A Fuzzy Controlled Approach to Anti-lock Braking Systems for Vehicles

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***Abstract* - Anti-lock brake system i.e. ABS is a nonlinear system which includes complex calculations of the slip ratio, adhesion coefficients and acceleration changes. This system may not be easily controlled by traditional control methods. An additional challenging issue which existing fuzzy ABS systems facing is the case of the so-called split-μ braking condition, where braking occurs while the wheels travel on different road surfaces. By keeping these conditions into account an advanced fuzzy ABS system is illustrated with different generalized mathematical models of wheel and vehicle. In this paper, multi stage cascaded fuzzy closed loop system is studied which has separate road surface recognition. An intelligent fuzzy ABS controller can be designed to adjust slipping performance for various kinds of road based on road identification and optimal slip ratio estimator. The fuzzy optimizer can be used to find the optimal wheel slips for the new surface which forces the actual wheel slips to track the optimal reference wheel slips. Enhanced fuzzy ABS algorithm can make sure the avoiding of wheel's skidding problem in different road conditions. Moreover, the obtained fuzzy control is advantageous from viewpoint of reducing design complexity, anti-jamming and robustness properties of the controlled system.**

***Index Terms* - Antilock braking system, closed loop system, fuzzy controller**

I. INTRODUCTION (HEADING 1)

An Anti-lock Braking System (ABS), originated from German word *Antiblockiersystem*; is a electronic safety system that allows the wheels of a motor vehicle to hold its grip over a road surface as directed by driver steering inputs while braking, preventing the wheels from locking up that is being stopped rotation and therefore avoiding skidding. ABS is implemented in automobiles to ensure optimal vehicle control and minimal stopping distances during hard or emergency braking. [1]

ABS was first introduced in cars in 1978, and the technology now is far more advanced than when initially launched. In many real world conditions ABS prevents wheels from locking as well as slows you down quicker than any manual braking technique, especially on wet or slippery roads. An ABS generally facilitate 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.

In a mathematical model of wheel and brake dynamics, slip ratio of wheel to be locked and adhesion or friction coefficient which depends on frictional force between wheel and road surface play important role. The goal of the braking control system is to maintain the slip ratio within the values which obtain the maximum adherence coefficient. Achieving this goal is difficult, because the maximum adherence zone varies with many parameters, for example adherence conditions between the road and the wheel, vertical load, inflation pressure, slip angle, and so on. Therefore, the ABS control systems need to know the exact point within the adhesion curves.

Fuzzy control systems have got immense importance in the field of vehicle technology. Fuzzy controllers are potential candidates for the control of nonlinear, time variant and also complicated systems. Anti-lock brake system (ABS) control mechanism may not find its absolute solution using standard and conventional systems because of its nonlinearities. Fuzzy logic based ABS system can have a solution to this problem. This paper also intends to identify conditions of road top which leads to an optimized brake efficiency for different complex conditions [2].

The presented ABS system is featured with additional road condition detection. It is a closed loop control system in which estimates the road condition prior to fuzzification. Slip ratio calculations are done before so as to avoid "split-μ braking" condition where braking occurs while the wheel travel on different road conditions, which make ABS system more efficient [2]. Feedback signal also deals with the vehicle velocity estimation and desired slip calculation will provide the command signal for the inner wheel velocity loop. The main purpose of this method is to identify road condition which will improve brake efficiency for different road condition.

II. ABS: AN OVERVIEW

ABS can be known as a part of a service brake system that automatically controls the degree of rotational wheel slip during braking by:

- Sensing the rate of angular wheel rotation.
- Transmitting signals regarding the rate of wheel rotation to one or more devices, which interpret these signals and generate responsive controlling output signals.
- Transmitting those signals to one or more devices which adjust braking forces in response to the signals.[3]

