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Project Proposal

1. **Introduction**

The proposed project will support the Notre Dame Formula Hybrid team in their participation in the Formula Hybrid SAE national competition. The project will be a smart system for the vehicle that provides computational capabilities and safety features. The system will act as an electronic differential, an accumulator management system, and a motor monitoring system. It must also activate the regenerative braking system, and be able to output the current state of the controller inputs and outputs to the driver through serial communication and to an external person through RF signals. The system will meet the specifications of the Formula Hybrid rules for the 2019 competition year.

2. **Problem Description**

The Notre Dame Formula Hybrid team is constructing a series hybrid-electric race car. The car has a Kawasaki Ninja 250 IC engine connected to a Motenergy 1616 electric generator. The energy storage medium is an accumulator bank of Maxwell 3000F Ultracapacitors connected in series. The accumulator bank is used to power the two Enertrac MHM602 hub motors on the rear wheels. Each motor and the generator are controlled by one of three Kelly KLS 8080I14001 motor controllers.

The team has a need for a system that will monitor the activity of each of the aforementioned components and can both provide information on and control of the car's performance. This system must provide connectivity between the various electrical systems of the car as well as computational power. It must also serve as the Accumulator Management System (AMS) as detailed in the Formula Hybrid Rules. This system is used to monitor the energy. The system must be reliable and robust and must meet the specifications of the 2019 Formula Hybrid Rules.

3. **Proposed Solution**

The proposed system can be understood in terms of the inputs and outputs of the device. It will serve as a basic feedback loop for the car's electrical systems, with some safety features. The proposed device will take inputs from the accelerator and brake pedals, steering wheel, accumulator bank, and IC engine. These inputs will give the system information on the voltage and temperature levels of the vehicle components that provide a picture of overall car performance. This feedback will be run through the proposed device, which will compute optimal performance characteristics such as torque on each wheel, charging rate for capacitors, and IC engine throttle position. The system will provide a readout of all components being monitored both on an onboard screen and offboard via radio connection. Lastly, the system will have the ability to shut down the tractive system as part of the accumulator isolation relay circuit. It is important to note that this system cannot be the only way to open the accumulator isolation relay loop, but is just one of several components that can break the loop.

4. Demonstrated Features

The accumulator must be monitored whenever the tractive system is active or the accumulator is connected to a charger. The proposed device must also monitor all critical voltages and temperatures in the accumulator as well the integrity of all its voltage and temperature inputs. If an out-of-range or a malfunction is detected, it must shut down the electrical systems, open the AIRs and shut down the I.C. drive system within 60 seconds. The tractive system must remain disabled until manually reset by a person other than the driver. It must not be possible for the driver to re-activate the tractive system from within the car in case of an AMS fault.

The device must continuously measure cell voltages in order to keep those voltages inside the allowed minimum and maximums stated in the cell data sheet. Additionally, it must monitor the temperature of at least 10% of the ultracapacitors. The system will monitor any errors signaled by the ultracapacitor balancing boards, which observe the functionality of the ultracapacitors.

All voltage sense wires to the AMS must be protected by fuses or resistors so that they cannot exceed their current carrying capacity in the event of a short circuit. Input channels of the AMS used for different segments of the accumulator must be isolated from one another with isolation rated for at least the maximum tractive system voltage. This isolation is also required between channels or sections of the AMS that are connected to different sides of a SMD, HVD, fuse, or AIR. Any GLV connection to the AMS must be galvanically isolated from the TSV. This isolation must be documented in the ESF.

Driver input information from the brake and gas pedals as well as the steering wheel angle will be processed to determine the optimal torque settings for each rear wheel motor. Gas pedal input will increase the torque value to both wheels, and brake pedal input will engage regenerative braking. Steering wheel angle will affect the relative torque outputs of each of the two wheels, allowing the car to navigate turns more tightly by generating a yaw moment.

Monitoring the generator controller setting, informs about the charging rate for the capacitors. To achieve a constant RPM, the system will continuously monitor the engine's RPM to inform the device how the gas throttle position must be adjusted accordingly. At all times, the device will display information on the system's state. The system will have a liquid crystal display for the driver to observe all feedback information. The team on the trackside will receive the system's information through wireless communication through a transceiver.

