Study on Algorithm of braking Pressure Estimation for Single Channel Anti-Lock Braking System

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ABSTRACT
In this Paper, the vehicle equipped with electromechanical brakes are taken as research objective, and the simulation and research on the control strategy of Anti-Lock braking system is done. The force acting upon the wheels is analyzed first using quarter vehicle model and simulated in order to understand the vehicle dynamics. Next, the performance characteristics of the hydraulic unit were analyzed. Finally, a closed loop feedback control algorithm is developed to modulate the pressure in accordance with the force acting on the wheels. The result shows that the actual wheel slip and force can be tracked by estimating the angular velocity of the wheels with an allowable pressure error.

Keywords
Automotive engineering, braking, hydraulic control unit, pressure estimation, estimation force, single channel anti-lock braking system, force estimation, quarter vehicle model, mathematical model, Slip of wheel.

1. INTRODUCTION
Anti-Lock Braking system is a driver assistance system that greatly reduce the hazards associated with astringent braking and inopportune road conditions. It is an automobile safety system that averts the wheel from locking up and sanctions the driver to have control on the steering by maintaining congruous traction between the road and the tire. The rudimentary concept of the ABS is quite simple and can be understood with the avail of mu slip curve 1. It defines the relationship between tire slip and the available braking force. It can be optically discerned by observing figure that maximum friction coefficient lies in between 0.2-0.3 value of slip and as the slip transcends this value the braking force reduces i.e. wheels commences to lock up and gets thoroughly locked up when slip value reaches 1 and at this point driver loses control on steering conveyance commences skidding due to lack of traction between tire and road [1].

What ABS system does is it endeavors to maintain the value of tire slip in vicinity of the region where traction is maximum by modulating the braking force applied. By doing this, the wheels never lock up and driver has consummate control on steering and additionally it can be visually perceived that the available braking force is more astronomically immense than the locked tire thus it reduces the braking distance as well. What ABS system does is it tries to maintain the wheel slip in between the stable and unstable region brake pressure is perpetually modulated so to keep the slip back and forth of the desired slips.

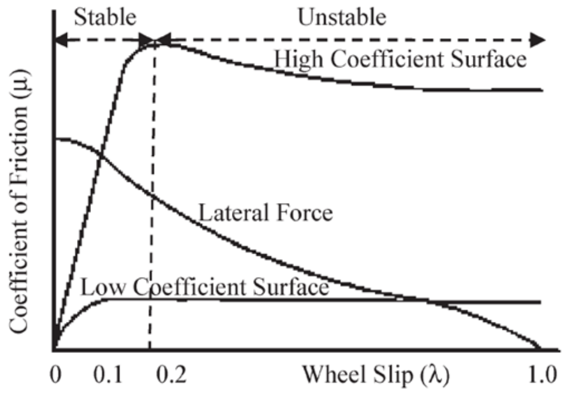

Fig.1: Relationship between coefficient of friction μ and the wheel slip λ (Mu-slip Curve)

2. ABS METHODOLOGIES
The methodologies of the ABS tries to reduce the longitudinal tire slip which is achieved by processing the information obtained from wheel speed sensors. These sensors provides the wheel speed Vw which is the compared with vehicle reference speed Vv to detect any slip. The tire slip cannot be directly calculated but it is calculated by the formula.,

$$S = 1 - Vw/Vv \qquad \ldots (1)$$

Where,
Vw = wheel speed and is calculated as ώ x Rtire,
Vv= Vehicle Speed,
ώ = Angular velocity of the wheel,
Rtire is the radius of the wheel

To accomplish the controlling following variables and parameters are continuously monitored by the ABS controller,

- Wheel velocity - is the angular velocity of the wheel.
- Vehicle Velocity - is the linear velocity of the vehicle.
- Wheel Spin Acceleration - is the angular acceleration of each wheel.
- Tire Longitudinal Slip - Relative velocity between the tire and road, expressed as a fraction of vehicle velocity.
- Brake System Pressure - is the pressure produced due to the application of the brake by the driver (input variable).
- Wheel Brake Pressure - is the brake applied to the wheel assembly (output variable)