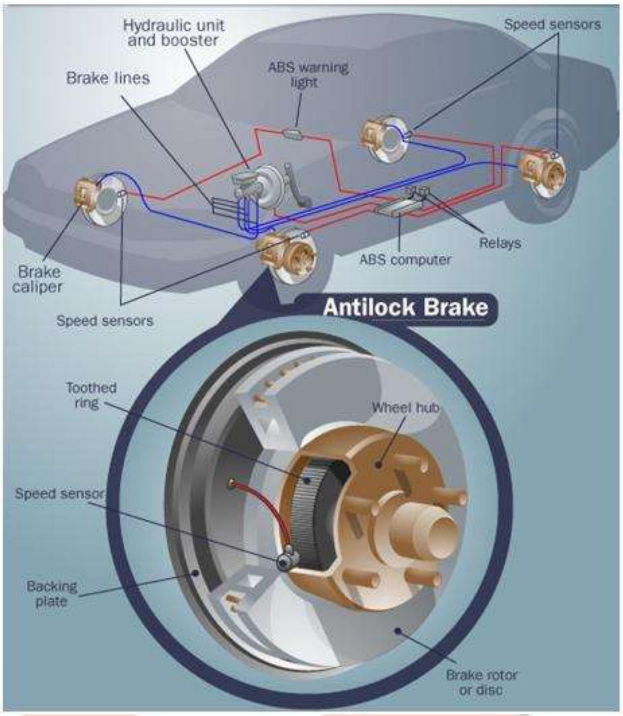

Figure: 1. General ABS System with components

A typical ABS is shown in Figure 1 which includes a central electronic control unit (ECU), four wheel speed sensors, and at least two hydraulic valves within the brake hydraulics. The ECU constantly monitors the rotational speed of each wheel; if it detects a wheel rotating significantly slower than the others, a condition indicative of impending wheel lock, it actuates the valves to reduce hydraulic pressure to the brake at the affected wheel, thus reducing the braking force on that wheel; the wheel then turns faster. Conversely, if the ECU detects a wheel turning significantly faster than the others, brake hydraulic pressure to the wheel is increased so the braking force is reapplied, slowing down the wheel. This process is repeated continuously and can be detected by the driver via brake pedal pulsation. Some anti-lock systems can apply or release braking pressure 16 times per second [1,4].

III. ABS: TECHNICAL ASPECTS

The main disadvantage of the ordinary brakes is that the driver can not precisely control the brake torque applied to the wheels. Moreover, as the driver does not have enough information of the road conditions, he may cause locking up the wheels by applying extra pressure on the brake pedal. The wheel lock up not only ends to have maximum stopping distance, but also causes lateral instability of the vehicle. Hence its very necessary for ABS to forecast correct decision that prevents locking of wheels under all parameters considered. Anti-lock brake should not only decrease the stopping distance of vehicle but also improves controllability of vehicle in compare with other brake systems lacking ABS.

Slip Ratio and Adhesion Coefficient Calculation

Chen and Shih [5], Sudeendra kumar et. al. [6] and Keshmiri et. al. [7] discussed basics about calculations of slip ratio and adhesion coefficient. When the vehicle is running on road, ground forces acting on the wheel is shown in the figure 2. These forces are normal force F_z, the longitudinal force F_x and the lateral force F_y. F_z occurs due to vehicle’s overall load which changes due to load transfer effect in case of brake applied. The lateral force F_y represents vehicular movements during turns. The reduction in the braking distance depends on whether F_x can be maintained at its maximum value. During braking the constant patch between tire and ground begins to slip. This substantially affects both the longitudinal and lateral friction coefficients [5]. The slippage can be modelled with slip ratio. The wheel slip ratio is defined as

$$S.R. = \ (V_v - R.\omega) \ / \ Vv \tag{1}$$

Here, V_v is the absolute vehicle speed, R is the effective radius of the wheel and ω is the angular speed of the wheel.

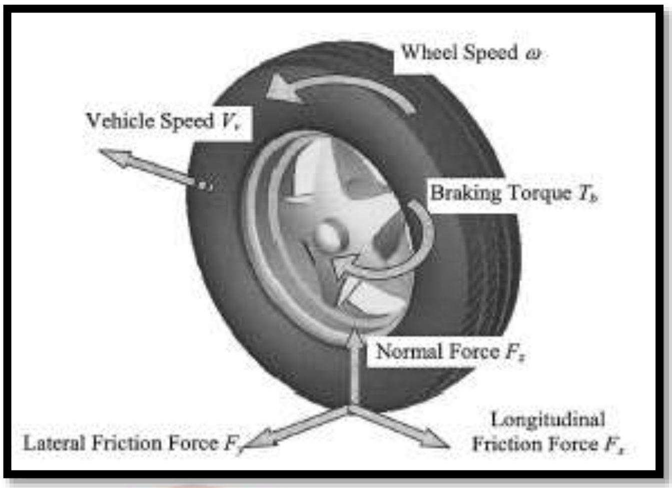

Figure: 2. Modelling wheel for slippage mechanism (Courtesy: [5])

