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Road Condition Monitoring for Optimized Antilock Braking System

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Abstract: The aim of an anti-lock braking system is to detect the locking of wheels and to adjust the breaking force accordingly so as to prevent this locking. This action provides improved stability and controlled steering during the application of vehicle brakes in an emergency. However, antilock braking suffers from a few drawbacks, i.e. the interaction between the road and the tire is nonlinear, the vehicle dynamics are complex and there is uncertainty of road conditions. Since it is difficult to obtain information about these uncertainties in real time directly, this is a serious research challenge to accurately identify road condition in real time. ABS used presently are based upon empirical formulation, their activation takes place when the slip ratio exceeds a preset threshold (usually 0.2).

However, this mechanism is defective as the slip ratios for various road surfaces are different. Furthermore, sensor data is used by present ABS systems to determine the slip ratio. This measurement is susceptible to noise as slip ratio is usually a small quantity and accuracy of the computed value is therefore questionable. Moreover, aging, cost and maintenance of the sensors to prevent dust etc increase the likelihood of failure of the system. In order to overcome the limitation of sensor based ABS systems, In this a sensor less system has been proposed to accurately identify the optimum slip ratio in order to optimize the antilock braking system. In this research work an indirect approach is used in which variations in the dynamic response of the vehicle are investigated and from the dynamic variations optimum slip ratio is identified using a Fuzzy inference system. The dynamics of the vehicle are estimated using Kalman filtering approach. Effectiveness of proposed method is affirmed by the presented simulation results.

Keywords: ABS, slip ratio and Kalman filter

1. INTRODUCTION

With each passing day, governments and vehicle manufacturers are paying more attention to safety during driving. This has resulted in changes to the infrastructure such as better lighting of the streets, improving road conditions, appropriately placing sign boards etc to increase road safety. Safety improvement can also be improved within the vehicles. This gives rise to two types of safety systems, namely active and passive. The job of a passive safety system (e.g. airbags) is to minimize injury to the passenger during a crash. On the other hand, active safety systems aim to avoid crashes and ensure stability in vehicle steering during the application of emergency braking.

In some situations, the application of emergency braking is unavoidable and due to such braking on wet or dry road surfaces, wheel are locked .because of the locking of the wheels the adhesion between the road surface and the tires of the vehicle decreased which results in the vehicle becoming un-steerable.

Consequently, the vehicle is not responsive to steering from the driver and skids towards the obstacle. The job of the anti-lock braking system is to detect when the locking of the wheels is about to take place and then free the brakes so it is prevented thereby making the longitudinal stability better and allowing proper control of the vehicle so as to avoid collision with obstacles. The ABS also attempts to increase the frictional forces between the road and the tires so as to minimize the braking distance as depicted in **(Fig.1).**

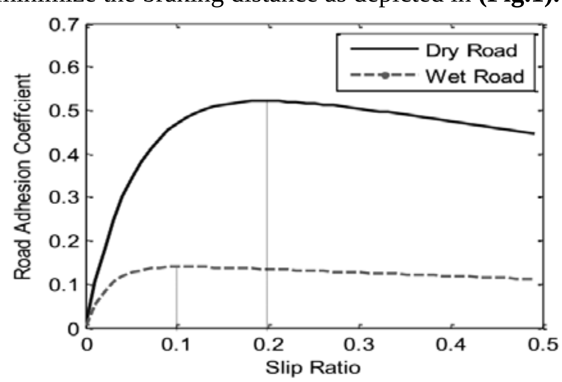

Fig.1: Road adhesion coefficients for wet and dry Road

The ABS system was invented by Bosch in 1936 (Robert 2003).. They patented an "Apparatus for preventing lock braking of wheels in a motor vehicle". However, implementation of this method was not possible due to the unavailability of suitable technology. The initially proposed method was modified by engineers from Mercedes-Benz during 1967 and 1970 who suggested the use of sensors based on the induction principle in place of the mechanical sensors (Daimler 2008,).. With the advent of miniaturized and robust electronic circuits, the measurement of data from sensors on the wheels was possible. This also allowed

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for reliable actuators being used to adjust the hydraulic pressure of the brakes. A major milestone in the development of ABS systems took place in 1978 when a Mercedes-Benz Class S was installed with the second generation of ABS. Currently, research work is ongoing to make ABS more robust and adaptive using the linearities in the relationship between the tire and the road. As shown in **(Fig.-2),** ABS operation is not able to operate optimally due to factors such as weather and other environmental conditions.