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3. LITERATURE REVIEW

This section of this paper cover a detail review on the various proposed ABS systems and their functionalities. All advanced ABS system development is mainly intended to ensure the passengers safety by maintaining the traction between the tire and the surface and keeps the slip ratio in the region where friction is best between the surface and the tire. The main functional modules of the ABS systems are the sensors (speed, traction) and a controller for processing the data from sensors. In [1], different implementation techniques associated with ABS are reviewed thoroughly. Hall Effect based speed sensors is the dominant sensor by considering the importance of high quality sensor data. In their paper [2], author proposed “a hybrid control system with a recurrent neural network (RNN) observer is developed for anti lock braking systems. This hybrid control system is comprised of an ideal controller and a compensation controller. The ideal controller containing an RNN uncertainty observer is the principal controller; and the compensation controller is a compensator for the difference between the system uncertainty and the estimated uncertainty.”

Another author [3] presented “a design of a fuzzy logic network and a decision logic network has been proposed in another reading. The controller identifies the current road condition and generates a command braking pressure signal, based on current and past readings of the slip ratio and brake pressure. The controller detects wheel blockage immediately and avoids excessive slipping. The ABS system performance is examined on a quarter vehicle model with nonlinear elastic suspension. The parallelity of the fuzzy logic evaluation process ensures rapid computation of the controller output signal, requiring less time and fewer computation steps than controllers with adaptive identification.”

In another paper [4], an optimized fuzzy controller is proposed for ABS. The objective function is denned to maintain the wheel slip to a desired level so that maximum wheel traction force and maximum vehicle deceleration are obtained. All the components of a fuzzy system are optimized using genetic algorithms. The combination of fuzzy and PID controller has been used to get the best of both [5]. PIC provides better controlling and fuzzy provides uncertainty required for generation of proper control signals. A thorough research and study on the calculation of the wheel slip, importance of wheel angular acceleration in ABS [6], Data acquisition [7], and control logic for ABS [8] have been done so as to develop a higher understanding in vehicle dynamics associated with the moving vehicles.

[9] Depicts the methods and device for driving a Solenoid Valve which acts as a switch between the pressure applied to the brakes. [10] Discusses the characteristic test and analysis on the oil returning pump of ABS which allows to modulate the pressure during pressure release cycle of ABS. [11] Presents a model based recursive least square algorithm for estimation of brake pressure and road friction.

4. VEHICLE MODEL

Basically, a complete vehicle model that includes all relevant characteristics of the vehicle is too complicated for use in the control system design. Therefore, for simplification a model capturing the essential features of the vehicle system has to be employed for the controller design. The design considered here belongs to a quarter vehicle model as shown in Fig 2. This model has been already used to design the controller for ABS.

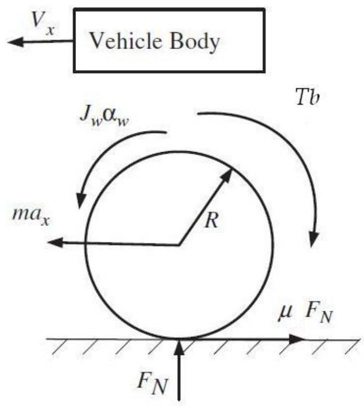

Fig 2: Quarter Vehicle Model

The longitudinal velocity of the vehicle and the rotational speed of the wheel constitute the degrees of freedom for this model. The governing two equations for the motions of the vehicle model are as follows:

