FrostAV Development

Stage 1: Base

Updated November 4, 2019

Contents

1 System Abstraction

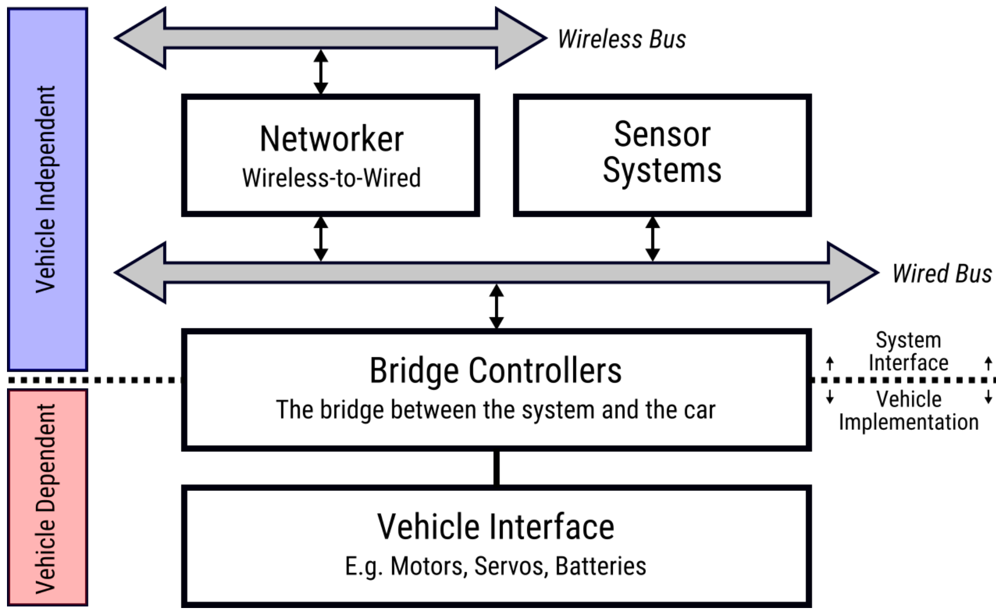


Figure 1: Fundamental module abstraction. Consists of a wired-bus for inter-communication between modules on the Frost vehicle, and a wireless-bus for communication with a server or an ssh client. Bridge Controllers act as the coupling between the vehicle and the modules that do not depend on the vehicle interface.

1.1 Abstract System Operation Description

The Frost Autonomous Vehicle consists of a vehicle and a system for controlling the vehicle. The vehicle provides an interface mainly to move it and to steer it. Bridge Controllers handle the peripherals that make up the vehicle interface. Bridge Controllers cannot operate unless they have instructions. These instructions come from a wired-bus. Different types of modules can send instructions to the wired-bus. The most important modules are the Networker and each individual Sensor System. Sensor Systems provide feedback for the Bridge Controllers to act upon. Furthermore, the Networker transfers information between the wired-bus and the wireless-bus. The wireless-bus allows for communication with devices that are not on the vehicle itself. Overall, the abstract system provides a map for how information is received and directed towards the vehicle's interaction with the environment.

1.2 Bridge Controllers

"Bridge" refers to a software design pattern from the Gang of Four, which intends to "decouple an abstraction from its implementation so that the two can vary independently." As such, the Bridge Controllers will have software that implements the Bridge design pattern, so that implementation code (for a specific vehicle) is decoupled from the system interface.

