

Friction Coefficient Mapping during Brake Interventions

Adarsh Venkata Padmanabhan, Hariram Ravichandran,
Lokendra Pavan Kumar Pappala, and Shreyas Shenoy
Robert Bosch

ABSTRACT

This paper comprises obtaining friction coefficient (μ) measure by extracting surface and texture information using sensors during brake interventions. A primary estimate of friction coefficient has been obtained using wheel and vehicle signals. The estimates have been compared and combined to obtain a more accurate measure of friction coefficient. Finally, a suitable interpolation technique is used to obtain a μ -grid around the vehicle. The grid is graphically realized with the aid of visualization techniques using vehicle traces. This type of surface characterization usually enables brake distance optimization and effective countermeasures pertaining to a standard ESP system.

KEYWORDS: Friction Coefficient Estimation, Active Safety, Wheel Dynamics

CITATION: Venkata Padmanabhan, A., Ravichandran, H., Pappala, L., and Shenoy, S., "Friction Coefficient Mapping during Brake Interventions," *SAE Int. J. Passeng. Cars – Electron. Electr. Syst.* 8(1):2015, doi:10.4271/2014-01-2496.

INTRODUCTION

A vehicle is in contact with the surface of the road through its tires. In order for the vehicle to be put into motion, the tires must have a good grip onto the road surface. This is provided by the tire/road friction. If the friction is too less, the tires slip on the road surface and hence the vehicle does not move or moves with a very less acceleration with limited steerability. Hence an optimum friction is required for the tires to roll on the road. The friction of the surface determines the slip of the tire which changes the vehicle behavior with its velocity. Since the friction directly affects the vehicle movement, combined active and passive safety functions can use or would benefit from the estimation of friction coefficient. This is of the utmost importance for maintaining stability and steerability of the vehicle in the movement. Some of the active safety systems that directly deal with frictional coefficient are ABS (Anti Lock Braking System), TCS (Traction Control System), VDC (Vehicle Dynamics Control) and in general ESP (Electronic Stability Program).

This paper focuses on the visualization of the road surface characteristics by the estimation of friction coefficient. It is accomplished with the help of ECU signals such as braking pressure, acceleration of the tire, acceleration of the vehicle, slip of the tire, velocity of the tire and velocity of the vehicle. The experimental setup and the analysis methodologies are discussed in the following sections.

LITERATURE SURVEY

Stephen Muller, Michael Uchanski and Karl Hedrick have developed slip-based maximum road friction estimator that makes use of data from short braking maneuvers to classify the road surface as either dry or lubricated. [1]

K Li, J A Misener and K Hendrick have developed an onboard road condition monitoring system which evaluates the slipperiness and coarseness of the road surface and classifies it into one of the four grades: normal, slippery, very slippery and rough surface. The classification algorithm makes use of the characteristic of the relationship between friction coefficient and slip (slip curves). A separate classifier based on the variance of filtered wheel signals is used for coarseness detection. [2]

Changsun Ahn, Huei Peng and H.Eric Tseng have proposed two methods for μ estimation. The first method makes use of direct calculation based on front tire self aligning torque. The second method is based on a nonlinear least square method. [3]

Shruti Gupta, Joe Funke and Thomas Lipp have developed a machine based friction estimation method that can yield a real time estimate of one of several friction values based on vehicle longitudinal and lateral dynamics. [4]

Samadi, Behzad, et al (2001), have proposed an approach to estimate the tire road friction forces using an extended Kalman filter on parameters obtained during ABS modulation.

proposed method utilizes vehicle mounted sensors and does not require prior knowledge of the tires' mathematical model. [5]

Ray and Laura R have applied extended Kalman-Bucy filtering (EKBF) and Bayesian hypothesis selection to estimate motion, tire forces, and road coefficient of friction (μ) of vehicles on asphalt surfaces. Simulation results have shown excellent convergence and accuracy of μ estimates, and results of processing field test data demonstrated the ability to construct useful tire models. [6]