For braking force balance in longitudinal direction (vehicle)

$$ma_x = -\mu F_N = m\frac{dV_x}{dt} = -\mu F_N \qquad (1)$$

umming torque at wheel centre (wheel),

$$J_\omega \alpha_\omega = \mu R F_N - T_b \qquad (2)$$

For convenience Slip Ratio is defined according to:

$$\lambda = \frac{V_x - \omega R}{V_x} \qquad (3)$$

Differentiating both sides with respect to time (t), we get

$$\lambda' = \frac{V_x'(1-\lambda) - \omega' R}{V_x} \qquad (4)$$

The nomenclature in the above equations is presented as follows,

Vx = Linear Velocity of Vehicle
ax = Linear Acceleration of Vehicle
ω = Rotational speed of wheel
αω= Angular acceleration of wheel
Tb = braking torque
λ = Slip Ratio
μ = Friction Coefficient
R = radius of tire
m = mass of model

State space representation of above equation is presented below. During braking, the slip ratio is dependent on the input torque u and the vehicle velocity Vx. The system state variables are:

x1 = Sx, (5a)

x2 = Vx, (5b)

x3 = λ, (5c)

Where Sx is the stopping distance. The state space equations are,

X1 = x2 (6)

X2 = -μFN/m (7)

$$X_2 = \frac{-\mu F_N}{x_2}\left(\frac{1-x_3}{m} + \frac{R^2}{J_w}\right) + \frac{R}{J_w x_2} T_b \quad (8)$$

By controlling the braking torque u in the simulation tests to evaluate the performance of ABS, using different control strategies.

The value of coefficient of friction as a function of linear velocity and slip ratio,

$$\mu(\lambda, V_x) = [c_1(1-e^{-c_2\lambda}) - c_3\lambda]e^{-c_4 V_x} \quad (9)$$

Assuming C1, C2, and C3 into the simulation environment the relation between coefficient of friction and Slip Ratio is given by Fig. 3. And thus the optimum value for λ is found out to be 0.2-0.4.

5. PROPOSED SYSTEM

Auto-motives are the greatest revelation that greatly reduces the human effort associated with a particular work. But, with the incrementation in automation a threat is associated as the no. of accidents has greatly incremented. According to a survey a contingency takes place in India in every 3 minutes. So, by including the Anti lock braking system along with the mundane brakes, these figures can be greatly reduced.

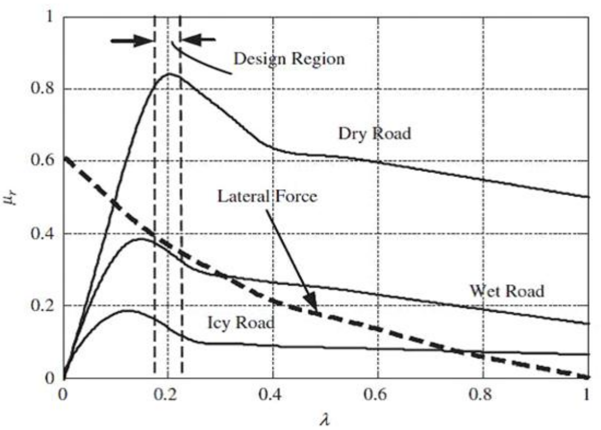

Fig 3: Desired region of design

As we have discussed sundry techniques and algorithms of ABS system, now we will discuss the proposed scheme for efficient implementation of ABS system, in the proposed scheme An Algorithm has been developed for programming the ECU (Atmega328) which reduces the computation time and engenders control signals in fewer cycles as compared to the algorithm utilized in present ABS and thus increases efficiency. As we have observed in Fig 1 we have culled a desired region of operation of the system and withal desired value of wheel slip is postulated to be 0.28 any deviation from this value will be provided as a feedback in a closed loop system and accordingly the brake pressure is modulated by the solenoid valve that is connected in the front and the return line of the brake system. The block diagram of the proposed scheme is shown in Fig 4. As the relationship between coefficient of friction and wheel slip shows that optimum value for wheel slip where traction is maximum is 0.2 so we will try to maintain it to that value only to maintain control on the steering and prevent locking up of wheels. To maintain the traction in almost all types of surface condition we have selected an optimum region which is shown in figure. This is where the value of wheel slip ratio will lie. The system responds well in this region and thus maintains slip between 0.2-0.3 gives good stability in almost all the surfaces [9].

