified brake model can be derived. [Krishnamachari (1996)]

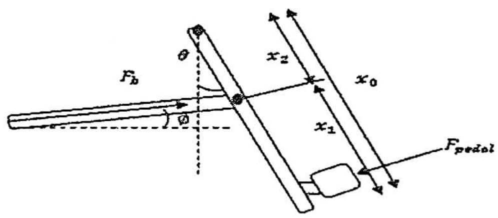

Figure 2: Brake Pedal Mechanism

The equation of the brake pedal mechanism

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

$$P_m = k_m * F_b \tag{13}$$

$$F_p = P_m * A_p \tag{14}$$

$$T_b = \mu_b * F_d * r_{eff} \tag{15}$$

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

Simulation Model

Based on the equations above, the quarter vehicle modeling and hydraulic actuator modeling is developed using Matlab SIMULINK. The passive braking is developed using the equation [12] to represent the human input to produce the brake torque to the wheel. The passive braking is compared with intelligent control braking system to control the wheel slip and stopping distance of a vehicle. This system is known as the antilock braking system. Two types of controllers are used which is PID controller and Fuzzy logic controller to show the performance of the comparison of antilock braking system over the passive braking system. These controllers are implemented into passive braking by replacing the brake pedal equations. 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 which is the electrical current, i, is obtained from the controllers. Figure 10 shows the simulation model developed in Matlab. The results of the quarter vehicle ABS which is wheel slip, wheel and vehicle speed and stopping distance is obtained from the simulation.

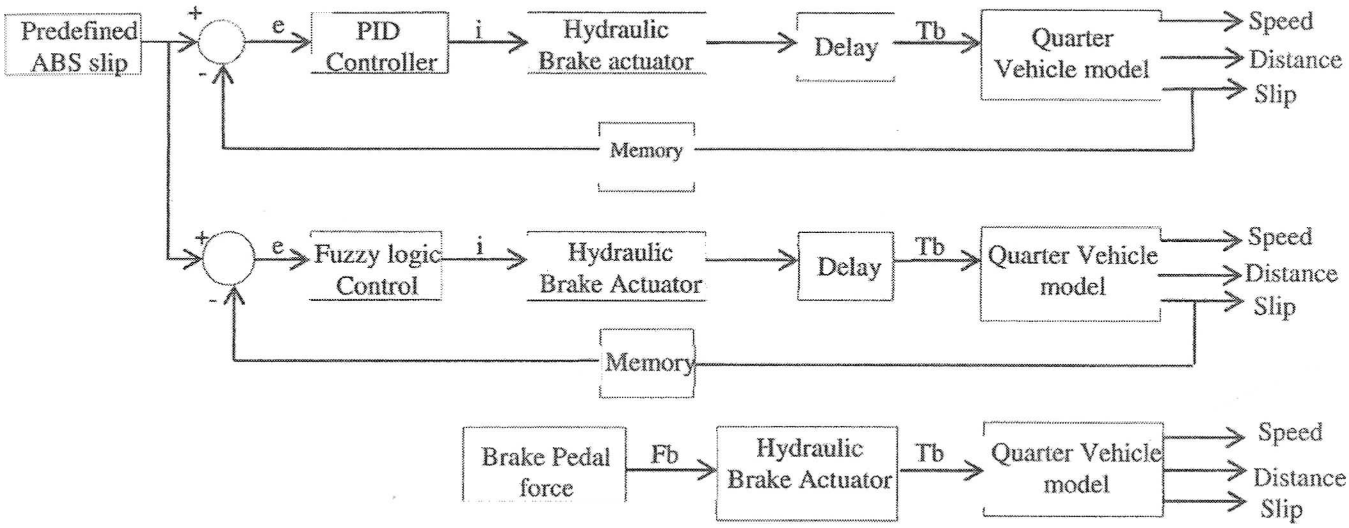

Figure 3: Control Structure of ABS and non-ABS (Passive Brake)