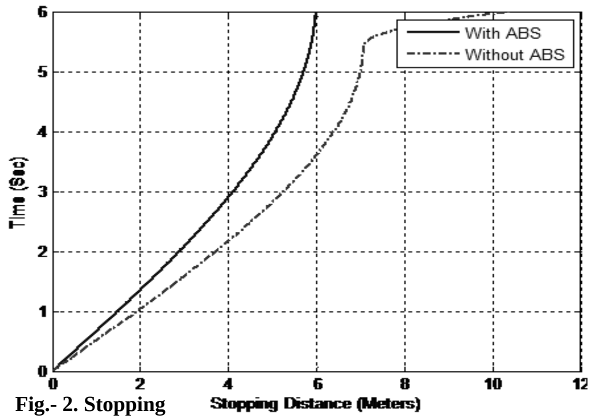

Fig.- 2. Stopping Distance with ABS and without ABS

Currently designed ABS systems are constructed on the basis of data gathered experimentally. They get activated when the value of the slip ratio becomes larger than a preset fixed value (i.e. 0.2) (Rau, *et al.*, 2012)". However, the slip ratio varies or different road surfaces and therefore this is not suitable.

This problem has been the focus of many researchers. For developing a control system for a vehicle, it is necessary to determine the coefficient of tire-road friction in real time. Unfortunately, the coefficient of road-tire friction is hardly measured directly and several approaches have been proposed to determine it real time estimate. The authors in (Robert 2003). use the texture information within images of the road to perform road surface classification. Their method is based on the observation that rough surfaces have a larger spread in the pixel luminance value as compared to smooth surfaces. However, the reliability of this method deteriorates when the captured images are blurry due to the vibration and speed of the vehicle. Road wetness is measured in (Holzmann, 2006) and (Sato, 2007) through optical sensors used for light detection. They showed their technique to for the determination of road conditions, but the efficiency of this method has a large dependence on light intensity and direction. Only vision information is generally not adequate to perform an estimation of the condition on the road since they are affected by other factors which may not be easily determined by using this information alone.

Several reasons exist for the un-applicability of sensor based approaches to be used widely. The signals generated by some of the sensors are very susceptible to noise and extraction of the useful data can be difficult. Second, some of the sensors have very specific environment and position requirements and thus are difficult to be used in commercial vehicles. Thirdly, these sensors have high cost. Hence, such methods which are based on sensors are problematic when used widely.

To develop a sensorless system, techniques like Kalman filters, recursive least squares and state observers are used to perform this estimation. Here, the dynamics of the vehicle are utilized for estimating the remaining dynamics. A Kalman filter is set of recursive mathematical equations used to minimize the estimated variance of the process state. The past, current and future state can be estimated using a Kalman filter. It has the ability to determine this estimation even with the availability of an accurate model of the system (Welch, and Bishop, 2001) This paper presents a sensor-less antilock braking system which uses system dynamics for slip ratio estimation and also for monitoring the present conditions of the road as opposed to operating with predefined slip ratio values.

2. PROPOSED SYSTEM

The work aims to estimate the slip ratio using the system dynamics and use it to determine the road condition. We have taken in to consideration two types of road conditions, wet and dry and use the Kalman filter (or estimator) to calculate the system dynamics error. Based on the calculated errors, it is possible to describe road conditions as shown in **(Fig.-3).**

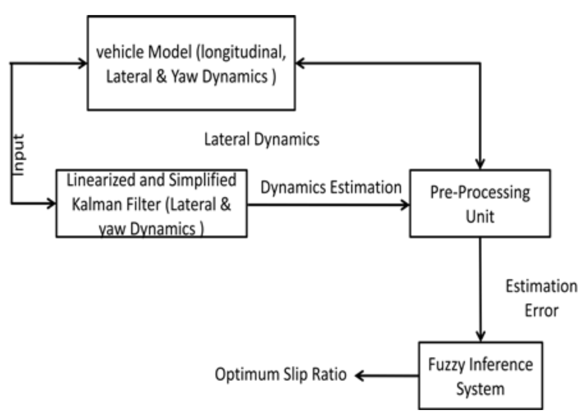

Fig. 3: Proposed System Block Diagram

We use a Kalman filter tuned at high creep curve (slip ratio of 0.2), therefore, it gives the minimum value of the error when the road conditions are dry. As the condition of the road is changed, the error will increase to the maximum and observing this, we indicate the road condition. The identification of road conditions from the observed conditions is carried out using a fuzzy inference system as done in (Hussain, *et al.*, 2014)

The end system will allow for continuous monitoring of the road conditions and if they change, the system should be able to detect and determine the changes and give an optimum value of the slip ratio to be used. For dry road conditions, the slip ratio is 0.2 and for wet conditions, the slip ratio is 0.1.