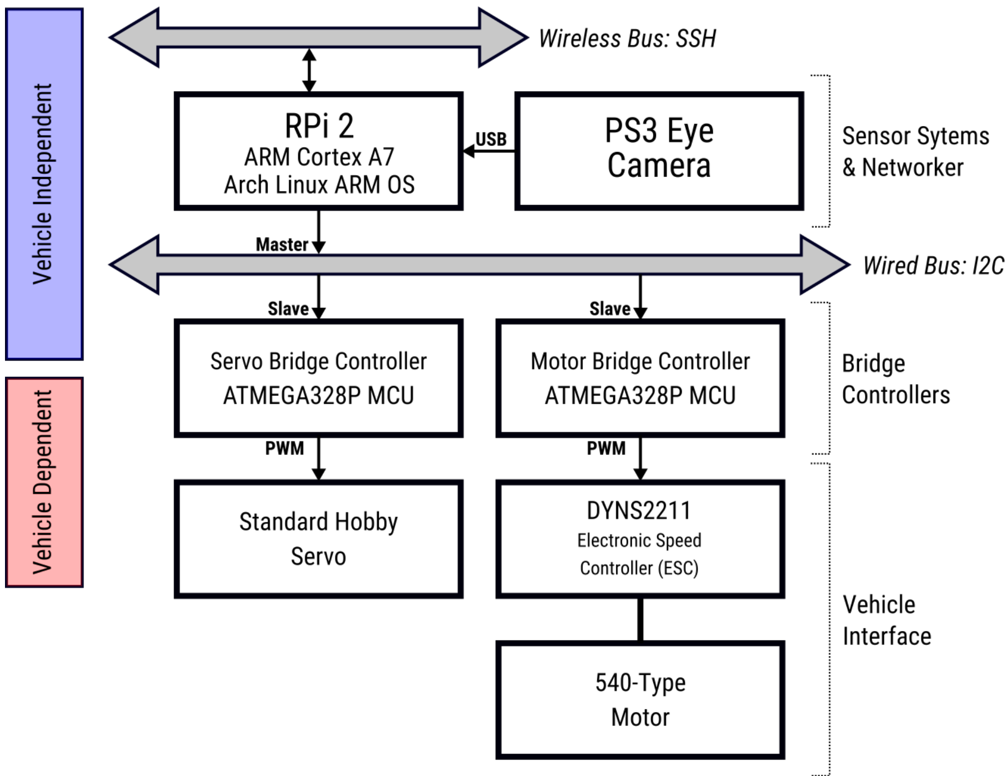
1.3 Networker

The Networker is reponsible for transfering information between the wireless-bus and the wired-bus.

1.4 Sensor Systems

Various Sensor Systems may be added to the wired-bus. An individual Sensor System should receive information from a sensor, process the information, and send the result to the wired-bus.

2 System Plan



2.1 System Operation Description

The PS3 Eye Camera provides visual information about the environment. This information will be processed with the OpenCV library on a Raspberry Pi 2 with an Arch ARM operating system. Processed camera information will then be piped through I^2C to the Bridge Controllers. The Servo Bridge Controller has a PWM output which directly drives the steering servo. The Motor Bridge Controller has a PWM output that is handled by the electronic speed controller (ESC), which drives the motor.

2.2 System Assumptions

The assumption made in this development stage is that the motor speed and servo steering angle can be controlled individually, such that motor speed and steering angle do not require direct knowledge of each other. Hence, the arrows from the wired-bus to the Servo and Motor Bridge Controllers are unidirectional. This assumption is meant to simplify the I^2C wired-bus configuration - since bi-directional communication on this bus would require arbitration.

2.3 Bus Communication

JSON will be used as the format for data for both the wireless and wired buses. JSON provides easy to understand data structure packets that can be serialized and sent as a stream. Using JSON sacrifices speed for readability and extendability of the system.

2.3.1 Wireless-Bus

In this stage the wireless-bus should allow for an SSH client to connect to it. As such, JSON packets that would normally be sent to the wireless-bus, will instead be stored locally in the system, but will be callable from an SSH client.

2.3.2 Wired-Bus

For the wired-bus, I^2C will be used. I^2C addressing will be done manually for each slave connected to the bus. Data will be sent from master to slaves via the JSON format.

2.4 Block Function Description

2.4.1 Raspberry Pi 2 (RPi2)

The RPi2 has an Arch Linux ARM operating system. It is responsible for processing camera information from the PS3 Eye. It is also responsible for being the Networker, which transfers information between the wired and wireless buses.

2.4.2 Servo Bridge Controller (ATMEGA328P)

Processes commands from the wired-bus to control the vehicle steering servo.

2.4.3 Motor Bridge Controller (ATMEGA328P)

Processes commands from the wired-bus to control the vehicle motor's speed.

2.4.4 PS3 Eye Camera

Provides images over USB, for environmental perception.

2.4.5 Electronic Speed Controller (DYNS2211)

Takes in a PWM signal and outputs an amplified and directional PWM wave to the vehicle's motor.