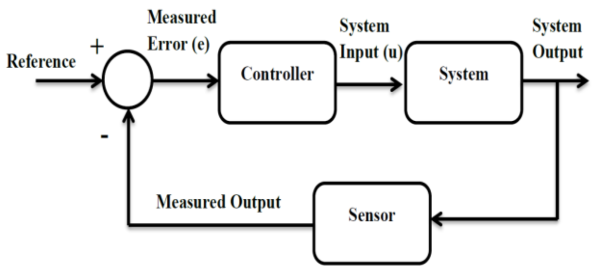

Fig. 4: Block diagram of the proposed system

6. WORKING OF PROPOSED SYSTEM

Hardware typically used in the proposed system and their functionality is:

- Electronic control unit (ECU) - This is the main control module of the ABS system it reads various variables and parameters and accordingly modulates the brake pressure on the wheels.
- Wheel speed sensors- These sensors are basically based on Hall Effect, the output of this sensor is a voltage signal whose frequency is proportional to speed of the wheel. This frequency is used to calculate the speed.

  V = -I*B/n*e*d … (10)

- Brake pressure modulator- This modulates the brake pressure on the wheel on the basis of the control signal provided by the ECU.

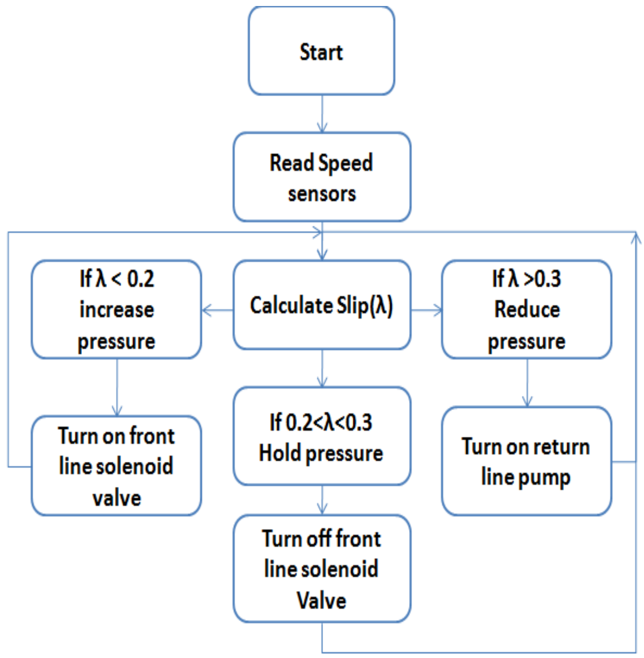

Fig. 5: Flowchart of the Control Algorithm

Proposed algorithm (Fig.5) that is utilized for efficient implementation of ABS system is predicated on the fact that floating point math operation takes more cycles than that of integer type math operation and additionally takes much recollection. Utilizing this fact the algorithm is made such that the calculation of the Slip is not done in the theoretical way (i.e. ratio of wheel speed to the angular speed) but is done in a different way that reduces number of ordinant dictations to be executed and withal float values are converted into integer values so as to do more expeditious execution. Table I show the analysis of the time and recollection reqd. by the precedent and proposed algorithm. We will be utilizing Atmega328 board for testing and then will be shifting to specialized microcontroller for final implementation. Hall effect sensors has been made and magnets are affixed to the wheels, this magnet makes the output of the sensor to go low and thus controller counts the no. of pulses and on the substructure of this control signals are engendered.

When the brake pedal is applied, the hydraulic signal activates the actuator. Initially the main line is on so the brake is applied directly to the wheel. The celerity of the wheel is perpetually monitored by the haste sensor and the output signal is alimented to the microcontroller. The microcontroller is alimented with the developed Algorithm for operation of the ABS. And hence it manipulates the celerity value and the desired value and provides congruous output. This works as a closed loop control system.