Simulation Results

The Fig. 4 to Fig. 7 shows the comparison of the non-ABS (passive braking) model and ABS control structure using PID controller and Fuzzy controller. The results show that quarter vehicle controlled by the intelligent control performed better than passive braking system. The longitudinal slip of wheel, stopping distance and wheel and vehicle speed is compared based on the simulation above. The difference obtained from the passive braking and antilock braking system is observed and analyzed

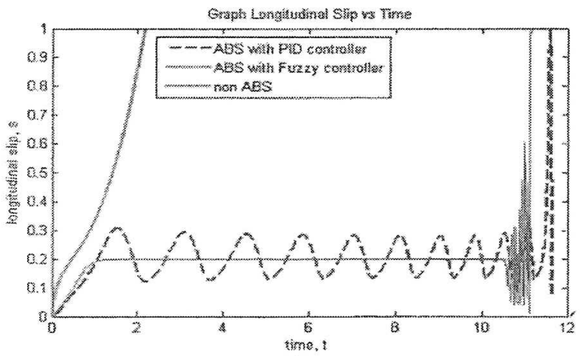

Figure 4: Longitudinal Slip

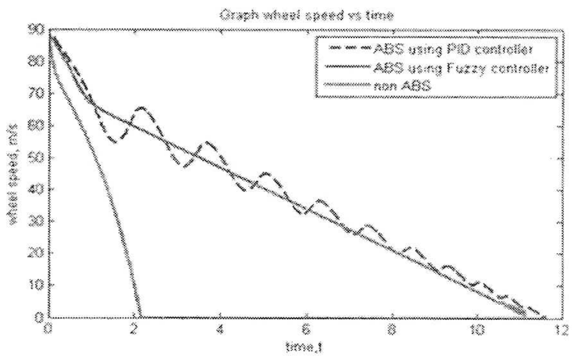

Figure 5: Wheel Speed

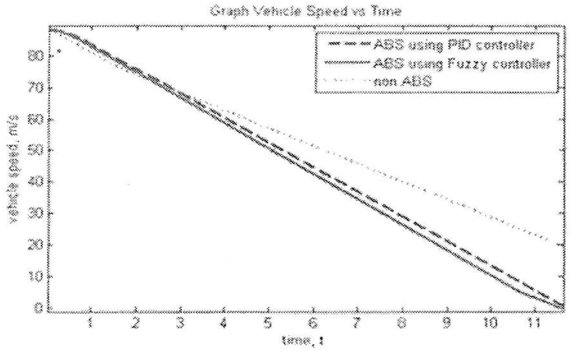

Figure 6: Vehicle Speed

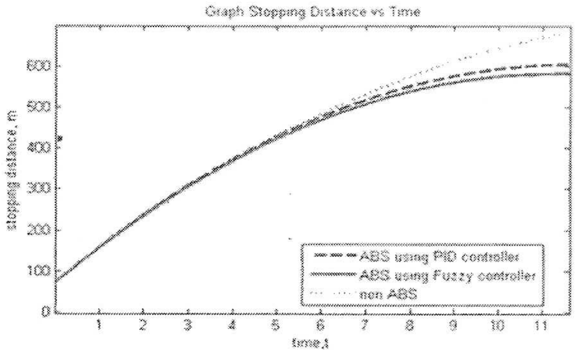

Figure 7: Stopping Distance

Based on the results, intelligent control system can produce better performance compare to the passive braking. Between the intelligent control system, PID controller can reduce the stopping distance of the vehicle. Other than that, the PID controller also can control the wheel slip to regulate the slip in between 0.1 to 0.3 till the wheel fully stop. At the same time, the Fuzzy controller can produce better results compare PID controller. Figure 5 shows that 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 as shown in Figure 7. Overall, the 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 control is obtained from the error and error rate of the PID control. This range values help to reduce the percentage error of the ABS control structure using Fuzzy control. Hence, the results obtained using Fuzzy control is better compare to PID controller.

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.

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