When S=0 the wheel is in perfect rolling motion without slipping. On the other hand, when S=1 the wheel is locked and pure sliding happens. The slip ratio greatly affects the longitudinal and lateral forces. During braking, in addition to the longitudinal force on the wheel, the lateral force maintains vehicle stability in a straight or turning motion. Therefore both lateral and longitudinal forces should be considered to achieve shorter braking distance without losing its maneuverability [5]. The application of brakes generates a force that impedes a vehicles motion by applying a force in the opposite direction. The braking force or the adhesion coefficient of braking force (μ_{bf}) measured in the direction the wheel is turning is function of slip [6,7]. Which is dependent on Road surface material condition, tire material, pressure, tread depth, tread pattern and construction [6].
According to Dugoff's experimental results[3], the adhesion coefficient μ on a dry road surface decreases linearly with the increase of slip speed and can be modeled as:

$$\mu = \mu_0(1 - A_s \cdot Vv \cdot S.R\,) \tag{2}$$

Where μ_0 is the coefficient at the slipless state and A_s is a linear decreasing factor due to slip speed. On a wet road surface, the coefficient decreases exponentially with the raise of slip ratio and it is modeled as:

$$\mu = \mu_{0.}\,exp\left(- \ \frac{Vv.\ S.R}{Vc}\right) \tag{3}$$

Where, V_c is the road surface – property velocity, which is related to the root mean square texture height of the road surface.

Relation between Slip Ratio and Adhesion Coefficient

The relations between adhesion or friction coefficients (longitudinal and lateral friction coefficients, μ_x and μ_y respectively) and slip ratio λ are shown in figure 3. On a dry road surface, the longitudinal friction coefficient increases initially and drops after its maxima. The lateral friction coefficient that influences the vehicle maneuverability decreases after increased slip ratio. The optimal region to be controlled is around the max value of longitudinal coefficient μ_x since it can keep maximum braking force while still maintaining the maneuverability (μ_y). However the max of μ_x may change for different road condition and vehicle speeds.[5]

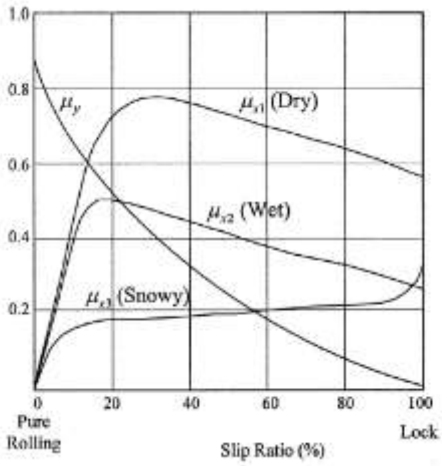

Fig. 3 – Relation between longitudinal, lateral friction coefficients and slip ratio [3]

Graph is normally divided into two areas: stable and unstable. In the stable zone, balance exists between the braking effort applied and the adhesion of the road surface. In unstable zone when the critical slip is passed, no balance exists and the wheel will lock, unless the braking force is reduced. The slip ratio increases, the adhesion, will peak and then decline. After the peak, the rotating tire can then lock up abruptly thus resulting in even less adhesion [6].

IV. ABS: FUZZY SYSTEM INTERPRETATTION

After ABS is a nonlinear system which may not be easily controlled by classical controller based methods. Major problem in ABS is to deal with different road conditions where modelling of wheel changes with different road conditions as shown in table 1.This ultimately results in failure of braking system while the wheels travel on different road surfaces. The option for designer is to introduce intelligent fuzzy ABS controller which can be manipulated with necessary slipping performance adjustment for variety of roads. The fuzzy optimizer finds immediately the optimal wheel slips for the new surface and forces the actual wheel slips to track the optimal reference wheel slips. . Further, it can be modified in accordance with road top conditions to optimize brake efficiency which could lead to intelligent control system [2].

Table 1. The slip ratio values at different vehicle speeds

Speed (km/hr)	Road Surfaces	
	Dry	Wet
20-30	0.58	0.25
30-40	0.49	0.21
40-50	0.43	0.186
50-60	0.39	0.169
60-70	0.36	0.156
70-80	0.337	0.146
80-90	0.317	0.138
90-100	0.29	0.13

Fuzzy controlled ABS system is shown in figure 4. A closed loop control system in given figure has cascaded structure of Fuzzy controlled ABS integrated with road condition detector prior to slip ratio calculations which prevents wheel to get lock during various speed and road conditions. The lower loop includes the vehicle momentum approximation and desired slip calculation will be commanded by upper loop which behaves as input for S.R. calculations. The main purpose of this method is to guide wheeling system of vehicle according to road and slip ratio conditions which leads to an optimized brake efficiency for complex scenarios.

