

A Method of Frequency Content Based Analysis of Driving Braking Behavior

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ABSTRACT

Typically, when one thinks of advanced driver assistance systems (ADAS), systems such as Forward Collision Warning (FCW) and Collision Imminent Braking (CIB) come to mind. In these systems driver assistance is provided based on knowledge about the subject vehicle and surrounding objects. A new class of these systems is being implemented. These systems not only use information on the surrounding objects but also use information on the driver's response to an event, to determine if intervention is necessary.

As a result of this trend, an advanced level of understanding of driver braking behavior is necessary. This paper presents an alternate method of analyzing driver braking behavior. This method uses a frequency content based approach to study driver braking and allows for the extraction of significantly more data from driver profiles than traditionally would have been done. The use of this method presents opportunities for advancement in the understanding of driver braking behavior and in the evaluation of proposed safety systems, which take driver braking behavior as an input.

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INTRODUCTION

When analyzing the braking behavior of passenger or commercial vehicle drivers, the metrics most often discussed are the peak pedal force or system pressure and the time from the onset of braking until the peak brake pedal force/ system pressure is achieved. This view of events results in braking being perceived as a simple event in which force is applied over a given time and at a given force, without regard to how this application occurs.

In [1] commercial vehicle driver braking behavior was analyzed and the results from this analysis indicate that a significant percentage of drivers exhibited multi-stage braking in emergency situations. The presence of multi-stage behavior indicates that not only are the brake application time and peak pedal force important but also the shape of the application profile must be considered. Prior research has shown that multi-staging behavior is present and expected in passenger car driver braking behavior as well.

In [2] Prynne and Martin express that two-stage braking is an innate part of the human emergency braking process. This is due to humans not having instinctive reactions to emergency situations and having to make decisions about how much braking should be applied during the process. This indicates that multi-stage braking should be expected in all types of vehicles when drivers are placed in extreme situations.

In papers such as that by Prynne and Martin where two-stage braking is recognized as being an innate part of the human braking process, a more comprehensive but still fundamental perception of human braking is generally used. This behavior is described similar to a

linear characterization of braking, drawn when only peak pedal force and application time are considered, with the exception that a pause at a given time and of a given duration is added. [Figure 1](#) shows a profile with this characteristic.



Figure 1. Example of a brake force application profile parameterized using a two-stage approach.

In reviewing Figure 1, it can be seen that there are seven parameters necessary to define a brake application profile using this method: F_{Start} is the minimum force required to be deemed brake application. F_{Pause} is the level of force at which the pause occurs. F_{Max} is the maximum brake pedal force in a given application. T_0 is the time at which braking begins. T_1 is the time from the beginning of braking to when the pause force is reached. T_{Pause} is the duration of the pause. Finally, T_a is the total application time. Note, T_2 is also shown in Figure 1, but is not an independent parameter because it can be shown algebraically to be defined based on other parameters and is only included for convenience of notation ($T_2 = T_a - T_{Pause} - T_1$).

Though able to fit reality more closely than a purely linear model, a large amount of deficiencies remain in this model. One such shortcoming being that this model is unable to account for instances of decreasing brake pedal force during application. Furthermore, this method of analysis is unable to account for scenarios during which multiple pauses in braking occur. Based on the wide variation in braking profiles scene in reality, both of these situations are expected to be encountered and therefore a method capable of more closely fitting reality should be investigated.

Advanced vehicle control systems are being developed which use measurements of driver braking behavior in order to determine if system intervention is necessary. The development of these systems necessitates a deeper understanding of driver braking behavior than what can be drawn from current metrics in use. In order to accomplish this goal, a method of analyzing driver braking behavior through analysis of frequency content is presented.

By increasing the level or knowledge about how drivers apply the brakes in a given situation, braking models may be improved to better represent how drivers behave in near limit situations. Furthermore, advanced applications may be able to use statistics to extrapolate what braking behavior would be expected from a larger population of drivers given the behavior of a comparatively small group. This method would further improve the understanding of driver behavior in extreme situations without large amounts of data available.

