Enhanced Anti-lock Braking System using Fuzzy Logic Road Detector

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ABSTRACT

Antilock braking system (ABS) stops a vehicle wheel without locking while decreasing the stopping distance. Here we use fuzzy logic to detect the road conditions. Vehicle dynamics and braking systems is complex and proposed controller in different road detected states. They behave strongly non-linear which causes difficulties in developing a classical controller for ABS. Fuzzy logic, however facilitates such system designs and improves turning abilities. The underlying control philosophy takes into consideration-wheel slip, vehicle and wheel velocity as well as the tire and road adhesion coefficient in order to recognize braking tendencies. A fuzzy road detector is designed to detect three different road conditions. Simulations under these road conditions are performed to demonstrate the effectiveness of the proposed controller. Simulation results show good performance of the proposed controller in different road detected states.

Keywords: Antilock braking system, Controller Anti-lock Brake, Electronic control unit, Fuzzy Logic.

1. INTRODUCTION

An Anti-lock braking system (ABS) is a safety system that allows the wheels on a motor vehicle to continue interacting tactilely with the road surface as directed by driver steering inputs while braking, preventing the wheels from locking up (that is, ceasing rotation) and therefore avoiding skidding. An ABS generally offers improved vehicle control and decreases stopping distances on dry and slippery surfaces for many drivers; however, on loose surfaces like gravel or snow-covered pavement, an ABS can significantly increase braking distance, although still improving vehicle control. The anti-lock brake controller is also known as the CAB (Controller Anti-lock Brake). A typical ABS includes a central electronic control unit (ECU), four wheel speed sensors, and at least two hydraulic valves within the brake hydraulics. The nonlinearity in the vehicle braking dynamics, variation of model parameters over a wide range due to variation of road surface and vehicle conditions, operation of controller at unstable equilibrium and uncertainty of sensor signals are the difficulties that arise in design of a controller. Therefore, robustness of the controller is an important issue which is to be addressed in solving these problems. SMC is a good candidate that because of its effectiveness in a nonlinear system has widely been investigated in recent decades. The analytical modelling information, systems governed by fuzzy controllers are often highly robust and because of their effectiveness at handling the uncertainties and nonlinearities associated with complex systems such as antilock braking systems, they are another suitable option to be chosen. Most of the researches consider the optimal slip ratio a constant value or defined it in a specified range but there is a strong dependency between road condition and optimal slip ratio, so the kind of road must be identified. To achieve this aims we design a new road condition detector by use of fuzzy logic method. In this method, the effects of road condition changes and the vehicle speed on the target slip ratio are considered. This paper is organized as follows: Section 2 describes the ABS problem, slip ratio and tire/road friction model used in the
study, the following section 3, the road condition detection and gain control technique is discussed. The simulation results are presented in section 4 and future scope constitutes 5th the last part of the paper.

2. THE ABS PROBLEM

Since ABS systems are nonlinear and dynamic in nature they are a prime candidate for fuzzy logic control. For most driving surfaces, as vehicle braking force is applied to the wheel system, the longitudinal relationship of friction between vehicle and driving surface rapidly increases. Wheel slip under these conditions is largely considered to be the difference between vehicle velocity and a reduction of wheel velocity during the application of braking force. Brakes work because friction acts against slip. The more slip given enough friction, the more braking force is brought to bear on the vehicles momentum. Unfortunately, Slip can and will work against itself during cornering or on wet or icy surfaces where the coefficient of surface friction varies. If braking force continues to be applied beyond the driving surface’ useful coefficient of friction, the brake effectively begins to operate in a non-friction environment. Increasing brake force in a decreasing frictional environment often results in full wheel lockup. It has been both mathematically and empirically proven a sliding wheel produces less friction a moving wheel.

2.1. Wheel Slip/Slip ratio

Slip ratio is a means of calculating and expressing the locking status of a wheel and is vital to the effectiveness of any anti-lock braking system. When a vehicle is being driven along a road in a straight line its wheels rotate at virtually identical speeds. The vehicle’s body also travels along the road at this same speed. When the driver applies the brakes in order to slow the vehicle, the speed of the wheels becomes slightly slower than the speed of the body, which is travelling along under its own inertia. This difference in speed is expressed as a percentage, and is called ‘slip ratio’. The ideal slip ratio for maximum deceleration is 10 to 30%.