5. Available Technologies

- An absolute rotary encoder can provide information about the angle of the steering wheel. The sensor communicates via serial connection. https://www.mouser.com/datasheet/2/670/amt21-1309538.pdf
- To monitor the rotational speed of the internal combustion engine, the waveform from it's alternator will be converted to a square wave, which can be read by the microcontroller. The NCV1124 Dual Variable−Reluctance Sensor Interface IC can perform this conversion. https://www.digikey.com/product-detail/en/on-semiconductor/NCV1124DR2G/NCV1124DR2GOSCT-ND/3487438
- PIC Microcontroller-PIC32MX Series
- Since the ultracapacitor balancing boards operate at high voltage, they must be isolated from the low voltage system using optical coupling. https://www.mouser.com/ProductDetail/ON-Semiconductor-Fairchild/FOD8314TR2?qs=sGAEpiMZZMuIaPd8bG7xI46Ha79ckRH9gJBxm3n4QDNeN65GlU88kg%3d%3d
- Information about the state of each system will be sent wirelessly to a transceiver located trackside. This data will be viewable on a laptop for real-time monitoring of vehicle performance. The following readily available transceiver circuit communicates via serial connection. https://www.digikey.com/product-detail/en/seeed-technology-co-ltd/113990039/1597-1229-ND/5487781
- A LCD display will be used to give the driver feedback. https://www.adafruit.com/product/198
- The ultracapacitors will be balanced automatically by a board made specifically for this purpose. The Hybrid team has already obtained these boards.

https://www.digikey.com/product-detail/en/maxwell-technologies-inc/INTEGRATION-KIT-ACTIVE/1182-1035-ND/3079299

- Additional support is available from Formula Hybrid sponsors, such as Linear Technologies
  https://formula-hybrid.org/students/parts/supplier-sponsored/

6. Engineering Content

Hardware:

The engineering design of the hardware of this project entails determining the scope and use of sensors and devices needed to intake inputs from the mechanical and electrical systems of the vehicle. These mechanical systems include the operation of the gas engine, motors, the steering wheel. The electrical systems include the charging and discharging of the ultracapacitors. Each of these systems must be monitored by a a separate sensor receiving certain inputs. For example, monitoring the steering wheel system will require a rotary encoder to take the input angle of the steering wheel and output this information in order to send required data for controlling the motors and power of the car. Other sensors needed include a throttle sensor to monitor the gas engine and the braking system and a sensor to monitor the charge of the ultracapacitors. All of these sensors must be incorporated into the same circuit board in order to accept inputs from the systems and at time have their outputs serve as inputs to other parts of the system. There will be a display aspect of hardware necessary as well. This will involve an LCD display as well as a transmission of data remotely. The functionality of these individual systems and their connectivity are all aspects of the hardware design necessary in this project.

Software:

The software component of this project will be mainly focused on the functionality of the various sensors working in conjunction. This will require programs tasked to accept the outputs of some sensors and, after computation, relay as inputs to other components. For example, the input to the motors will be an output computed from the rotary encoder connected to the steering wheel. This main software function will be the emphasis of the design of this project, having sensors of different systems able to input and output values to use in other systems as well as display for the driver and remotely store data.

Safety and Feedback:

The sensors, PCB, and software must be designed to ensure the high voltage systems of the vehicle are monitored and operating safely. This is mainly safety for the board itself rather than safety for the driver which must already be accounted for by manual mechanical stops within the vehicle directly linked to those systems. The safety features protecting the electronic will need to be accounted for on the circuit board design. This will be monitoring the voltage levels being input to the board from the electrical systems such as the ultracapacitors in order that the board monitoring the systems, accepting inputs, and provide outputs does not get overheated.

Design Testing:
The completed system will be tested in conjunction with the Formula Hybrid racing team. This will also include documentation of the system functioning in accordance with the rules of the Formula Hybrid competition. Various parameters of the system will be tuned for optimum performance once the vehicle is completed.

7. Conclusion

Our system will represent an integral development for the Notre Dame Hybrid Formula team in their process to complete a vehicle for the Formula Hybrid SAE national competition. Previous experience of team members involved in the formula team ensures an understanding of the particular needs and requirements that the system must satisfy. Progress as we begin to work will reveal the level of complexity of the various components of our project, as well as which will require higher involvement and troubleshooting.