

Fuzzy Logic Approach to Vehicle Stability Control of Oversteer

2011-01-0268

Published
04/12/2011Jeffery R. Anderson and E. Harry Law
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doi:10.4271/2011-01-0268

ABSTRACT

Traditional Electronic Stability Control (ESC) for automobiles is usually accomplished through the use of estimated vehicle dynamics from simplified models that rely on parameters such as cornering stiffness that can change with the vehicle state and time. This paper proposes a different method for electronic stability control of oversteer by predicting the degree of instability in a vehicle. The algorithm is solely based on measurable response characteristics including lateral acceleration, yaw rate, speed, and driver steering input. These signals are appropriately conditioned and evaluated with fuzzy logic to determine the degree of instability present. When the “degree of instability” passes a certain threshold, the appropriate control action is applied to the vehicle in the form of differential yaw braking. Using only the measured response of the vehicle alleviates the problem of degraded performance when vehicle parameters change.

INTRODUCTION

Electronic Stability Control is a very heavily researched topic with widely understood benefits to the safety of transportation. It will be federally mandated that in the model year 2012, all light vehicles will be required to have ESC [1]. Traditionally, stability control is accomplished through the use of estimators and observers to estimate vehicle dynamics based on driver inputs to the vehicle. The traditional two degree-of-freedom bicycle model is typically used and relies on parameters that are prone to change such as the tire cornering stiffness, vehicle yaw inertia, mass, etc.

This research proposes a method of inferring stability based on measurable vehicle dynamics (i.e., steering wheel angle, speed, lateral acceleration, and yaw rate). By using

measurable parameters as suggested by Fey and Vaduri, the amount of oversteer present at any point in time can be estimated [2,3]. From the estimate of the level of oversteer, differential braking can be commanded to prevent a vehicle from “spinning-out.” This approach to stability control removes the necessity of an observer and its inherent problems as described above. Also, the ESC algorithm is simplified to signal conditioning and fuzzy logic.

This ESC algorithm has been shown to be robust in the sense that one ESC algorithm (without tuning) was able to maintain stability over ten case studies which encompassed several different vehicles, maneuvers, conditions, and drivers. Four very different vehicles ranging from a sports car to a sport utility vehicle (SUV) in multiple configurations including degraded rear tires and different loading conditions are used in evaluating the proposed ESC using CarSim®. These vehicles and configurations are subjected to multiple maneuvers including a double lane change and a fishhook maneuver with tire-to-road conditions such as split μ and low μ to simulate slippery road conditions. The main result of this research is a new ESC concept where performance is not based on a vehicle model with set parameters that lose effectiveness in estimating the vehicle dynamic states when the vehicle and road conditions change. Instead, the algorithm relies only on the current measured dynamic response of the vehicle to preserve stability.

Fuzzy logic is not new to stability control and has been used very successfully. The majority of the work done with linking fuzzy logic and ESC has been to use fuzzy logic in addition to the traditional ESC in order to better control the vehicle in a severe situation. For example, Tahami, et. al, uses a very traditional ESC algorithm with a simplified vehicle model to compute a desired yaw rate and then compares that to the measured yaw rate yielding an error in yaw rate. Once the

error in yaw rate passes a threshold, control action is then calculated. The fuzzy logic calculates the control action based on the magnitude of the yaw rate error and rate of change in this error [4]. Boada, et. al, also uses a similar approach in integrating fuzzy logic with stability control. They still use a simplified vehicle model to provide a reference signal that the fuzzy logic would use to modify the control action [5]. The goal of this paper is the integration of fuzzy logic and stability control so that the necessity of a simplified vehicle model is removed and in turn, the complications that are associated with using a simplified vehicle model.

VEHICLE AND DRIVER MODELS

In this research a front wheel drive (FWD) subcompact vehicle programmed in CarSim® was the main vehicle model utilized. This model has been proven accurate and was validated with objective test data. In addition, several internal CarSim® vehicle models were used including an SUV, sedan, and sports car to demonstrate the robustness of the ESC algorithm. CarSim® and Simulink® were run in conjunction with a fixed time-step to solve the overall system. CarSim® solved for the vehicle dynamics and the internal driver model while Simulink® was utilized for the ESC algorithm as well as an alternate driver model which will be discussed later.

