Designing a Battery Management System for High Performance Racing

(Technical Paper)

How Motorsport Drives Technological Advancements for Consumers through Innovation

(STS Paper)

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On my honor as a University Student, I have neither given nor received unauthorized aid on this assignment as defined by the Honor Guidelines for Thesis-Related Assignments.

Introduction

Racing has long served as a breeding ground for technological advancements, with its insatiable quest for speed, efficiency, and safety in a competitive arena. This spirit of competition and innovation often produces technologies that find their way into consumer vehicles. Features such as anti-lock braking systems, traction control, and aerodynamic enhancements are just a few examples of racing-derived technologies that have become mainstream. With the world currently at the brink of an electric vehicle (EV) revolution, the role of high-performance racing in shaping the future of transportation technology is more vital than ever.

The environmental implications of this shift are profound. Traditional internal combustion engine vehicles are a significant contributor to carbon emissions, exacerbating climate change and contributing to air pollution that threatens public health. In the United States alone, there are over 233 million licensed drivers, and their collective switch to electric vehicles represents a monumental opportunity to mitigate these adverse impacts. As society becomes more cognizant of environmental sustainability, the focus is increasingly turning towards electric vehicles as a viable and necessary replacement for their ICE counterparts. This mass adoption of electric vehicles is not without its challenges, however. Issues surrounding range, charging infrastructure, and efficiency are hurdles that need to be overcome. Engineering a high-performance Battery Management System (BMS) for an electric racecar serves as the technical focal point of this prospectus. The BMS is essential for optimizing the performance, lifespan, and safety of the batteries that power electric vehicles. Its significance in a racing context, where the margins for error are slim, and the demands on performance are high, can provide critical insights and solutions that are directly applicable to consumer electric vehicles.

Beyond the technical aspects, this prospectus also delves into the Science, Technology, and Society (STS) dimensions of racing innovation. Specifically, it explores how the developments in high-performance racing can drive broader societal shifts towards sustainable modes of transportation. The racing industry, with its emphasis on pushing the limits of what is technologically possible, can act as a catalyst for change, influencing both public perception and policy decisions. Through this dual lens of technical innovation and societal impact, the aim is to foster a holistic understanding of how racing can not only entertain but also contribute constructively to the global transition to sustainable transportation.

Designing a Battery Management System for High Performance Racing

As a part of ECE 4440, the capstone class for the department of Electrical and Computer Engineering, instructed by Adam Barnes, I will be engineering a high-performance battery management system (BMS) [3] for an electric racecar in conjunction with my group members Silas Schroer, Gabriel Binning, and Asad Shamsev. A BMS serves as the central nervous system of an electric vehicle's high voltage configuration, undertaking a multitude of functions that are integral for the safe and optimized performance of the vehicle. It is responsible for continuously monitoring an array of critical parameters such as battery voltage, current, and temperature. This ensures that each battery cell operates within its optimal performance envelope, thereby maximizing the vehicle's range, speed, and overall efficiency. The development of this highly robust and reliable BMS will be designed with a particular focus on the Virginia Motorsports VM24 Formula SAE electric race car which will be used to compete in the Formula Student competition in June 2024.

The stakes for developing such a system are elevated in the context of high-performance racing, where even minor inefficiencies or malfunctions can lead to a significant loss of competitive edge or even pose safety risks. Racing environments subject vehicles to extreme conditions, including high-speed operation, abrupt accelerations and decelerations, and variations in external temperatures. These conditions place enormous demands on the BMS to rapidly adjust and balance the battery cells, ensuring they remain within safe operating conditions while delivering maximum performance. Furthermore, the system needs to be highly responsive, providing real-time data that can be used by the driver for strategic decision-making during races.

The complexity of engineering a BMS for such an application is compounded by the need for seamless integration with other vehicle systems. This includes but is not limited to the electric motor, power inverters, thermal management systems, and telemetry frameworks. In addition the Formula Student competition denotes a set of rules that each team must strictly adhere to. These regulations specify high level measurement guidelines as well as trace thickness and spacing for PCBs. The BMS must interact flawlessly with each of these components to create a harmonious and efficient vehicle ecosystem. Incompatibilities or failures in communication between these systems can lead to suboptimal performance or even catastrophic failure, with potentially dire consequences in a racing scenario.

The focal point of the research is to construct a Battery Management System (BMS) utilizing advanced microcontrollers from TI, the BQ79656-Q1, temperature sensing elements, and high speed communication protocols. One of the primary hardware issues to overcome is the presence of high Electromagnetic Interference (EMI), generated during rapid accelerations and decelerations, which can lead to communications issues and mismeasurements. High operating temperatures present another significant hardware problem. Elevated temperatures can degrade the battery cells and even pose a risk of thermal runaway, leading to potential catastrophic failures. The utilization of the TI microcontrollers is pivotal for real-time monitoring of voltage and temperature levels and the 32bit mainboard is imperative for immediate intervention, such as cutting off power and notifying the driver to prevent any damage to the electrical system or the vehicle/driver itself.