3. SYSTEM MODELING

We can linearize the vehicle model by assuming small angle approximation while neglecting higher order terms. However, if we consider longitudinal velocity as a state of the system, we get a non-linear vehicle model. Consequently, we need to assume longitudinal velocity to be constant to form a linear model of the vehicle. Furthermore, we assume that the role of the tire in the vehicle model is linear. If we rewrite the non-linear lateral acceleration and yaw angular acceleration, we get (Rusty and Bevly 2005)

$$\dot{V}_y = \frac{F_{yf}}{m}\cos\delta_f - \frac{F_{xf}}{m}\sin\delta_f + \frac{F_{yr}}{m}\cos\delta_r - \frac{F_{xr}}{m}\sin\delta_r - V_x r \quad (1)$$

$$\dot{r} = \frac{Lf}{I_z}\left(F_{yf}\cos\delta_f - F_{xf}\sin\delta_f\right) - \frac{L_r}{I_z}\left(F_{yr}\cos\delta_r - F_{xr}\sin\delta_r\right) \quad (2)$$

Here, we can neglect the aerodynamic drag and the rolling resistance as the vehicles longitudinal velocity is taken to be constant.

The two longitudinal tire forces, F_{xf} and F_{xr} then become zeros. Due to the assumption of the small angle, the sine and cosine terms are reduced such that $\sin\delta_f=\delta_f$, $\cos\delta_f = 1, \sin\delta_r = \delta_r$ and $\cos\delta_r = 1$ We can then simplify Equations (1) and (2) as

$$\dot{V}_y = \frac{F_{yf}}{m} + \frac{F_{yr}}{m} - V_x r \quad (3)$$

$$\dot{r} = \frac{Lf}{I_z}\left(F_{yf}\right) - \frac{L_r}{I_z}\left(F_{yr}\right) \quad (4)$$

The linear lateral tire force can be calculated while operating in their linear region from

$$F_{yf} = -C_{\alpha f}\alpha_f \quad (5)$$

$$F_{yr} = -C_{\alpha r}\alpha_r \quad (6)$$

Where the front and rear tire cornering stiffness are $C_{\alpha f}$ and $C_{\alpha r}$ respectively. The slope of the linear region on the lateral force vs. slip angle plot is used to determine the tire cornering stiffness.

Assuming that there is no steering on a rear wheel (δ_r=0), equations (3) and (4) are linearized by substitution of linearized lateral forces to complete the linear model. The state space representation of this model can be written as shown in equation (7).

$$\begin{bmatrix}\dot{V}_y\\ \dot{r}\end{bmatrix} = \begin{bmatrix} -\frac{C_f+C_r}{mV_x} & \frac{-L_fC_f+L_rC_r}{mV_x} - V_x \\ \frac{-L_fC_f+L_rC_r}{I_zV_x} & -\frac{L_f{}^2C_f+L_r{}^2C_r}{I_zV_x}\end{bmatrix}\begin{bmatrix}V_y\\ r\end{bmatrix} + \begin{bmatrix}\frac{C_f}{m}\\ \frac{L_fC_f}{I_z}\end{bmatrix}\delta_f \quad (7)$$

4. KALMAN FILTER

The process of state estimation involves that various states of a process need to be estimated while having only partial and/or noisy measurements from the process. This is a ubiquitous problem in the fields of engineering and science and has been the attention of researchers in various areas such as economic forecasting, robotics etc where it is needed to ascertain of how a system can react to uncertainties in an optimal manner. This optimality can be expressed a minimum mean square error state estimation problem.

The Kalman filter is considered the most popular state estimator, performing in an optimal manner for linear systems, but most real world systems are non-linear. Therefore, before we can use the Kalman filter with such systems, they need to be linearized. Hence, this area has been the focus of research in application in the fields of autonomous or assisted navigation. The Kalman filter comprises of a set of mathematical equations and the process statements are estimated through an efficient (recursive) computation which reduces mean squared error to the minimum value possible.

The Kalman filter provides optimal operation and is robust to noise produced by the track and thus it was chosen for this task. Moreover, the easy formulation and implementation of the Kalman filter renders it suitable for performing online real-time processing. In this research, we make use of the Kalman Bucy filter for state estimation which is a continuous time variant of the discrete Kalman filter.