The driver model used for the majority of this research is the internal CarSim® driver model that uses optimal control theory to calculate steering wheel angle. The controller uses eight feedback variables: the x and y coordinates of the front axle, the x and y components of vehicle velocity, yaw rate, yaw angle, and front and rear steer control variables (for factors such as suspension kinematics) [6].

In addition to the CarSim® driver model, the driver model proposed by Genta was used for Case 6. This model is a simple path-following model which includes a driver lag time, preview distance, and driver gain. The driver looks ahead at some preview distance and the error between where the vehicle will be and the target path is calculated. A gain is then applied to this error as well as a driver lag to account for human lag and the time to enter the steering input [7].

OVERSTEER INDICATORS

In this section, the driver input and the response characteristics (i.e., lateral acceleration, yaw rate, etc.) and their relationships that are used to determine vehicle instability will be discussed.

STEERING WHEEL ANGLE

First, steering will be initially low-pass filtered at 3.5 Hz (the approximate bandwidth of an average driver). This removes high frequency content from other sources such as vehicle interference (i.e, noise and vibrations). The data is then low-

pass filtered again at 0.5 Hz. This low frequency content represents the activity of a “balanced” driver. It preserves the general steering inputs and trends of the driver and removes corrections to the general trends. In other words, “balanced” refers to general trends of the vehicle and driver and falls in the very low frequency domain below 0.5 Hz. In the range between 0.5 to 3.5 Hz, the driver's corrections to the general trends remains. Therefore, the difference in the two filtered signals represents the driver's reaction to the imbalances in the vehicle [3]. Large and small differences in the two filtered signals correspond respectively to large and small imbalances (or tendencies to oversteer). It should be noted since this is a real-time algorithm, a first order Butterworth filter is used to prevent as much lag as possible in the data conditioning step.

LATERAL ACCELERATION

Lateral acceleration is also used to detect an oversteer situation. According to Fey, and oversteering vehicle will produce dips in the lateral acceleration time history as the chassis loses and regains grip. He also states, confirmation (of an oversteer event) lies in the steering signal [2]. Therefore, when there is a dip in lateral acceleration corresponding with a large steering imbalance (described above), there is likely an oversteer event.

In order to cue on these dips in the lateral acceleration, the signal is filtered in the same way as the steering wheel angle. The 0.5 Hz low-passed signal represents a balanced vehicle (preserves general trends in the data) and the 3.5 Hz low-passed signal shows much more of the vehicle's response while filtering inherent noise and unwanted data from other sources. The difference in these two traces represents the vehicle's imbalance.

YAW RATE

The final signal that is used in this ESC algorithm is yaw rate. This signal is a physical check for the rest of the system and is in place if the driver does not enter the correct steering input (i.e., freezes and does not respond to an emergency situation). If yaw rate is too large, the vehicle is considered to be spinning-out. Yaw rate, steering difference, and lateral acceleration difference are the three signals examined in the fuzzy logic to determine a level of oversteer present in the vehicle at each instant.

EXAMPLE

An example of the indicators of oversteer is plotted along with the oversteer number calculated by the oversteer-indicating fuzzy logic in Figure 1. This figure illustrates a stable lane change at 100 kph without ESC, an unstable lane change at an increased speed of 105 kph without ESC, and a stable lane change at 105 kph with ESC. This example is for a front wheel drive (FWD) subcompact traversing a double lane change (DLC) with degraded rear tires. Plotted are the

three signals that the oversteer-indicating fuzzy logic used: (1) the difference in the 3.5 Hz and 0.5 Hz steering wheel angle signals (ΔSWA), (2) the difference in the 3.5 Hz and 0.5 Hz lateral acceleration signals (ΔAy), and (3) the absolute yaw rate (AVz). Note how the oversteer number OS (discussed later) is reduced for the 100 kph and 105 kph (ESC on) cases.

