Problem Statement and Goals
Mechatronics

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Table 1: Revision History

Date	Developer(s)	Change
September 25th, 2022	Abhishek Magdum, Dharak Verma, Jason Surendran, Laura Yang, Derek Paylor	Initial document population

1 Overview

Machines are designed by humans, for humans, to make everyday life easier. Until a machine has a method to control it, either through human control or autonomous control, they are nothing more than a paperweight. In our everyday world, cars are a ubiquitous machine used to transport people and goods to their destination, and thereby are a key pillar of a productive economy and society. In the 21st century, vehicles are becoming more interconnected and sophisticated than ever and use computers to control almost every subsystem of the vehicle. Control systems encapsulate the "brains" behind such machines, allowing them to interpret their environment using sensors, determine a desired state, and manipulate the environment using actuators to achieve the desired state. They convert a physical stimulus (from the environment, including a user) into a control signal for a component. Some examples of control systems seen in modern cars today are engine/transmission controls, HVAC controls, battery management (in hybrid/electric vehicles, anti-lock braking (ABS) and electronic stability program (ESP).

1.1 Project Description

We are aiming to design, simulate, implement, and test a vehicle control system for a quarter-scale Formula 1 style electric vehicle. The control system will allow the vehicle to be operated in basic driving conditions by managing the following vehicle subsystems: battery management, cooling, vehicle mode selection, tractive motor, and vehicle dynamics. This capstone will be in collaboration with the MAC Formula Electric FSAE team, where we will be responsible for providing them with a suitable control system for their vehicle within competition rule specifications. We will be working with the embedded hardware provided by MAC Formula Electric for implementing and testing our control system once software-based simulation and validation is complete.

1.2 Inputs

Inputs to the control system are sourced from the various hardware sub-systems of the vehicle, such as the battery management system, motor controller kit, inertial sensors (accelerometer, gyroscope), and driver inputs via steering and pedal sensors.Inputs from the battery management system regarding its current state, battery module temperatures, voltage output, and current draw must all be within safe operating specifications and thus will play a large role in the overall state of the vehicle control system. To comply with FSAE rulesets regarding the enabling of the tractive system, entering ready-to-drive mode, and safely shutting the vehicle down, the control system must also take input from the vehicle's driver via physical push buttons mounted on the steering wheel. Lastly, the control system will be responsible for communication with the motor controllers which will be based on inputs from the driver via the pedal tray.All the aforementioned inputs to the control system will play a role in dictating the current state of the vehicle and its various sub-systems.

1.3 Outputs

Based on the hardware and system state inputs described above, our control system should output digital control signals for the vehicle's actuators within each of the vehicle's subsystems, such as battery, cooling, and motor controllers.Some vehicle systems work independently of each other. For example, the battery cooling loop must only enable once a set temperature is met, and fan speed is modulated based on heat generation and battery module temperatures. On the other hand, there are systems in the vehicle, for example the systems that control vehicle propulsion, that must work together in order to propel the vehicle. A simple push of the accelerator pedal must translate to various messages to the battery management system and motor controllers. These systems must be controlled and work in unisense to propel the vehicle forward. All of these considerations and limitations must be accounted for when programming of the vehicle control system commences.

1.4 Stakeholders

Primary stakeholder for this project, apart from the members of this group, include:

- MAC Formula Electric Team. The control system will be developed for the team to be able to utilize it in the final vehicle and compete in competitions.
- Dr. Smith

Secondary stakeholders, who are not the focus but can still benefit from this project being open source, include:

- Current and future electric car developers, including future students on the Formula team who can learn from this project

1.5 Environment

The environment of our software control system will depend somewhat on the state of the vehicle's production. Control system programming will initially be done in a software environment, negating the need for hardware, until a concrete control system program exists. Simulation (using software models) will be employed to verify basic functionality and catch unsafe conditions that may be caused through control logic errors. The control system can then be compiled and tested on the existing MAC Formula Electric electronics test bench, which includes all the vehicle ECU's and any hardware peripherals we require for input or output. Whether the control system ends up on the final vehicle before the completion of our capstone depends on a large number of external team factors such as chassis manufacturing, electrical integration and packaging, and push to the Formula FSAE vehicle, and its corresponding controllers.

2 Goals

3 Stretch Goals

Table 2: Goals

Goal	Description
Reliability of output	Ensure that state of the vehicle control system corresponds to the physical state of the vehicle including motor RPM, battery state of charge, and all driver inputs such as ready-to-drive button, emergency shutoff, and pedal inputs. Validate that the control system accurately takes feedback from the various vehicle sub-systems and commands state changes as required. Verify that all commanded sub-system state changes are as expected and can be replicated.
FSAE rules compliance	Ensure that the vehicle startup and shutdown sequence follow the FSAE rules. This will be achieved by creating flowcharts depicting the required state of each model based on user input and the rules-defined timing based state changes. We can then validate the output state changes of our control system with our flowchart for a 1:1 match.
Maintainability	We will ensure future maintainability of our control system by separating all sub-systems into individual simulink models and controlling them via an overarching state machine. For example, we can create a single model for controlling a motor, and then utilize that model multiple times to enable a four-wheel drive system. We will also ensure all our models are thoroughly documented both inside the Simulink model itself and via project documentation.

Table 3: Stretch Goals

Goal	**Description**
Vehicle Dynamics - Stability Control Program	Stability control is a great feature for keeping a vehicle on the road, and heading towards an intended direction, commanded by the driver. This is done by checking the position of the steering wheel, and comparing it to the z-axis rotation of the vehicle. When the driver commands a turn and the vehicle is slow to react, wheel slipping is detected. To reduce/eliminate the loss of traction, the vehicle can brake the wheels closest to the apex of a corner, to help apply a rotational moment on the vehicle and assist the driver to turn the vehicle around a corner.
Vehicle dynamics - torque vectoring	Torque vectoring works similar to a vehicle stability control program, except in this case, the creation of a moment on the z-axis of a vehicle is purely done through acceleration. This means that when acceleration of the vehicle is requested through the accelerator pedal, based on steering direction, the vehicle can vary torque to different sides of a vehicle. Usually when going around a corner, the torque will be applied to the wheels furthest from the corner apex, helping apply a moment on the z-axis of the vehicle to help achieve higher cornering velocities along with increased driver confidence.
Over the air data acquisition	Over-the-air data acquisition will allow us to gain vital vehicle data, while the vehicle is out running laps. This can help us diagnose any issues live, if we see any anomalies in the control system, increasing vehicle performance and safety.