Real-Time Anticipatory Suspension Control for Single Event Disturbances

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ABSTRACT

Most commercial vehicles currently on the market are still equipped with a passive suspension system, while some luxury brands may already use an adaptive suspension. Active suspension systems on the other hand are rarely found, however, they offer great opportunities to close the gap of the well-known trade-off between ride comfort and handling. Besides that, they can also be used to mitigate single event disturbances, an objective of the USA Army as announced in a solicitation which initiated and motivated this research. In addition to that, several studies were found stating the impact and danger of potholes and their impact on the vehicle and passenger.

Reviewing the literature, several control strategies for controlling active suspension systems were found. However, most of these approaches used feedback control and did not try to mitigate single event disturbances. Since literature also suggested making use of look ahead preview, research at the Performance Engineering Research Lab at Virginia Tech was started in 2015 combining look ahead preview and an adaptive system to generate optimal force profiles. This introductory research succeeded and proved the approach used to be very promising. However, the used adaptive system was not designed to operate in real-time and did not show any correlation between different road profiles.

Therefore, the main objective of this research project is to evaluate and analyze each of the adaptive systems by searching for correlations in their solutions. The results then should be used in order to design a control law which emulates the adaptive system and can be used in a real-time environment.

First, an overall research methodology was derived. According to this methodology a software application was developed which extracts ideal force profiles from single event disturbance signals in order to mitigate their impact to the vehicle. The application uses a quarter car model with a partially loaded active suspension system, a set of predefined road profiles, a road profile preprocessor, and an adaptive algorithm. The preprocessing includes geometric filtering using a Tandem-Cam Model and the adaptive processor used an iterative version of the Filtered-X Last-Mean-Square algorithm.

During evaluation and analysis of several generated data sets, high correlations in the generated and adjusted adaptive systems were discovered. From these an empirical and theoretical universal filter model was derived, which was then used to design an open-loop control law named Optimal Force Control.

The original control law and an adjusted version designed for a real-time environment were tested for all predefined road profiles over all considered vehicle velocities and proved to perform much better than the offline solution using the adaptive system.

In summary, a control law named Optimal Force Control was designed which can be used and implemented in a vehicle to extract an analytical and ideal force profile given a road profile input. Implementing an active suspension system with tracking controller, this approach can be used in order to mitigate single event disturbance signals by reducing the vertical vehicle acceleration.

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GENERAL AUDIENCE ABSTRACT

Most commercial vehicles currently on the market are still equipped with a suspension system consisting of springs and shock absorbers (passive suspensions), while some luxury brands already use suspension systems including parts which can change their behavior based on the driving situation (active suspensions). While these active suspension systems are still rarely found, they offer great opportunities to make the vehicle stable and at the same time easy to handle. Also, they have the potential to reduce the risk of an accident while driving over a pothole or disturbance in the road, an objective of the USA Army as announced in a solicitation which initiated and motivated this research.

Reviewing the literature, several control strategies for controlling active suspension systems were found. However, most of these approaches required measuring the current state of the suspension system. Research at the Performance Engineering Research Lab at Virginia Tech was started in 2015 in order to control active suspension systems by using data of the road profile ahead of the vehicle. This introductory research succeeded and proved the approach used to be very promising. However, the used system was designed to work in a laboratory environment only.

Therefore, the main objective of this research project was to evaluate and analyze the used control strategy by searching for intersections and similarities in the different solutions. The results were then used to design a control strategy which can be applied in a real-world vehicle environment.

First, an overall research methodology was derived. According to this methodology a software application was developed that generates the ideal control signal for the active suspension system in order to reduce the impact of a disturbance in the road profile. To that end a set of predefined road profiles were used, and a computer algorithm called Filtered-X Last-Mean-Square algorithm calculated the ideal control signal for the active suspension system.

During the evaluation and analysis of several generated data sets, a lot of intersections and similarities were discovered. Based on these findings a new control strategy was designed in order to be implemented into a real-world vehicle environment.

The new control strategy for the real-world vehicle environment was tested for all predefined road profiles over all considered vehicle velocities and proved to outperform the control strategy for the laboratory environment.

In summary, a new control strategy named Optimal Force Control was designed, which can be used and implemented in a vehicle. The implementation of an active suspension system can be used to mitigate disturbances in the road by reducing the vertical vehicle acceleration.

Research Project

The research project presented in this Master's Thesis aims to develop a real-time anticipatory suspension controller for an active suspension system mitigating single event disturbances by using a Least-Mean-Square (LMS) algorithm based on a quarter car model. It is a joint research project between the Institute of Automotive Engineering (FZD) at Technische Universität Darmstadt (TUD) and the Performance Engineering Research Lab (PERL) at Virginia Polytechnic Institute and State University (VT), also known as Virginia Tech. The research project is advised by Prof. Dr. Steve C. Southward (VT) and by Prof. Dr. rer. nat. Hermann Winner (TUD).

The reserach project was carried out according to the requierments for the Dual Degree Master Program between Technische Universität Darmstadt and Virginia Polytechnic Institute and State University. The Published Version of the Master's Thesis can be found via Universitäts- und Landesbibliothek Darmstadt and the German National Library:

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