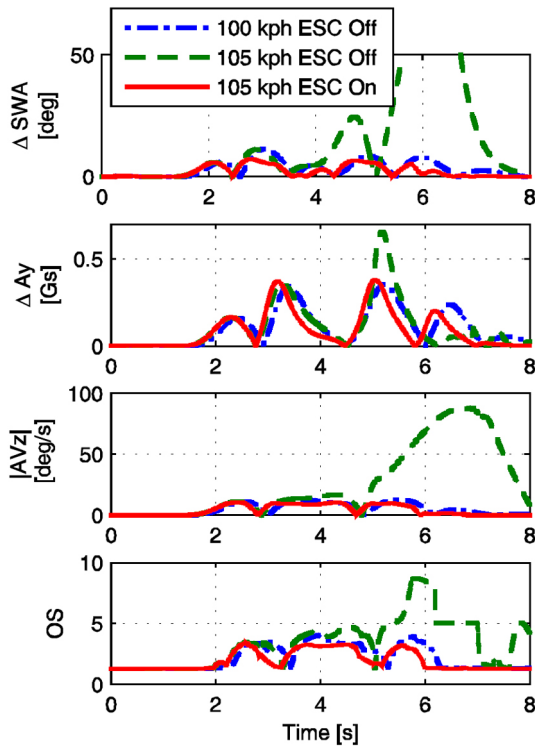


Figure 1. Oversteer Indicators ΔSWA (Difference in Steering Wheel Angle), ΔAy (Difference in Lateral Acceleration), AVz (Yaw Rate), and OS (Oversteer Number).

FUZZY LOGIC ESC ALGORITHM

This research utilized a high fidelity vehicle model in CarSim[®] that ran in parallel with the Simulink[®] implementation of the stability control algorithm. These programs both run at a fixed time step. At each time step, CarSim[®] solves for the vehicle dynamic states and passes variables of interest to Simulink[®]. The Simulink[®] program outputs control inputs (corrective brake torque) back into CarSim[®] where the process continues with time. An overview of the ESC system can be seen in the [Appendix A](#).

OVERSTEER INDICATING FUZZY LOGIC

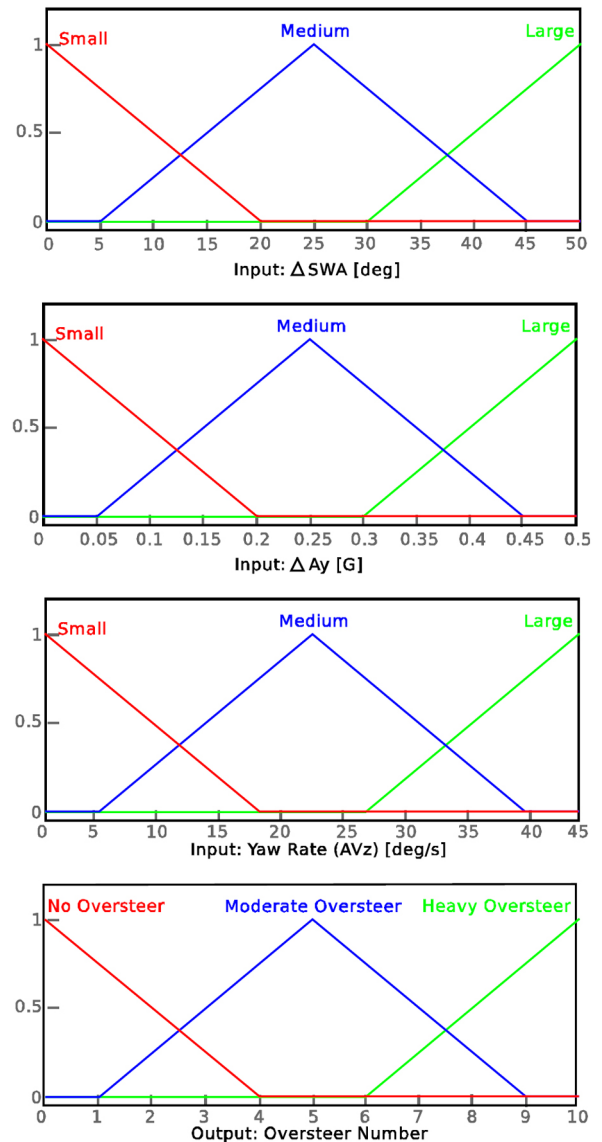


Figure 2. Oversteer-Indicating Fuzzy Logic Membership Functions.

Now that the signal traces have been appropriately conditioned, the fuzzy logic strategy implemented in Simulink[®] can evaluate the level of oversteer at each time step. For this algorithm, large, medium, and small triangular membership functions are defined for each input parameter (difference in lateral acceleration, difference in steering wheel angle, and absolute yaw rate). Three triangular membership functions are also defined for the output (oversteer number) and are defined as no oversteer, moderate oversteer, and heavy oversteer. The four membership functions for the three inputs and one output can be seen in [Figure 2](#). These membership functions define what are considered to be large, medium, and small input values as