METHODOLOGY

In order to analyze braking behavior using a frequency content based approach, a method based on the Fourier series is used. The first step in this method is to subtract the linear function that extends from the initialization of braking to the braking peak from the application profile. This linear function is referred to as the fundamental slope and the remaining data is referred to as the profile deviation. An example plot of a brake force profile with the linear application profile is shown in Figure 2. While, the profile deviation for the same brake application data is shown in Figure 3.

The profile deviation is a representation of the driver's deviation from the fundamental slope or linear application profile. Therefore, if a driver followed a linear application profile the values in this dataset would be zero. Since the value of this function is not zero, a frequency content fit of this data will allow further information to be gained about the nature of this braking.

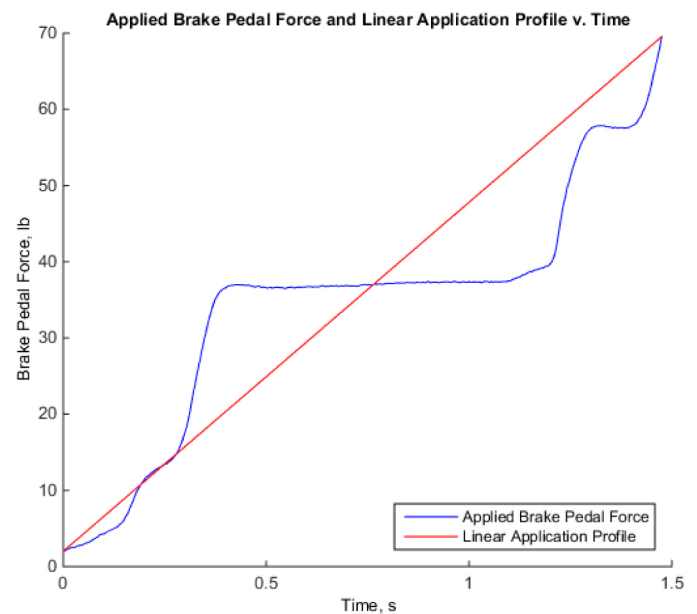


Figure 2. Plot of an example brake application profile plotted with the fundamental slope.

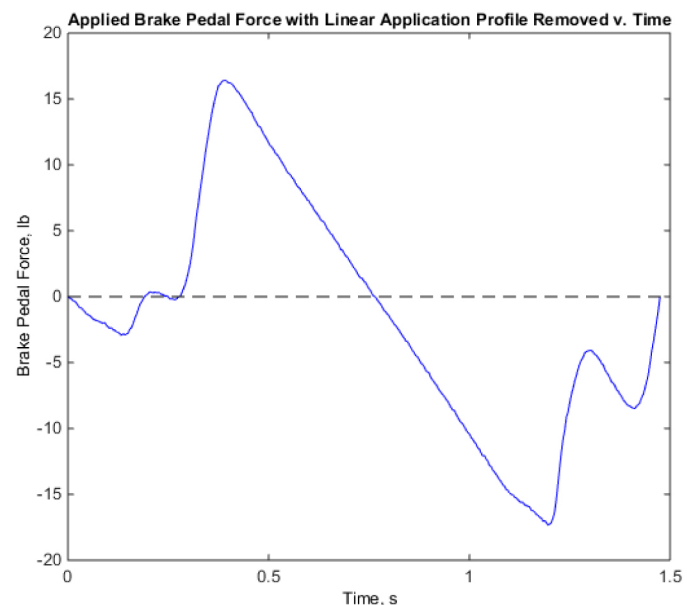


Figure 3. Plot of the profile deviation from the fundamental slope for an example brake application profile.

Since the chosen method of analysis is based on the Fourier Series, it is important that the derivation of the method starts as such. The expression for the Fourier Series as defined in [3] is given as Equation 1.

$$\mathcal{F}(t) = A_0 + \sum_{n=1}^{\infty} A_n \sin(n\omega t + \phi_n) \quad (1)$$

The removal of the fundamental slope forces the value of the profile deviation to be zero at the first and last points. It can thus be decided with the available data that the profile deviation function is the fundamental period of a sum of sine function. It can also be