Slip ratio is calculated in equation 1.

\[
\text{Slip Ratio } \% = \frac{V_{\text{Vehicle Speed}} - V_{\text{Wheel Speed}}}{V_{\text{Vehicle Speed}}} \times 100 \alpha \frac{\text{Road Coefficient of Adhesion}}{\text{Coefficient of Adhesion}}
\]  

(1)

Road coefficient of adhesion is a nonlinear function of wheel slip ratio, which is a well known parameter to represent slippage and is represented as in equation 2.

\[
\mu_x(\lambda_x, V_x) = \left( C_1 \left( 1 - e^{-C_2 \lambda_x} \right) - C_3 \lambda_x \right) e^{-C_4 \lambda_x V_x}
\]  

(2)

where

\[ \mu_x - \text{coefficient of adhesion} \]

\[ \lambda_x - \text{slip} \]

and

\[ V_x - \text{Vehicle velocity} \]

Where \( C_1, C_2, C_3 \) and \( C_4 \) are coefficients depending upon the road conditions and their values are given below in TABLE 1
Table 1 Coefficients Depending upon the Road Conditions

<table>
<thead>
<tr>
<th>Road Condition</th>
<th>C₁</th>
<th>C₂</th>
<th>C₃</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dry asphalt</td>
<td>1.2801</td>
<td>23.9900</td>
<td>0.5200</td>
</tr>
<tr>
<td>Wet asphalt</td>
<td>0.8750</td>
<td>33.8220</td>
<td>0.3470</td>
</tr>
<tr>
<td>Snowy</td>
<td>1.1973</td>
<td>25.1680</td>
<td>0.5373</td>
</tr>
</tbody>
</table>

3. ROAD DETECTOR

The performance of the proposed fuzzy detector would be the following: Adhesion coefficient and slip ratio enter to fuzzy system as crisp data. These data are changed to linguistic data via the fuzzy membership functions. Then the resulting outputs go through an interference engine, consists of a set of fuzzy “if-then” rules. The fuzzy output from interference engine is then changed back to a crisp value by the defuzzification process and is nominated as “road condition”. The fuzzy rules are established according to adhesion characteristic curve and performance point of vehicle on it. Section 3.1 shows the rule table and the FIS editor in Matlab and Section 3.2 shows the membership function graphs, ruler editor and the rule viewer for Road detection.

3.1. Fuzzy Rule Table

Table 2. Linguist Variables

<table>
<thead>
<tr>
<th>V. Small</th>
<th>Small</th>
<th>Small Medium</th>
<th>Medium</th>
<th>Medium Large</th>
<th>Large</th>
<th>V. Large</th>
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</thead>
<tbody>
<tr>
<td>V. Small</td>
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<td>Wet</td>
<td>Wet</td>
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<td>Wet</td>
<td>Wet</td>
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<td>Small Medium</td>
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<tr>
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<td>Wet</td>
<td>Dry</td>
<td>Dry</td>
</tr>
<tr>
<td>Medium Large</td>
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<td>Snow</td>
<td>Wet</td>
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<td>Snow</td>
<td>Snow</td>
<td>Wet</td>
<td>Dry</td>
<td>Dry</td>
</tr>
<tr>
<td>Very Large</td>
<td>Snow</td>
<td>Snow</td>
<td>Snow</td>
<td>Wet</td>
<td>Dry</td>
<td>Dry</td>
</tr>
</tbody>
</table>

Figure 1. Fis Editor
3.2 Membership Function Plots

Figure 2a. Waveform of Input Variable Slip

Figure 2b. Waveform of Input Variable Adhesion Coefficient

Figure 2c. Waveform of Output variable Maximum or desired Slip

Figure 2d. Rule Editor
3.3 Gain Control

Sliding mode control is a kind of robust control that is used to control nonlinear plants. As it is known to us, ABS is a nonlinear plant, so SMC provides an effective method to control it. Common sliding-surface is used which is defined as $S = \lambda - \lambda_d$. The control objective is to find a control brake torque such that the slip ratio tracks the desired slip ratio $\lambda_d$. The control brake torque ($\tau_b$) in the SMC consists of two parts:

1. The equivalent control torque ($\tau_{b,eq}$) that forces the systems states to move along the desired sliding surface,
2. The switching control torque ($\tau_{b,sw}$) that ensures the trajectory of the system approaches to the desired sliding surface. In this sliding-surface design, the equivalent control is determined from the condition of $S = 0$

$$\tau_{b,eq} = \frac{VJ(\lambda - 1)}{R} + R(F_x - F_f) + \frac{(VJ\lambda_d)}{R} \tag{3}$$

Where $\tau_{b,eq}$ - equivalent control brake torque
$\tau_b$ - break torque on the wheel
$J$ - moment of inertia of the wheel
$F_x$ - road friction force
$F_f$ - rolling resistance force of the tire
$\lambda_d$ - desired slip ratio

