

Location-Aware Adaptive Vehicle Dynamics System: Brake Modulation

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ABSTRACT

A Location-Aware Adaptive Vehicle Dynamics System (LAAVDS) is developed to assist the driver in maintaining vehicle handling capabilities through various driving maneuvers. An integral part of this System is an Intervention Strategy that uses a novel measure of handling capability, the Performance Margin, to assess the need to intervene. Through this strategy, the driver's commands are modulated to affect desired changes to the Performance Margin in a manner that is minimally intrusive to the driver's control authority. Real-time implementation requires the development of computationally efficient predictive vehicle models. This work develops one means to alter the future vehicle states: modulating the driver's brake commands. This control strategy must be considered in relationship to changes in the throttle commands. Three key elements of this strategy are developed in this work. An algorithm is developed to determine when to switch from a throttle-only control strategy to a braking strategy. A linearized brake model is developed to estimate the required brake modulation to affect the desired changes in longitudinal force. These predicted changes to the brake commands are used in the correction stage of the algorithm in which a full non-linear vehicle model simulates the longitudinal force response. The predictor-corrector control loop is closed by comparing the desired longitudinal force to the resulting force. The effect of brake modulation is exhibited in simulation results through a case study. Results show that the proposed approach yields a significant overall performance improvement. Future work will include an integration of brake and throttle modulation models.

CITATION: Cho, S., Bandy, R., Ferris, J., Schlinkheider, J. et al., "Location-Aware Adaptive Vehicle Dynamics System: Brake Modulation," *SAE Int. J. Passeng. Cars - Mech. Syst.* 7(2):2014, doi:10.4271/2014-01-0079.

INTRODUCTION

Autonomous vehicles have been an active area of research for over 30 years; steady progress has resulted in many impressive contributions [1] [2] [3]. As noted by Matthews, one seminal question that faces the vehicle's driver (either human or computer) is predicting the capability of the vehicle as it encounters upcoming terrain [4]. A model of the vehicle and the excitation of this model must both be considered when predicting the resulting vehicle performance. In this way, the driver can make informed decisions about the manner in which the vehicle should be driven.

Of course, when a human drives the vehicle, the computer is still of great assistance. Anti-Locking Braking Systems (ABS) and Electronic Stability Control (ESC) systems help maintain stability during braking and agile cornering. However, most of the current Driver Assistance Systems are reactive and only act to control the vehicle based on the current vehicle state with minimal information about the local driving environment. Presently, more Advanced Driver Assistance Systems (ADAS),

such as Collision Avoidance Systems and Lane-Keeping Systems are being developed that are predictive, rather than reactive.

The focus of Location-Aware Adaptive Vehicle Dynamics (LAAVD) research is to develop a system to assist the driver in maintaining vehicle handling capabilities through various driving maneuvers. The proposed method is predictive, estimating the ability of the vehicle to successfully navigate upcoming terrain, and it is assumed that the future vehicle states and local driving environment are known. An Intervention Strategy must be developed such that the vehicle is navigated successfully through a corner via modest changes to the driver's commands, and in a manner that is in harmony with the driver's intentions and not in a distracting or irritating manner. In addition, this Intervention Strategy should use a novel measure of handling capability, the Performance Margin, to assess the need to intervene [4]. Clearly this research relies on the numerous new technologies being developed to capture

and convey information about the local driving environment (e.g., bank angle, elevation changes, curvature, and friction coefficient) to the vehicle and driver.

One critical component of this Intervention Strategy is the development of a predictive brake modulation model that is realizable in real time. This prediction is then used in a predictor-corrector algorithm within the Intervention Strategy. The linear model is used to make fast predictions in real time and the full non-linear model is used to make corrections to these predictions. Although the full nonlinear model is not required to run in real time, it still must run quickly enough to make corrections to the linear predictive model several times a second.