For the linearized vehicle model for the kalman Filter shown in equation (7), the Kalman Bucy filter can then be given as follows

$$\hat{\dot{x}}(t) = A\hat{x}(t) + Bu(t) + K[z(t) - C\hat{x}(t)] \quad (8)$$

$$K = PC^TR^{-1} \quad (9)$$

$$\dot{P} = AP + PA^T - KRK^T + Q \quad (10)$$

The-1 superscript indicates matrix inversion and superscript T indicates matrix transposition in the above equation.

The estimated state vector is represented by $\hat{\dot{x}}$, in equation (8). The Kalman filter gain (K), is used to weight the measurement innovation $z(t) - C\hat{x}(t)$. We can calculate the Kalman filter gain K using equation (9), where estimation error covariance is given by P and it depends upon the selection of the measurement noise covariance R and the process noise covariance Q which calculated using equation (10), here k is calculated using lqe(linear Quadratic Estimator) command

[K P E]=lqe(A,B,C,Q,R)

The block diagram of the Kalman filter is shown in **(Fig.-4).** . The parameter values are shown below

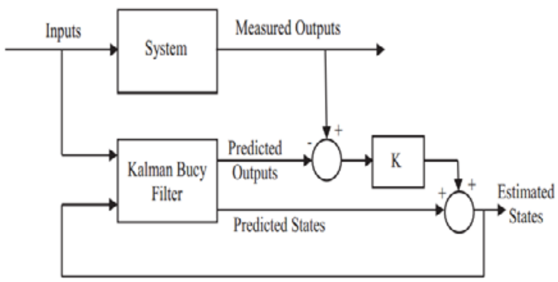

Fig.-4 : Block Diagram of kalman Filter

Here $A=\begin{bmatrix} -\frac{C_f+C_r}{mV_x} & \frac{-L_fC_f+L_rC_r}{mV_x}-V_x \\ \frac{-L_fC_f+L_rC_r}{I_zV_x} & -\frac{L_f{}^2C_f+L_r{}^2C_r}{I_zV_x} \end{bmatrix}$, $B=\begin{bmatrix} \frac{C_f}{m} \\ \frac{L_fC_f}{I_z} \end{bmatrix}$,

$C=\begin{bmatrix} 1 & 0 \\ 0 & 1 \end{bmatrix}$, $D=\begin{bmatrix} 0 \\ 0 \end{bmatrix}$

5. FUZZY INFERENCE SYSTEM

In this work, the purpose of designing of Fuzzy Inference System is to identify optimum slip ratio value from error (calculated from pre-processing unit) information, here Memdani model have been used for FIS. **(Fig.-5 and 6).** show the membership functions of Inputs and Outputs respectively. The error is given as input to the fuzzy controller and the output is calculated using the lom(largest of maximum) method

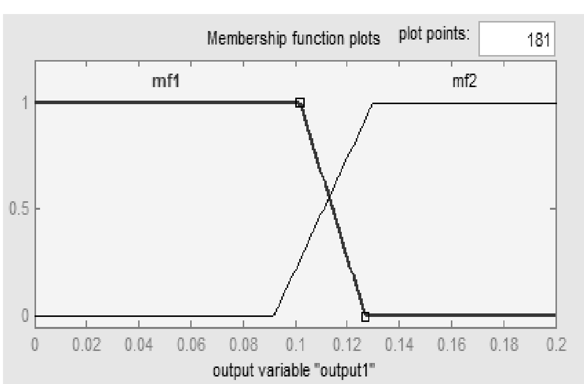

Fig. 5: Output membership function

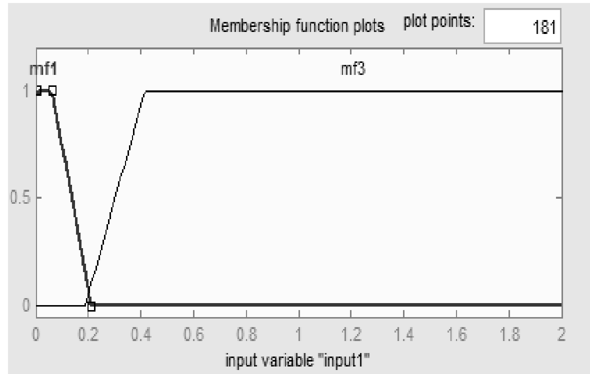

Fig. 6: input membership function

6. RESULTS

In this work an indirect method has been adopted for monitoring different road conditions, here only two taken wet and dry. Here Kalman filter tuned at high creep curve, we observed that the maximum error occurs for a low creep curve. We have determined two different road conditions using this data i.e. low and high adhesion surface which have a slip value of 0.1 and 0.2.

The data of the Kalman filter is processed by the fuzzy inference system, a wet road conditions is indicated when the estimated error has a high value. Consequently for a low value of error, the road condition is detected to be dry i.e. having high friction. We have demonstrated the potential of our research using simulations.