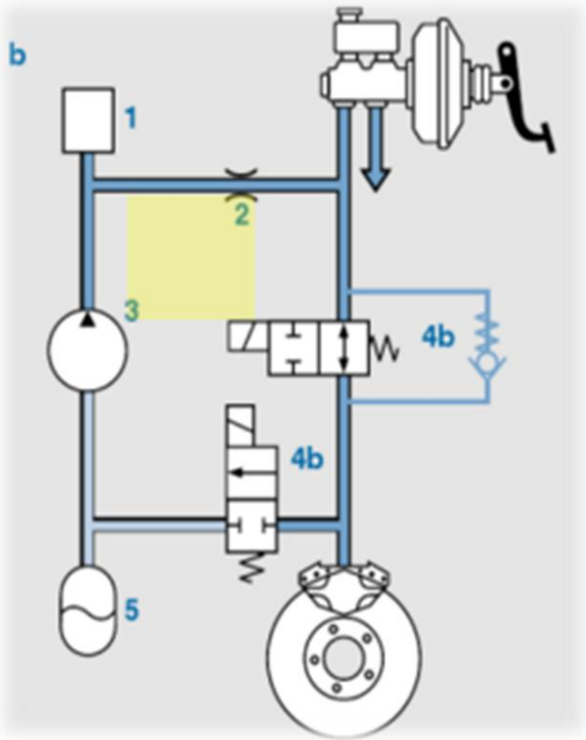

Fig. 6: Line diagram of the setup

Fig. 7: Hardware setup on Pulsar 135LS.

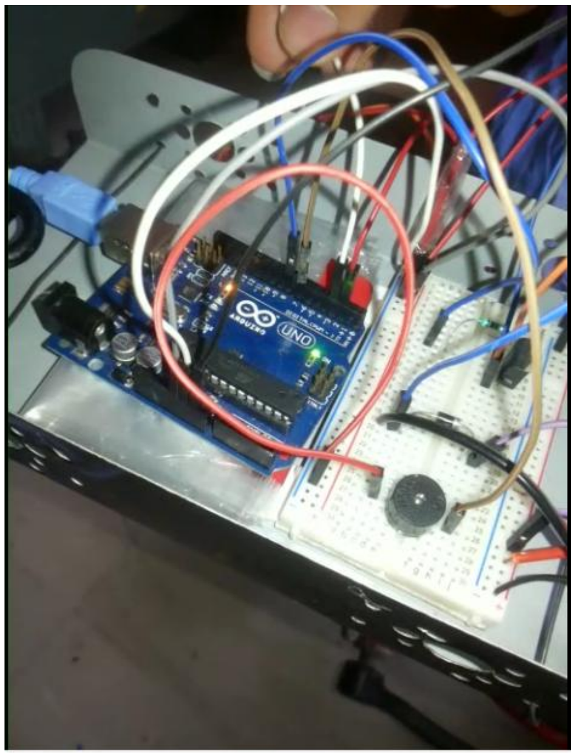

Fig. 8: ECU and Switching Circuit Setup

The working of the algorithm can be explicated as,

1. Initially when the slip is less than 0.2 the main line is on which directly applies the pressure to the brake caliper. This is normal braking condition. This cycle is normally called as Pressure Apply cycle.

2. When the calculated slip is in between 0.2-0.3 the ABS system senses with the information obtained from the speed sensor that this is the desired region of the slip so any further increase of the pressure is ceased and the pressure is maintained. This cycle is commonly referred as Pressure Hold cycle.

3. If the controller senses that the slip is beyond 0.3 it immediately releases the pressure from the caliper from the return line which reduces the pressure in the brakes and tire starts spinning again. This cycle is called pressure release cycle. A return pump is placed in the return line so as to move the fluid against the pressure.

These cycles are continuously repeated until the vehicle completely stops keeping the steer-ability of the vehicle and also maintaining maximum traction between the road and the tire.