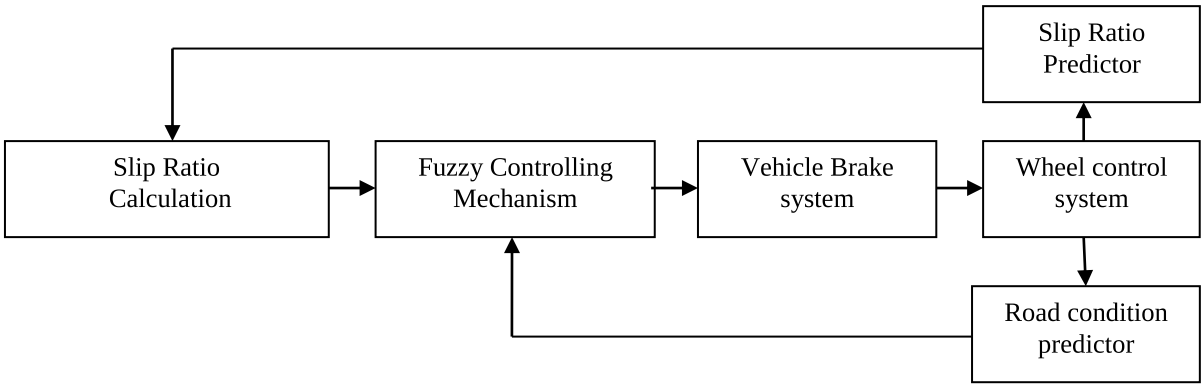

Fig. 4 – ABS Fuzzy Control System for Vehicles

Generalized ABS fuzzy system comprises four main stages: Fuzzification, rule base, inference mechanism and defuzzification. Fuzzification and defuzzification stage are needed to convert and reconvert real world crisp signals into fuzzy values and vice versa. The inference system determines the matching degree of the current fuzzy input with respect to each rule and decides which rules are to be fired according to the input field. Next, the fire rules are combined to form the control actions. Fuzzy inference mechanism exhibits the Takagi-Sugeno fuzzy model to constitute the fuzzy conversions.

Skip ratio and Adhesion coefficients are crucial to ABS control. For each road condition there exists an optimal wheel slip resulting in the minimal stopping distance if the brakes are applied so that wheel's sleep coincide with the optimal values of wheel slip. On the other hand, if the vehicle is equipped with an accelerometer, then knowing the vehicle acceleration corresponding to the particular values from the wheel slips, the road surface can be identified on which the vehicle is moving. Figure 5 tries to fuzzify speed and momentum of wheel where separate functions which are first normalized and are used for experiment as inputs to fuzzifier. A rule based is orchestrated based on inputs whose outputs are necessarily road predictor. Simultaneously, it will track any error in feedback to slip ratio to correct it to optimal value.

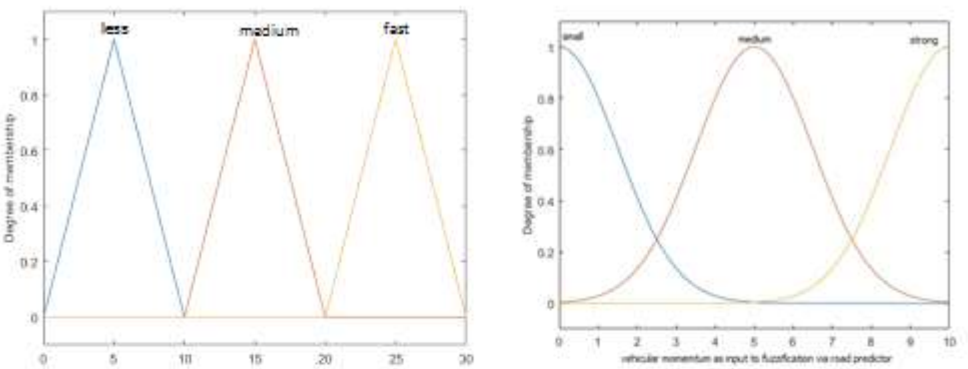

Figure 5: Membership functions for vehicular momentum and speed for fuzzifier

The expected output will be in the form of road conditions starting from dry to very wet and slip ratio change as outputs to simple if then rule base.

V. CONCLUSION

This paper does a case study and discuss primitive objectives of fuzzy ABS system which can tend towards efficiency with modeling and experimenting with more parameters – road condition, slip ratio as in discussed herein. In this closed loop multi stage fuzzy system, the fuzzy inference system can immediately rounds up the optimal wheel slip ratio for the new road condition and can present the actual slip ratio which is possible by tracking vehicle and wheel mechanism in feedback. Further for more efficiency, two additional sensors could be added to help the system work which are a steering wheel angle sensor, and a gyroscopic sensor.

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