Tire/Road Friction Estimation for Front Wheel Driven Vehicle

Simon Johansson and Viking Persson, *Department of Automatic Control, Lund University*

Imagine yourself driving along on a nice road. It's fast and you feel confident that there's plenty of grip, the road is dry, now isn't it? Suddenly the road condition changes, wet leaves or black ice, but you don't notice. Wouldn't it be nice if your car noticed this for you? With the latest driving enhancing technology, it can!

What is friction and why do we need to estimate it?

Friction is the force that prevents one surface to slide against another surface. It's denoted by a number, the coefficient of friction. A higher number means that the preventive force is higher. The two surfaces in a car on road scenario are the contact patch of the tire and the road itself. Naturally, a high friction coefficient is preferred, lots of force preventing the car to slide of the road is positive. High friction is also preferable when accelerating or braking, the preventive force in the longitudinal direction of the car is the same as traction.

In general snow and ice results in low friction, wet asphalt or gravel medium friction and a dry asphalt road is considered to have high friction. The coefficient of friction is expressed as the traction/side force normalized to the normal force:

$$\mu_0 = \frac{F_{x/y}}{F_N} \tag{1}$$

Normal force is the downward force generated by the weight of the vehicle. A vehicle is considered to have a coefficient of friction equal to 1 against a dry asphalt road. Looking at Equation 1 this means that $F_{x/y} = F_N$. In other words, all the normal force can be utilized to either accelerate/brake or move the vehicle sideways. Lower friction thus means that less of the normal force can be used to control the vehicle. This lost controllability is the main reason for a vehicle being harder to maneuver when driving on ice or snow.

A sudden change in friction will greatly alter the way a vehicle can be driven. If a system can warn the driver when for example black ice occurs it would be of great help. Instead of driving along as if the friction to the road is still high, the driver can adapt the speed and driving behavior and hopefully an accident can be avoided. But there's more than that to it. Modern cars of today are equipped with several driving and safety enhancing systems. The Anti-lock Braking System (ABS) and the Electronic Stability Program (ESP) are both based on complex control systems that uses several signals from the car. These systems could both benefit from knowing the friction in order to improve their functionality.

More performance oriented systems such as launch control and limited slip differentials can also benefit from friction estimation. Today the driver can help some by telling the vehicle what kind of surface (asphalt, gravel, ice etc.) it's driven on or specify a certain drive mode (normal, sport, track etc.). Major safety precautions still have to be applied though, it's of course not acceptable that the driver crashes the car just because the wrong setting was entered. If instead a built in system could estimate the friction in a robust way with high certainty, the systems could adjust themselves for optimal performance. For example a limited slip differential could be more aggressively controlled when it's certain that good grip towards the road is available. A good example of such a differential is the FXD from BorgWarner TorqTransfer Systems AB.

The FXD

A differential is a mechanical device that distributes torque between the driven wheels in a vehicle. It also enables the driven wheels to have different speeds which is a must when cornering. Most vehicles today have some kind of differential and most of them use a so called open differential. This is the simplest of all differentials. It enables different speed on the driven wheels and it always distributes the torque equally between the wheels. FXD is an abbreviation for Front Cross Differential and is an electronic limited slip differential. This means that with a simple electronic signal the torque distribution between the driven front wheels can be changed. This is a great advantage over the classic open differential. A great example of this is when cornering. In a corner the weight distribution of the vehicle will change, the outer wheel will be pressed against the ground and the inner wheel will lift. This means that the normal force will change and as seen earlier this will result in a difference of available traction between the driven wheels. Since the open differential always distributes the torque equally, the inner wheel with less normal force will prevent maximum torque output on the outer wheel. By changing the torque distribution with the FXD the total torque output will be higher with a FXD than with an open differential. This is shown in Figure 1.

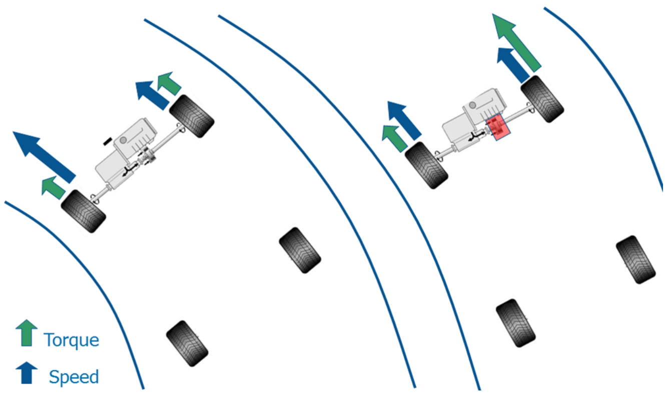

Figure 1: *Torque distribution while cornering with an open differential and with a FXD.*

Estimating the friction

The general idea for estimating the friction is to use two different models for the force acting on a tire. One should depend on the friction and the other one should be a reference model that doesn't depend on the friction coefficient and hence always can be trusted. By fitting the first model to the reference model, using a Recursive Least Squares (RLS) algorithm and the friction coefficient as fitting parameter, the friction can be estimated.

The friction estimation as whole works in the following way. The reference model, by nature, is always returning the actual force acting on a tire. The other model that depends on the friction coefficient follows the reference model by adjusting the friction coefficient. If the car is running on asphalt the model depending on the friction coefficient will equal the reference model when the value of the friction coefficient is around 1. Hence, the estimated value for the friction coefficient is 1, which is right when running on asphalt. If the road condition suddenly changes, appearance of ice for example, the reference model will instantly return a much lower force. The friction coefficient model will be adjusted by lowering the friction coefficient until the forces are equal again. This new lowered friction coefficient is the friction coefficient between the tire and the road. It works the other way around when the car hits dry asphalt again. The reference model will return a much bigger force and the new fiction coefficient will be acquired by adjusting it until the model equals the reference model.

The reference model is based on the forces from the drive shafts. This is great because it's a really easy way to do it but it's still very precis and it's not dependent on the road gradient. Although, here also lies the biggest restriction. Using a method as simple as this won't work good when turning because that will generate forces that's not coming from the drive shafts. This is solved by simply only estimating the friction coefficient when not turning. Hence, only longitudinal forces can be modeled, the lateral forces are neglected. The forces on the drive shafts is acquired from the engine torque and by calculating the force transformation through the gear box.

A model that's dependent on the friction coefficient needs to be a model based on the tire dynamics. Several tire models exist today, some are really simple and some are extremely advanced. A rather simple tire model is used since it doesn't need to account for lateral forces, as mentioned above.

The approach as whole is a very simple one. It won't return perfect results at all times since the lateral forces are neglected but when it do return a friction value it's very close to the real value. The biggest improvement to other approaches is that it only uses parameters that's available in a normal car. It won't help to have a solution that gives perfect values at all time if it doesn't work in the real world.