Exploring Smart Sensor Systems

An exploration of:

Slip Angle Sensors

Nathan Quadras & Kosta Sergakis

Electrical and Computer Engineering
Michigan State University
East Lansing, Michigan
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Introduction

Vehicles are more attainable than ever and are advancing quickly. Modern cars are equipped with sophisticated systems that enhance performance, safety, and driver comfort. Vehicle dynamics is a tremendous topic and an area of growing interest, especially as more automated driving technologies emerge. Vehicle dynamics is the study of vehicle motion in relevant user operations [1], which encompasses factors like kinematics, forces, and moments acting on a vehicle during acceleration, braking and steering. The core of vehicle dynamics involves the following primary aspects: the mechanisms that disturb a vehicle's state (inputs) and the mechanisms through which the vehicle responds (outputs). Arguably the most critical aspect of vehicle dynamics is tire behavior, specifically how a tire generates lateral force during cornering. Central to this behavior is the concept of slip angle – the difference between the direction a vehicle is traveling and the direction that the body of the vehicle is pointing (heading vs. true heading) [2]. Understanding slip angle is essential for analyzing handling characteristics, improving stability control systems, and optimizing driver feedback.

Vehicle Dynamics

Performance driving, autonomous driving and regular commuter driving all require the same characteristic: control. Controllable vehicles are what makes rapid maneuvers possible. On the other hand, the required motion must be stable to maintain directional stability under disturbances [3].

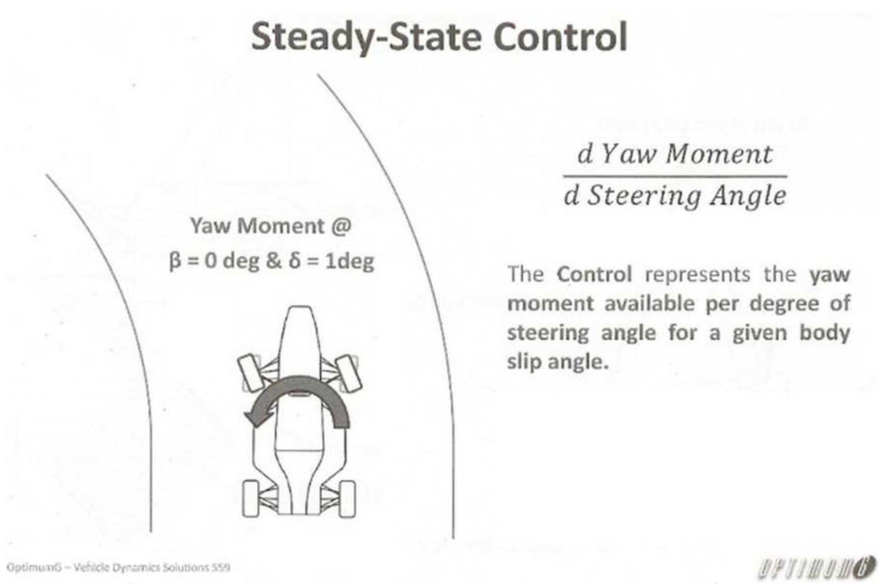

Figure 1: Definition of Control [3]