Estimation Error calculated from pre-processing unit for surface with high friction is shown in (**Fig. 7) (Fig: 8)** shows the slip ratio i.e. 0.2 which has been estimated using the Fuzzy Inference System Estimated error calculated from pre-processing unit for surface with low friction is shown in (**Fig: 9) (Fig.: 10)** shows the slip ratio i.e. 0. 1 which has been estimated using the fuzzy inference system

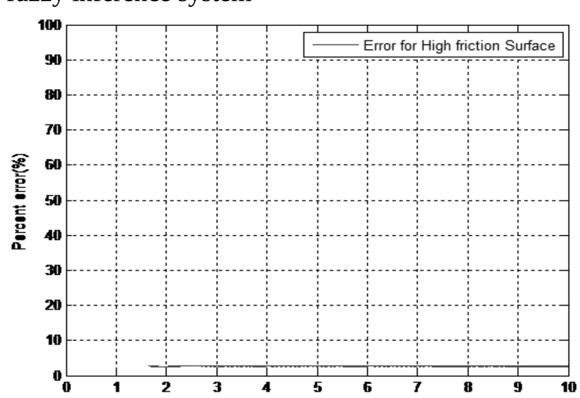

Fig. 7: Percent error for high friction surface

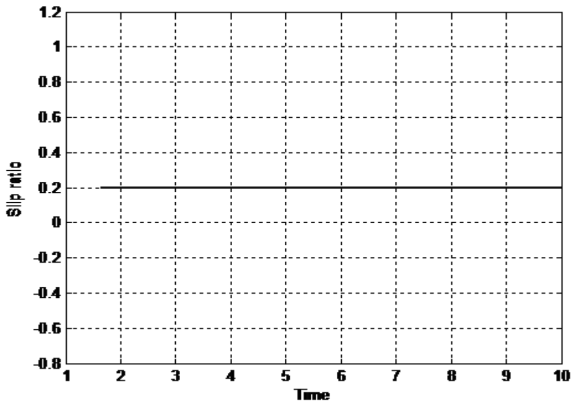

Fig. 8: Slip ratio for high friction surface

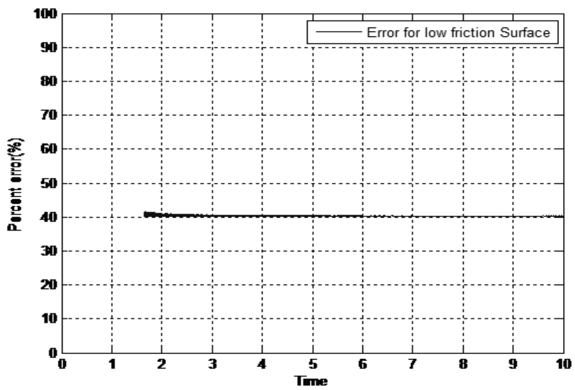

Fig. 9: Percent error for low friction surface

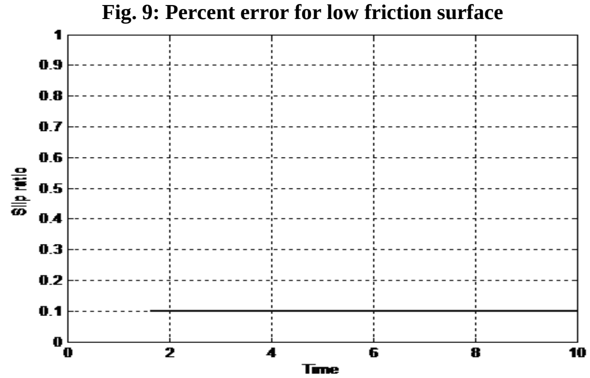

Fig. 10: Slip ratio for low friction surface

We found from the results of the simulation that the error estimation is only equal to 5% for dry road conditions. Using this error, the FIS determined the value of the slip ratio to be 0.2.

Likewise, the error increased to 40% for wet road conditions and thus a slip ratio of 0.1 was estimated by the FIS.

7. CONCLUSION AND FUTURE WORK

The currently used ABS are not effective under different is during different weather and environmental conditions (e.g. Rain, Snow).

In this work, we have therefore designed a system which can be used to monitor the parameters of the ABS for various road conditions. The potential of this idea has been demonstrated by means of simulations.

For further work, an adaptive method can be designed based on designed system which can automatically monitor road condition and provides optimum braking; also road condition may be increased.

This research work has the limitation of linearized Model, furthermore non linear Model may be considered for future work.

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