Adaptive Control for Regenerative Shock Absorber for In-Wheel Motors of Solar-Assisted Vehicles

Background and Motivation: Solar-assisted electric vehicles (SEVs) are the ultimate zero-emission vehicles since they do not contribute to greenhouse gas emissions. However, due to the low power output of the photovoltaic array, widespread use of SEVs can only be realized if the vehicle system is highly energy efficient. Such rigorous optimization for limited power applications will lead to universal efficiency increases in vehicles of all kinds. One major boost in vehicle efficiency is to utilize in-wheel motors. For example, Protean Electric's in-wheel motors were found to increase the 244 mile range of the Tesla Roadster by 14%.[1] However, this pivotal technology also increases unsprung mass; in Protean's case, 30 kg at each wheel. The addition of unsprung mass causes more energy losses in the shock absorbers due to increased vibrational forces in the suspension.[2] It also adds complications traditional vehicle control for ride comfort and safety.[3] I would like to propose a comprehensive approach to maintain ride comfort and vehicle safety while harvesting suspension energy loss so that in-wheel motors can become the enabling technology for SEV's.

Research Method: While working at the Advanced Transportation Energy Center (ATEC) and Future Renewable Energy and Electricity Distribution Management (FREEDM) Center at North Carolina State University (NCSU), I will develop multi-level control for an adaptive regenerative shock absorber (ARSA), which will lead to improvements in electric vehicle efficiency. An existing high efficiency ARSA will be optimized to make it comparable in weight to traditional shock absorbers. The novelty of the design will be the adaptive control strategy, which adjusts ARSA parameters to changing road conditions to optimize safety, comfort, and efficiency.

The first layer of the control strategy will determine if an energy consumptive active or energy regenerative semi-active control should be used. The second layer will use an adaptive algorithm to adjust ARSA parameters based on vehicle response to road excitation. At the third level, an energy optimization strategy will ensure that the most energy is captured based on the corresponding mode of operation. The dynamic nature of the suspension will require quick response from the control scheme so the controller will be implemented in a closed-loop with negative feedback.

Intellectual Merit: The SEV is a highly interconnected system and understanding the relationships between its subsystems can increase its overall efficiency. This work will result in more intelligent suspensions that allow in-wheel motors to make better electric vehicles, including those assisted or driven by solar-power – the pinnacle of sustainable transportation.

The potential of the ARSA is recognized among automotive suspension engineers worldwide.[4,5,6] Previous work has resulted in the development of suspension control algorithms optimized for specific conditions or objectives.[7] An adaptive, multi-level control scheme will allow all benefits of the ARSA in dynamic situations.

Facilities: NCSU is the ideal place for this research due to the extensive resources available and established collaborations. At FREEDM, I will have access to the dSPACE vehicle chassis simulator, which serves as the vehicle model, to quickly simulate the ARSA and develop control logic *via* software-in-the-loop (SIL). Once my design is constructed, I can integrate it with the Lab Rapid Assessment Tool (LabRAT), a bare-skeleton vehicle made for bench testing components, at ATEC. ATEC also has an all-wheel drive dynamometer which I will use to get control data for comparison to simulation and road tests. The solar car team, SolarPack, will provide access to the prototype SEV for full integration of the prototype ARSA. Connections through SolarPack, such as the Haas Formula 1 racing team, can be leveraged to arrange premier testing facilities for accurate practical experiments.

Timeline:

1. Year One - Simulation and Design

Objective: Design and simulate a highly efficient regenerative shock absorber with semi-active and active controls

Methodology: Literature review and optimization of existing ARSA topology. Use dSPACE simulator to implement active and semi-active controls to prototype which will be integrated in future multi-layer control. Simulation using stochastic road models will be used to guide design.

2. Year Two - Active Regenerative Shock Absorber Experimentation

Objective: Build ARSA and experiment with control parameters to optimize both active and semi-active logic.

Methodology: Integrate the ARSA into the LabRAT to iterate the control parameters in each control strategy.

3. Year Three - ARSA Integration, Controls Assimilation and Testing

Objective: To evaluate and improve robustness of control scheme which will result in an ARSA that is ready for integration to the SEV.

Methodology: The ARSA and multi-layer control will be integrated to the SEV for experimentation. Accurate road experiments will be done to iterate to robust control. Robustness will be assessed by designing to International Organization for Standardization requirements.

Broader Impact: With the anticipation that societal and economic growth will require increased movement of people and things, we must ensure that our methods of transportation are clean and efficient. ARSAs are a step towards a better future where transportation is not only sustainable, but more intelligent. The SEV represents the most efficient vehicle topology and will benefit from the development of the ARSA because it will enable the in-wheel motor. Using the in-wheel motor will result in improved vehicle range by decreasing energy usage of the drivetrain. The proposed control strategy is not constrained to passenger vehicles and can be adapted to all ground vehicle applications.

The findings will be communicated in IEEE and SAE conferences and journals, and the technology will be demonstrated in solar car outreach activities, such as the EV Challenge, the Science Olympiad, and minority engineering summer transition programs to engage early college and high school students in automotive engineering research. SolarPack has already arranged to show our SEV at future North Carolina Science & Engineering Fairs, which will be a great way to inspire K-12 students to break barriers in the automotive industry through research. The NSF Graduate Research Fellowship will allow me to engage sustainable transportation research on a deeper level and focus on contributing unique insights to the automotive engineering field.

References:

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