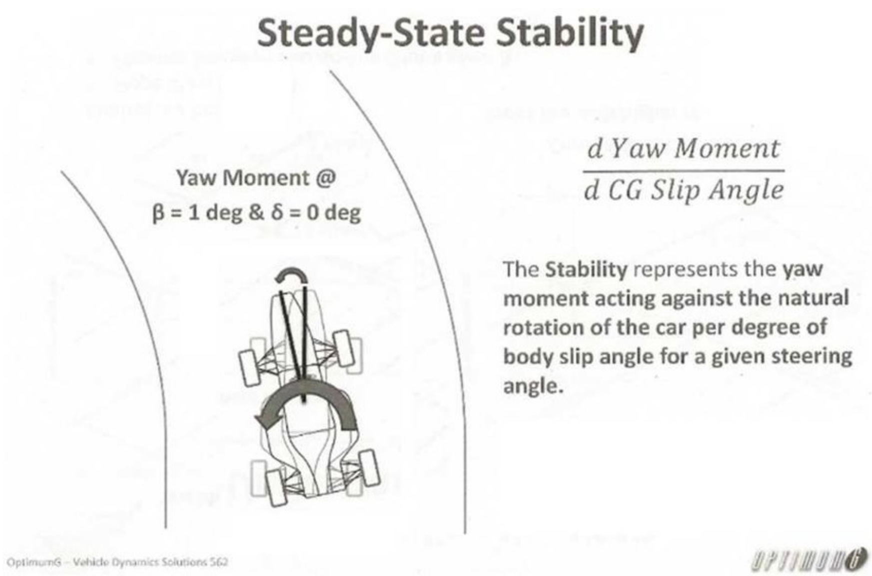

Figure 2: Definition of Stability [3]

It is crucial to define the tractive limit of the vehicle, or the "safety margin" to determine the range of possible motions that the vehicle can produce while maintaining stability [3]. Slip angle is incredibly important because it enables the concepts mentioned above. In other words, slip angle determines vehicle maneuverability. If slip angle is observed, various states of the vehicle can be determined.

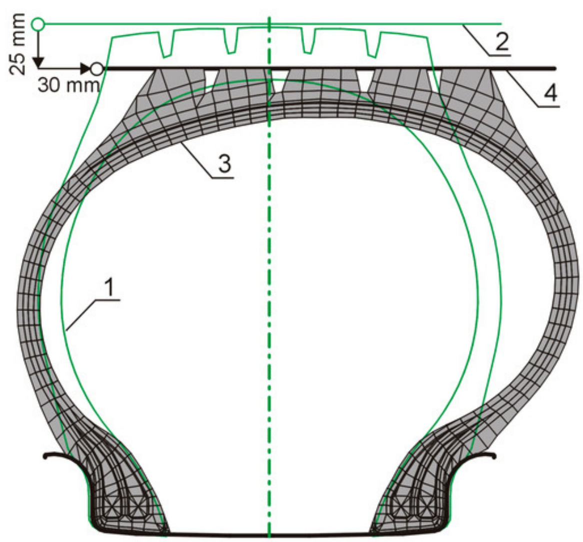

Figure 3: Tire Deformation [4]

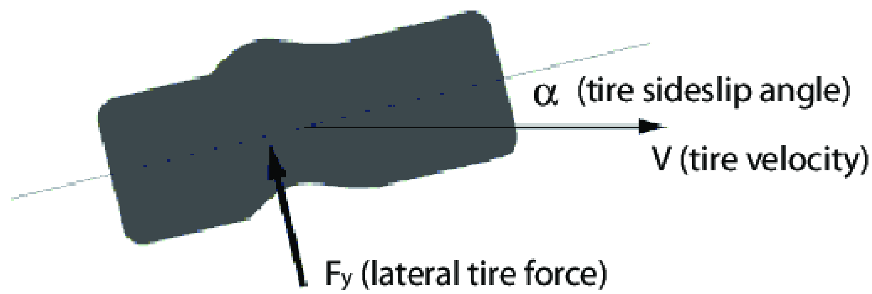

Figure 4: Tire Deformation [5]