2.4.6 Power Supply

Takes the 12v input from the battery and steps the voltage down to 5v to power the vehicle's systems. Also provides current and voltage monitoring.

3 Power Supply Design

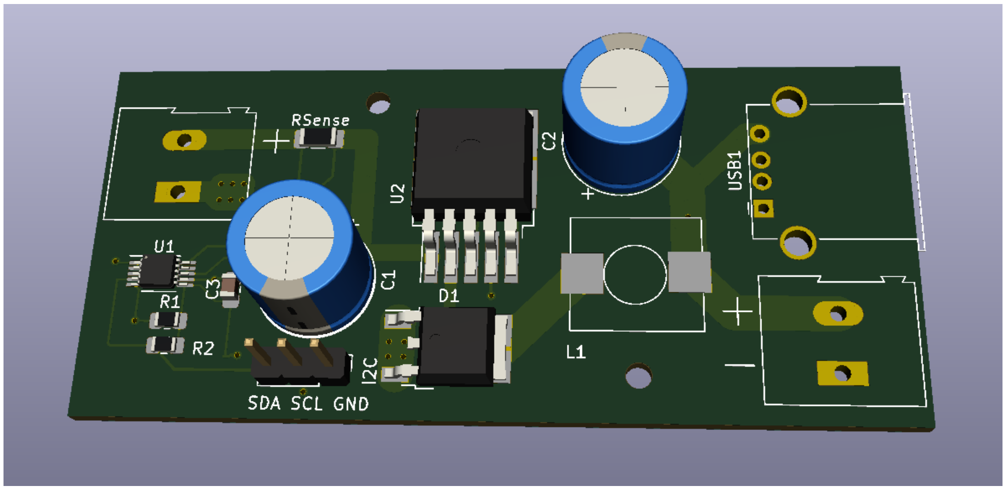


Figure 2: 3D Render of Power Supply

The function of the power supply is to step down the 12v (nominal) battery voltage to 5v for powering the vehicle's systems. The power supply is designed to be cabable of outputting 3A with a 9v input (9v is the lowest safe charge for a 3-cell LiPo battery). The system should use much less than 3A on average, but a 3A output provides a large margin of error. The power supply is also capable of measuring the battery voltage and battery current draw and reporting these values over the I2C bus.

3.1 Switching Regulator

The power supply is implemented using a TI LM2596SM-5.0 buck switching regulator. The switching regulator section of the power supply consists of C1, C2, L1, D1 and U2 in the schematic diagram. A switching regulator is used instead of a linear regulator (ex. 7805) for efficency reasons. A linear regulator has an efficency of about 40% with a 12v input, whereas a buck converter will have an efficency of about 80-90%. A linear regulator also produces a large amount of heat, which would require a large heatsink.

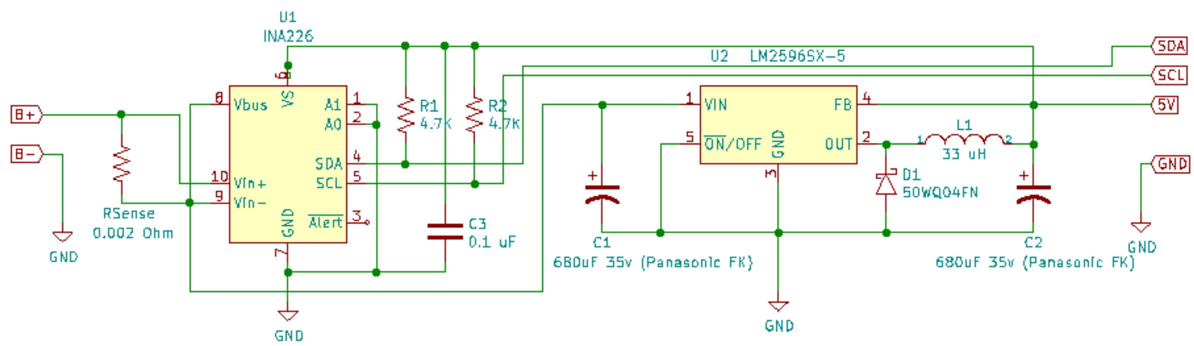


Figure 3: Power Supply Schematic

The regulator operates in a buck configuration, in continuous mode (the inductor current never falls to zero). A buck regulator operates in two cycles, shown in 4. The switching regulator IC (U2) acts as the switch. When the switch is closed, the inductor charges and produces an opposing voltage. This reduces the voltage across the load (following KVL). When the switch opens again, the inductor acts as a current source and discharges through the load. This switching creates voltage spikes, so the output capacitor is used to smooth them out. The output voltage is controlled by varying the ratio of switch on time vs off time.