Fig. 6 shows the Line diagram of the setup, 4a and 4b is the 2/2 solenoid valve, 5 & 1 is master cylinder, 3 is accumulator, 2 is the brake line. Fig. 7 and 8 shows the hardware setup and circuit setup respectively.

7. RESULTS

Utilizing the fact that the floating point math operation (Fig. 10) takes more cycles than that of integer type math operation (Fig. 9) the proposed Single Channel ABS system has been installed in pulsar 135 2011 model which has hydraulic brakes in the front tire only. The results show considerable improvement in the speed of the operation of the Electronic control module (ECU). Refer Table I. Fewer cycles were required by the system for generating control signals. Thus, lesser the cycles required to generate the control signals, faster is the system response. The algorithm is so made that it is smart enough to detect any spike in the power supply and it automatically after resetting takes just 0.02 milliseconds for starting the controlling again thus high security can be ensured. Also the algorithm requires total 5,102 Bytes of storage space (Fig. 11).

Table I: Timing analysis & Comparison

Headings	Comparison	
	Time	Memory
Execution time of previous (tire) algorithm (for one cycle)	588 microseconds	~7,100 Bytes
Execution time of the proposed algorithm	304 microseconds	~5102 Bytes

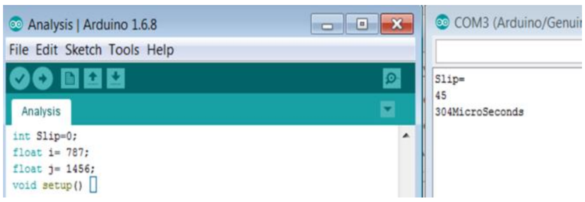

Fig. 9: Integer type math operation

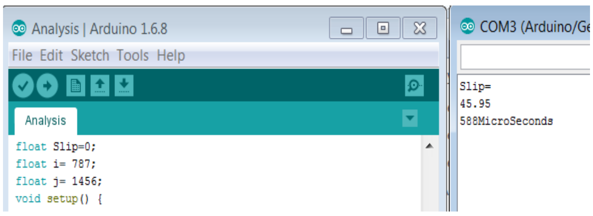

Fig. 10: Floating type math operation

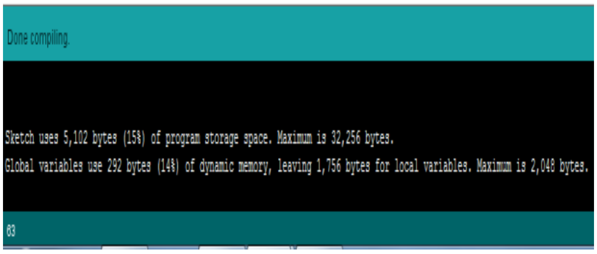

Fig. 11: Memory Requirement by the proposed algorithm

Presently the system has been tested on the dry asphalt only; there is no way for system to work with maximum efficiency on all the road conditions. The algorithm is less flexible thus it becomes a little difficult for it to adapt to varying road conditions. In future the same concept can be extended to make the algorithm smart enough to judge the road conditions and automatically adjusts the desired slip accordingly.

8. CONCLUSION

In this paper, we have reviewed the various technologies such as Neural Networks, Fuzzy Logic, Genetic algorithms etc. used for implementation of Anti Lock Braking System (ABS). Using Hall Effect based speed sensor we were able to get accurate reading of the vehicle speed and wheel speed. With Atmega328 we were able to develop a low cost highly reliable ABS system which can then be implemented on the cheaper vehicles as well, which not only will increase the safety but will also reduce the number of accidents that takes place due to skidding of the wheels. Also, faster execution can be performed and additionally the lag associated due to slow operation of mechanical parts is additionally compensated thus making the systems a few folds faster. Results show considerable amelioration in the haste of the system and withal the braking distance has been reduced.

9. ACKNOWLEDGMENT

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