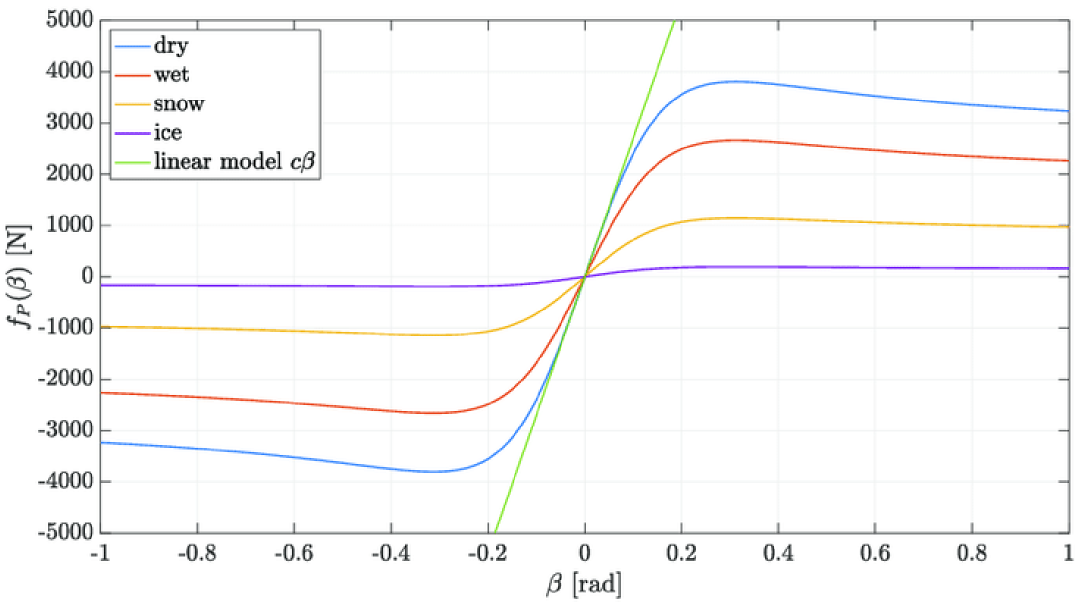

Figure 5: Example Pacejka Tire Model [6]

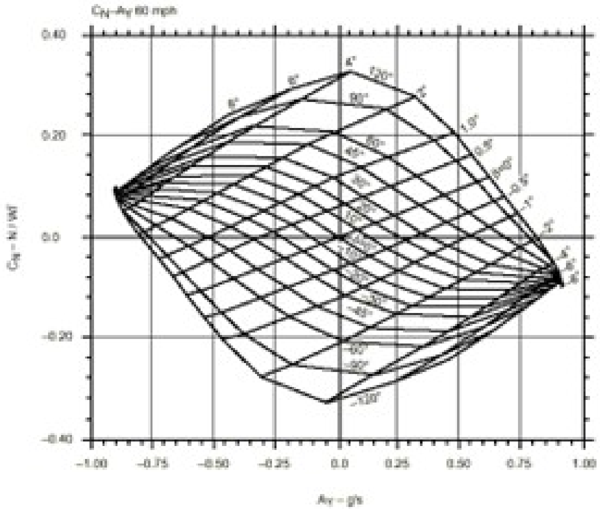

Figure 6: MMM [7]

A common way to observe/determine the limits of a vehicle is through a Yaw Moment Diagram, or the MRA Moment Method (MMM) [Figure 6] [7]. A critical component of the Yaw Moment Diagram would be the quantification of the forces necessary to hold a vehicle through a turn. As shown in figure 4, a primitive to determining the lateral force of a tire is the slip angle. Pacejka's formula can display the relationship between slip angle and lateral tire force as shown in figure 5. Ultimately, the goal is to determine the limits of the vehicle to prevent drivers from reaching the point of no return; a loss of stability, leading to control being removed from the driver.

Overview & Motivation

This smart system focuses on real-time slip angle estimation and control for ground vehicles. Accurate knowledge of slip angle enables Advanced Drive-Assistance Systems (ADAS), traction control, and autonomous driving algorithms to make more informed decisions when navigating corners, avoiding obstacles, or maintaining control on low-friction surfaces.

The motivation for this system stems from the growing demand for safer and more responsive vehicles in both human-driven and autonomous applications. While modern vehicles are equipped with various sensors, slip angle is notoriously expensive to measure directly due to the niche, specialized equipment involved. By designing a smart system capable of observing slip angle in real-time using accessible components, this solution offers a cost-effective and scalable method to improve vehicle safety, performance, and driver confidence across a wide range of driving conditions.

System Level Design

Microcontroller (Teensy 4.0)

Optical Sensor (PAW3515DB)

Inertial Measurement Unit (BNO055)

RGB LED

Software Design

Works Cited

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