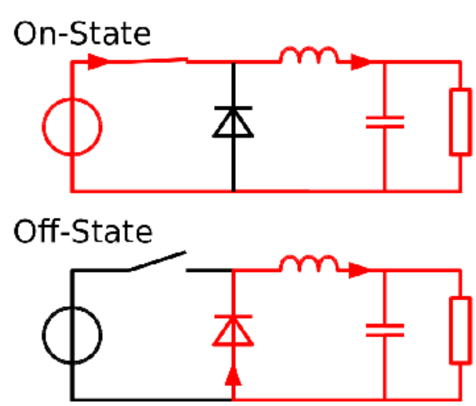


Figure 4: Buck Converter Cycles

The capacitors used for the switching section, C1 and C2 are both low ESR (equivalent series resistance) electrolytics. Low ESR capacitors are used so that they are capable of handling high current spikes without overheating. The inductor has a value of 330uH, which allows the regulator to operate in continuous mode to improve efficency. The specific inductor (Bourns SRP1038C-330M) was chosen because it is capable of handling 4A of DC current and has a saturation current of 6A. A saturation current of over 3A is needed for the regulator to operate, there were issues with the prototype where the inductor was saturating at about 2A and causing the output voltage to go out of regulation. The diode D1 is a 50WQ04 Shottky diode, which was choosen because of its low forward voltage and fast recovery. Fast recovery is important because the regulator switches at

150kHz and a standard silicon diode would not switch fast enough.

3.2 Power Measurement

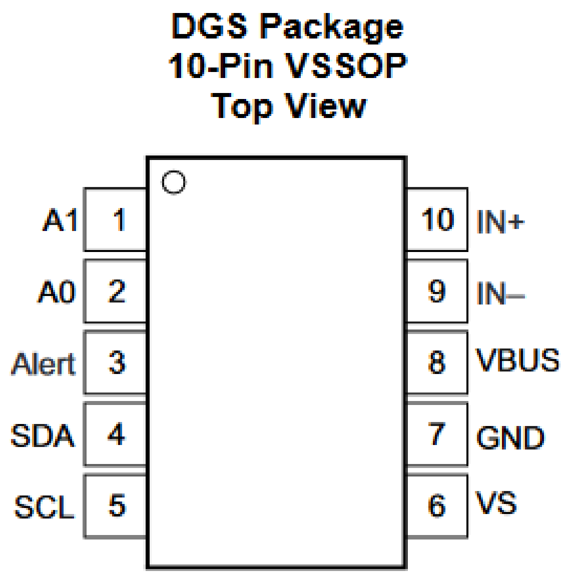


Figure 5: INA226 Pinout

A TI INA226 power monitor IC is used to measure the total power used by the system. This IC measures the total system power by measuring the input voltage and the voltage across a shunt resistor. The shunt resistor (shown as Rsense in the schematic) is connected in series with the input of the switching regulator to provide a more accurate reading. The resistor has a value of 0.002 ohm, and the current flowing through it can be calculated using Ohm's law.

The INA226 communicates using I2C and provides current, voltage and power measurements as well as the voltage across the shunt resistor. It also supports alerts over I2C and a dedicated digital output. The INA226 will be connected into the system wide wired-bus with an I2C address of 0x40. The power and voltage measurements will be used to calculate the remaining battery life, and the voltage measurement will be used to allow the system to put the car into a safe state before the battery is empty.

3.3 PCB Design

A PCB (printed circuit board) was designed for the power supply to provide more physical durability, as well as more stability for the buck converter. Since the buck converter operates at 150kHz traces connecting the inductor, output capacitor and diode need to be as thick and short as possible. The back side of the board uses copper fill as a ground plane to keep the impedance to ground as low as possible, and to act as a heatsink for the LM2596. Multiple vias are placed under the LM2596 to help with thermal and electrical conductivity. Surface mount components are used to keep leads short and make the finished product as compact as possible. Since the board will be hand soldered, larger pads are used for all components.