The second part of the controlled brake torque is switching control torque which is defined as in equation 4

$$\tau_{b,sw} = K\text{sat}(S) \tag{4}$$

Where $\tau_{b,sw}$ - switching control torque
$K$ - switching control gain

Therefore the braking torque is:

$$\tau_b = \tau_{b,eq} - K\text{sat}(S) \tag{5}$$

Applying the sliding mode controller to ABS model, results good responses. The performance of the proposed fuzzy controller is as follows: The input signal (vehicle speed) enters to fuzzy system as crisp data. This data is changed to linguistic data via the fuzzy membership functions. After that the resulting Output goes through an interference engine, consists of a set of fuzzy “if-then” rules. The fuzzy output from interference engine is then changed back to a crisp value by the defuzzification process and is nominated as “switching gain”.

Fig. 3 shows the rule table and the FIS editor in Matlab and Fig.4, Fig.5a and Fig. 5b show the membership function graphs of the the vehicle velocity, gain and rule viewer for gain control.
3.3.1 The fuzzy rules

1. If Velocity is very small (ss) or Velocity is small (s), then gain is small (s).
2. If Velocity is medium (m), then (gain is medium (m).
3. If Velocity is large (b), then (gain is very large (bb).

When vehicle speed is decreasing, the fuzzy controller decreases the switching gain too. Therefore, stability condition in sliding mode controller is satisfied.

3.3.2 Membership Function Plots

3.4 The Main Program

A function is written that will input the values of Vehicle velocity (V) and Angular Wheel Velocity (ω) and calculate the respective value of slip ratio and adhesion coefficient. These values are fed into the Fuzzy Inference System which uses the If-then rules defined to calculate the maximum or desired slip. The second Fuzzy inference system uses the input velocity and calculates the value of switching control gain required in the calculation of braking torque. MATLAB is used to show the simulations.
The output of fuzzy system is then inputted into the simulink block structure-

![Simulink block diagram]

**Figure 6. Fuzzy ABS Matlab Simulation**

### 4. RESULTS AND CONCLUSION

In this study, fuzzy logic concept is applied to the ABS through two different ways. In the first step, a new fuzzy road detector for Antilock braking system is proposed. In this fuzzy road detector, different road states can be detected through fuzzy rules. In the second step, a novel hybrid controller is proposed that consists of a sliding mode controller and a fuzzy controller. Fuzzy logic provides a simple solution to the non linear problem which arises during the execution of ABS. While it has shown a massive improvement over conventional brakes, with it’s concept of varying slip ratio, it has shown improvement from conventional ABS.

![Graphs showing vehicle and wheel speed variation](image1)

**Figure 7. Vehicle And Wheel Speed Variation During Braking Without Fuzzy**

![Graph showing variation between slip and time without fuzzy](image2)

**Figure 8. Graph Showing Variation Between Slip And Time Without Fuzzy**

When the values of vehicle speed and angular speed are inputted in the workspace, it calls the Fuzzy inference system and results in maximum slip and the switching control gain. This is shown in the Fig. 9.

This result is then fed into simulink which works in a loop to find the desired slip for the synchronised braking torques dependent upon the various road conditions.

![Graph showing slip variation](image3)

**Figure 9**

The following graphs are the result of Fuzzy ABS. Which shows improvement in slip ratio which in turn does not let the wheel lock up like the conventional ABS but provides minimal distortion in the slip which is varied according to the time.
5. FUTURE SCOPE OF THE STUDY

With Anti lock braking system becoming such a major consideration in the buying decision of people throughout the world it has become vital for automobile manufacturers to provide such safety equipment as standard. With cost being a deterrent to the implementation of ABS, researchers are finding new ways to overcome it. While the proposed controller provides the value of slip according to the road condition it still has too much rigid concepts which can be overcome by ADAPTIVE NEURO FUZZY LOGIC. Here with the updating of slip ratio as per proposed controller, the membership functions governing both the Fuzzy inference systems are also updated according to the dynamic learning it has inbuilt. With this feature as the control unit experiences new terrain, itself learn and will produce better results. With emerging technologies, ABS has now been started been implemented with ESP. ESP stands for electronic stability which reduces shuttering caused by the braking methodology of ABS. This does not let the various vibrations caused by braking to reach the occupants thus the driver has more control over the vehicle. Better defined membership functions can be formulated taking consideration of new inputs such as tire width, tire wear and tear. These which make the fuzzy system more stimulants to even the minutest changes.

REFERENCES