Alfred Pohl et al have estimated the friction coefficient by evaluating the mechanical strain in the tire surface contacting the road-utilizing the deformation of the tread elements. [7]

Fredrik Gustafsson has presented an approach to estimate the tire-road friction during normal drive using only the wheel slip. [8]

Chankyu Lee et al have employed a tractive force estimator, a brake gain estimator, and a normal force observer for the estimation of the friction coefficient. The proposed estimation method for the maximum tire-road friction coefficient was implemented using a fifth wheel and typical vehicle sensors such as engine speed, carrier speed, throttle position, and brake pressure sensors. [9]

Frédéric Holzmann et al have proposed a predictive methodology for the estimation of friction coefficient by using a camera and a microphone. The algorithm extracts the patterns corresponding of the different μ depending on the general luminance. These patterns will be matched on the current specimens to deduce the friction coefficient along the road ahead and a confidence value. [10]

Rajamani Rajesh et al have proposed three different algorithms based on the types of sensors available - one that utilizes engine torque, brake torque and GPS measurements, one that utilizes torque measurements and an accelerometer and one that utilizes GPS measurements and an accelerometer. Experimental results demonstrated that friction coefficients at the individual wheels and road gradient can both be estimated reliably. [11]

Main Section

Background

The following sections describe how the signals obtained from the ECU are used to estimate the friction of the road surface.

It is important to understand how the signals were obtained in the ECU before using them in the analysis. The wheel speeds

were obtained from the Wheel speed sensors (WSS) present at the four tires. The vehicle velocity was obtained from analyzing the WSS signals using a speed estimation algorithm. The slips at the four wheels were estimated using the wheel and vehicle velocities obtained. The acceleration of the vehicle was obtained from the longitudinal acceleration sensor. The pressure signal was obtained from Model Wheel pressure from the hydraulics module, wheel accelerations were obtained from sensor signal processing using wheel speed sensors.

Methodology

The methodology explains the estimation of friction coefficient of the road surface. It is as depicted in the following figure,

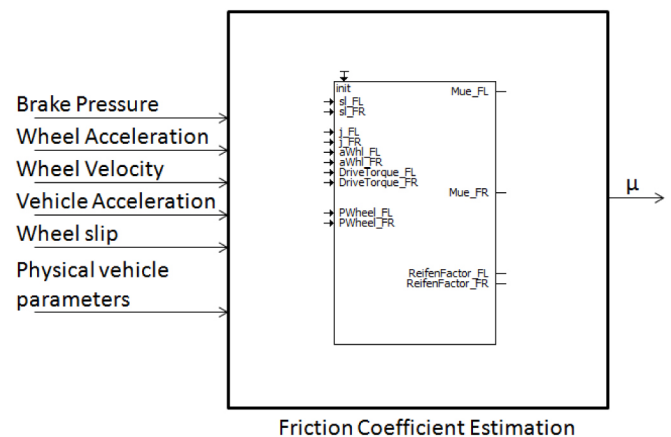


Figure 1. Block Diagram outlining the μ visualization

First, the estimation of friction coefficient is done with the help of ECU signals. These ECU signals include, as depicted in the figure, Brake Pressure (P_{wheel}), Wheel acceleration (a_{wheel}), Wheel velocity (V_{wheel}), Vehicle acceleration ($a_{vehicle}$), Vehicle velocity ($V_{vehicle}$) and Wheel slip (λ_{wheel}). Apart from the various physical vehicle parameters such as Weight of the vehicle, Radius of the wheel and Weight of wheel are also used.

The brake pressure is important for estimating the tire component of the road friction. The velocity signals help in estimating the rate of change of slip of the wheels with respect to the road. The acceleration signals along with the slip of the tires with respect to the road aid in estimating both the tire and road components of the friction coefficient. These are discussed in detail in the following sections.

Mathematical Modeling for Friction Coefficient Estimation

Let us consider the following figure which shows a various forces which act on a tire during its interaction with the road surface. It is a single corner model of tire/road interaction.