The objective of this work is to develop a prediction model that estimates the required brake modulation to deliver the desired longitudinal force. This work proceeds as follows. First, the switching model between the throttle-only control strategy and the use of the brake is developed. This model is used to determine whether the system can reach the desired change in longitudinal force by decreasing the throttle input without braking. Next, a simplified brake model is developed to estimate the required brake modulation to achieve the desired change in longitudinal force. Last, the prediction model, to estimate the required brake modulation and the resulting change in longitudinal force, is developed. The integration of these contributions is demonstrated through a case study wherein a desired change in longitudinal force is prescribed and the brake modulation required to achieve this change in force is predicted. The accuracy and limitations of the method are discussed followed by concluding remarks.

BACKGROUND

The feasibility of the proposed method is dependent on the ability to predict vehicle states and availability of information about the local driving environment. While there are no such systems included on any present commercial vehicle design, there is a great amount of research currently being done in both fields. An overview of the practicality of implementing a Global Positioning System (GPS)-based control system into ground vehicles is discussed by Beiker et al. [3]. Furthermore, Ahn proposes both longitudinal and lateral dynamics based algorithms to estimate friction using measurements from sensors that are available on typical commercial vehicles [5]. Lee develops a method to estimate the maximum tire-road friction coefficient by designing a tractive force estimator, a brake gain estimator, and a normal force observer [6]. Based on these successful studies, it is assumed in this work that information about the local driving environment is available.

As previously stated, the intent of the LAAVD research is to avoid the situation in which the ESC system would become active. One method of achieving this is to modulate the longitudinal force at the tire contact patch by controlling the

throttle input to the engine [7]. Cho, et al. demonstrates, however, that the engine has limited performance in the quasi-static range. In addition, a limit of how much negative change in longitudinal force can be derived from throttle manipulation alone exists due to physical limitations of the engine. To compensate, a method to modulate longitudinal force by brake control is developed here. Since brake intervention can be unfavorable for driver comfort, throttle intervention will always be given higher control authority and the system will be developed to rely only minimally on brake modulation.

The linear prediction-nonlinear correction process outlined by Bandy, et al. is fundamental to this work [8]. The system flowchart is reproduced here as Figure 1. A linear chassis model first determines the relationship between a desired change in performance margin and the necessary change in longitudinal force, followed by the linear powertrain model discussed by Cho [7]. This work adds the possibility of brake manipulation to this powertrain model, resulting in the throttle and brake commands represented in the Linear Predictions box in Figure 1.

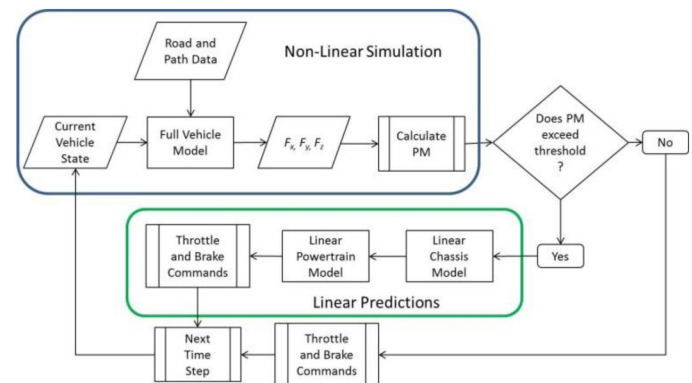


Figure 1. Overview of Intervention Strategy Implementation

The success of the Intervention Strategy relies on an accurate and computationally efficient inverse brake model which can estimate the required brake modulation necessary to deliver a desired change in longitudinal force at the tire contact patch. A significant amount of recent brake control research has focused on achieving such performance goals. Yi and Chung offer an approach for nonlinear brake control by developing a nonlinear computer model and a linear model of the hydraulic brake actuator system [9]. Liang, et al. concentrate on a vehicle's longitudinal brake control by developing a modified sliding control with variable control parameter [10]. Trachtler proposes the steering and suspension system as well as brake intervention scheme for optimized and integrated vehicle control [11]. Ioannou and Xu suggest vehicle speed control by controlling the throttle and brake input with sliding mode control [12]. Gerdes and Hedrick suggest an adaptive controller to handle the throttle and brake input [13]. Presently, a linear prediction and non-linear correction approach is developed in this work.