Active cell balancing is another critical hardware component of our research focus, which aims to improve overall battery efficiency. In a typical electric vehicle, not all battery cells discharge and charge at the same rates, leading to imbalances that can impair performance and battery lifespan. The TI microcontrollers in our proposed BMS will continuously monitor the state of charge of each cell and actively redistribute loads to maintain a balanced state. This is crucial for optimizing the range and performance of the electric racing vehicle, as even minor imbalances can result in a substantial reduction in overall efficiency.

How Motorsport Drives Technological Advancements for Consumers through Innovation

Electric vehicles are a critical solution for reducing greenhouse gas emissions, however, their acceptance in the market is hindered by several technological and societal challenges. From range anxiety and battery longevity to safety concerns and the high purchase prices, EVs have had a rocky rollout in the US. Interestingly, these challenges are reminiscent of the issues faced during earlier paradigm shifts in transportation technology. For instance, the transition from horse-drawn carriages to internal combustion engine vehicles was met with skepticism and various technological and infrastructural challenges, such as the lack of paved roads and refueling stations, not to mention the initial high cost of automobiles. Over time, however, societal adaptation and technological innovations helped to overcome these obstacles, leading to the ubiquity of gasoline-powered cars today.

High-performance racing functions as a critical testbed for pushing the limits of electric vehicle (EV) technologies, offering a high-stakes, real-world environment where engineers and researchers can rapidly iterate designs, troubleshoot issues, and deploy innovative solutions. The advancements nurtured in this competitive arena, be it in battery management systems, powertrain efficiency, or thermal management, often serve as pioneering blueprints for commercial electric vehicles. This symbiotic relationship between racing and consumer vehicles is particularly significant in the context of the global fight against climate change. Transitioning from fossil fuel-powered vehicles, which are major contributors to greenhouse gas emissions, to cleaner, more efficient electric vehicles could yield substantial reductions in emissions, thereby alleviating some of the most pressing environmental challenges facing society today. Thus, the role of high-performance racing extends far beyond entertainment and competition; it acts as an accelerated development platform that has the potential to expedite and refine the technologies required for widespread EV adoption, thereby contributing to broader efforts to mitigate climate change.

More widespread adoption of electric vehicles could, in turn, generate a cascade of societal benefits. For instance, reduced reliance on fossil fuel-powered vehicles would lead to a substantial decrease in greenhouse gas emissions, contributing significantly to global efforts to combat climate change. Beyond environmental gains, greater EV adoption could also have positive ramifications for public health by reducing air pollution, a leading cause of respiratory ailments and other health issues. Additionally, as electric vehicles become more prevalent, there would be a corresponding increase in demand for renewable energy sources, possibly accelerating the transition away from fossil fuel-based power generation, further diminishing our carbon footprint.

The societal changes also extend to the economic landscape. A shift toward electric mobility would create new markets and industries focused on EV technologies, from battery production and recycling to smart charging infrastructure. This could result in job creation and offer new avenues for economic growth and investment. Furthermore, increased EV adoption could lead to policy changes, with governments incentivizing green technologies and imposing stricter emissions standards, thereby creating a regulatory environment that further promotes sustainable practices.

Research Question and Methods

Questions

How can a BMS be optimized for high-performance electric race cars?

How do innovations in high-stress environments like racing contribute to the broader adoption and improvement of electric vehicles?

Methods

The research will employ a mix of simulation testing, prototyping, and real-world application. Firstly, the BMS will be designed using CAD software and simulated using MATLAB or similar tools to evaluate its expected performance. Following this, a prototype will be developed and integrated into the VM24 FSAE electric race car. Rigorous track testing will be carried out to validate and iterate the design. Concurrently, case studies will be examined to understand the societal impact of innovations derived from high-performance racing, especially as they relate to consumer-grade electric vehicles.

Conclusion

This research aims to deliver a high-performance Battery Management System (BMS) that will not only meet the rigorous demands of electric car racing but also serve as a cornerstone for advancements in consumer-grade electric vehicles. On the STS front, the research will provide a comprehensive understanding of how technological innovations in racing can accelerate societal shifts toward sustainable transportation. Upon successful completion, the BMS technology could significantly enhance the reliability, safety, and efficiency of electric vehicles, contributing to broader societal goals of reducing carbon emissions and mitigating the effects of climate change.

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