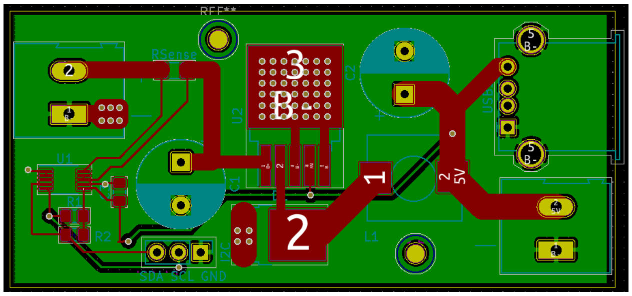


Figure 6: PCB Layout

The PCB and schematic were designed in KiCad, and while component footprints were available for most parts there was nothing matching the inductor so a custom footprint was made. The custom footprint was designed in the KiCad component editor. The component's datasheet was referenced for the size and spacing of the solder pads. The solder pads were widened and lengthened slightly to allow for easier hand soldering, although the spacing between them remains unchanged. Two 2.1 mm diameter mounting holes are included in the layout.

The power input and output connectors are 5mm pitch terminal blocks, in addition to a USB output port. The terminal blocks were picked because they are capable of accepting a 20 to 12 AWG wire which will allow more flexability when connecting the power supply into the system. The battery will be directly connected to the input terminals, the Raspberry Pi will be connected to the USB port (with a small microUSB cable) and all other 5v devices will be connected to the output terminals. The I2C signals from the INA226 are routed to a pin header, with pull up resistors.

3.4 Testing

To test the power supply, the setup shown below will be used. The voltmeters and ammeters are used to measure the current and voltage at the input and output of the power supply. The potentiometer (or decade resistance box) will be used to place a load on the system. The bench power supply can be used to test the range of input voltages, and an oscilloscope can be placed across the power supply's (DUT) terminals to measure the ripple on the output.

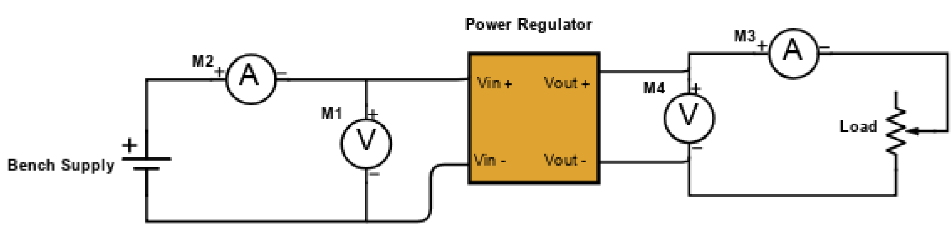
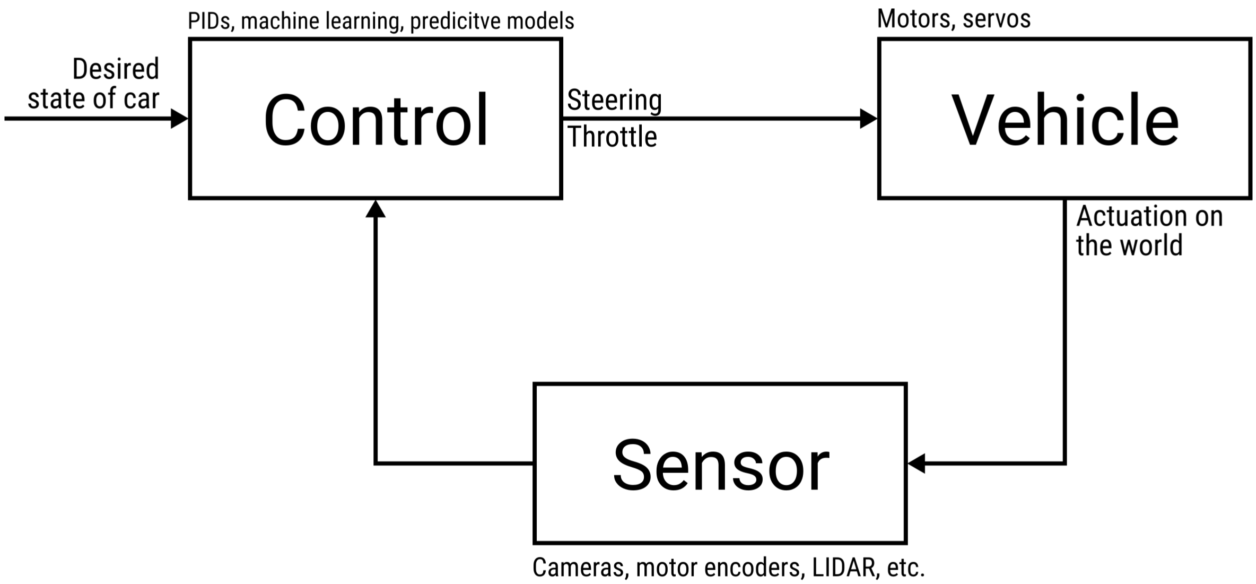


Figure 7: Test Setup

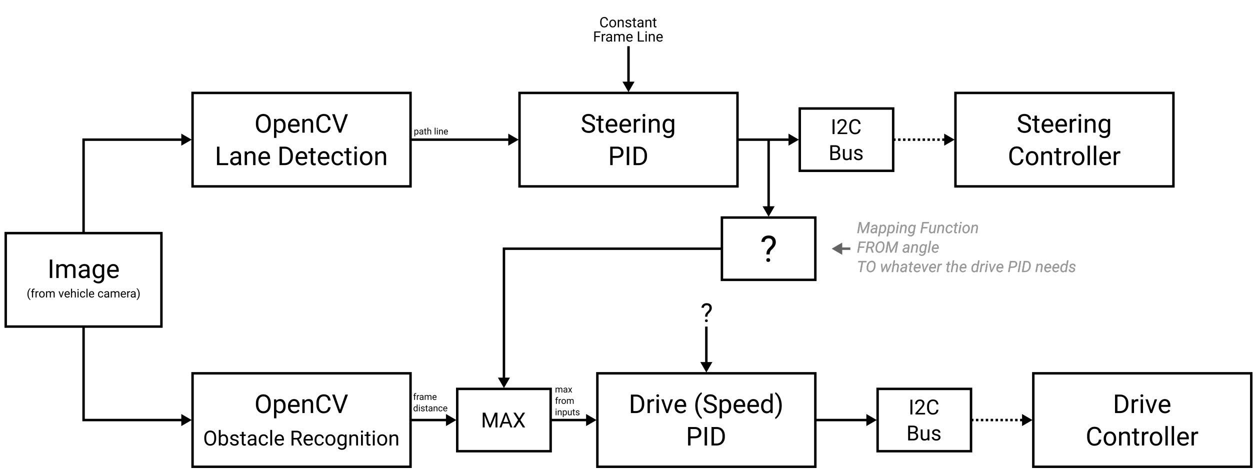
The switching regulator will be tested first by providing 12.6v to the input, which is the batteries maximum voltage. Then the load on the output will be increased from 0A to 3A in 0.5A steps, and the input and output voltages and currents will be recorded, along with the peak-to-peak ripple. This will then be repeated with an input voltage of 12.0v 11v 10v and 9v which will simulate the full range of battery voltages. These tests will ensure that the switching regulator is capable of providing the required output at all possible battery voltages.

Next, the power measurement section will be tested and calibrated. An Arduino will be connected to the I2C terminals on the power supply, and a simple sketch will be used to report the measured voltage, current and power over the serial console. The bench power supply will be adjusted until it is outputting exactly 10v, and then the difference between the measured and actual voltage will be found to get a calibration factor. Next, the power supply will be loaded until the input current is exactly 1.0A. Then the difference between the measured and actual current will be found to find a calibration factor. The calibration factors will then be written into the calibration registers on the INA226.

4 Control Abstraction



5 Control Plan



6 Future

6.1 I2C Arbitration

It is expected that modules communicating on the wired bus will need to communicate with each-other. In this case, there would be multiple masters on a single i2c bus. To implement this, arbitration would be necessary so that masters on the bus do not interrupt each other.