FAMU-FSU College of Engineering
Department of Electrical and Computer Engineering

System-Level Design Review

EEL4911C – ECE Senior Design Project I

Project title: SAE Baja Data Acquisition System
Team #: 5

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Project Executive Summary

The Society of Automotive Engineers encourages college students worldwide to apply classroom knowledge to real world design concepts through their annual competitions. SAE International hosts five categories of competition that include Aero, Clean SnowMobile, Formula, Baja, and Supermileage. The SAE team at the FAMU-FSU College of Engineering actively participates in the Baja competition each year and subsequently builds upon their designs from previous competitions for vehicle improvement.

Previously, the SAE Baja Team has made changes to the vehicle based on estimates of the performance of the vehicle. This year, Team E#5 will add a quantitative approach to the Baja design process by adding a data acquisition system (DAQ). The DAQ will record values from various vehicle systems and will be stored for later use. DAQ subsystems will include measurement for fuel, speed, acceleration, tire pressure, and suspension travel. In addition to recording and storing data, the DAQ system will include a communication component to help the team during competition. The communication component will have a signal going from the driver to the pit crew to alert the pit crew of low fuel or low tire pressure. This will allow the pit crew to prepare for the driver and decrease the time it takes for the vehicle to get back on the track.

Currently, the design is in the final stages of conceptualization. Some components have been purchased and tinkered with, however no implementation has been done as of the publication of this document. While some of the subsystems have been tabled indefinitely, the system will still meet most of the requirements and specifications set forth in the Needs Analysis and Requirement Specifications. Those include the measurement and display of the speed and fuel level of the vehicle, the measurement of the acceleration of the vehicle, wireless data transmission to a discrete pit unit and a DAQ-specific power system. The system will be easy to use by both the driver and the pit crew, requiring minimal setup to begin acquiring and displaying data.

The system will follow the competition design rules outlined by SAE International as well as hold up against the rough terrain of a Baja competition track. The system will be finished by the April 9th competition date in Auburn, Alabama and will stay within the $750 budget.

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Introduction

1.1 Acknowledgements

The SAE Baja DAQ design team would like to acknowledge our head advisor Dr. Frank for any advice, input and ideas offered on how to proceed during the design phase of the DAQ. The team would like to acknowledge the FAMU-FSU Society of Automotive Engineers for any sponsorship and advice they may provide and including this design team in this year's Baja car. The team would also like to thank Arrigo Dodge of South Florida for their contribution of four tire pressure monitoring system sensors to the Baja DAQ team. Finally, the team would also like to thank the FAMU-FSU Electrical and Computer Engineering department for their financial contributions towards the project.

1.2 Problem Statement

The acquisition of data can be a very important part of efficiently optimizing designs of many kinds, especially those involving mechanical systems such as automobiles, provided that the data collected is used in an appropriate manner. The design team aims to design and implement a Data Acquisition System (or DAQ) that will collect and store important data and ultimately make the FAMU-FSU Baja team's vehicle more successful in this year's competition.

In previous competitions, the SAE Baja team had little quantitative information to use when making changes to the vehicle. For example, refueling was done on a whim, determined only by how long the vehicle had been driving. In almost every case, the vehicle did not actually need refueling, wasting precious race time during the endurance portion of the competition. The DAQ will inform the SAE Baja team of the proper changes and procedures needed to improve the vehicle mid-race, allowing them to focus less on problem identification and more on problem solving. The DAQ will tell the driver and the pit crew when a fuel change is needed, when a tire change is needed and when a suspension adjustment is needed, as well as any other information the team may find helpful--all remotely and in real time.

1.3 Operating Environment

The Baja vehicle to which the DAQ will be mounted will be driven on rough terrain in a harsh outdoor environment during competition. The system will potentially be subject to shock and vibration due to the rough terrain, rain, dust, dirt, mud, rocks, heat (both due to weather and ambient engine heat) and RF interference from other similar systems on opposing vehicles. The system will need to withstand temperatures up to at least 120 degrees Fahrenheit. In designing the system, the team will make considerations for the inclement conditions which the system may face during the SAE Baja competition.

1.4 Intended User(s) and Intended Use(s)

1.4.1 Intended User(s)

The intended users of the DAQ are the members of the FAMU-FSU SAE Baja team. As all members of the SAE Baja team must be at least 18 years of age (for liability reasons), any and all users of the DAQ must also be at least 18 years of age. Any user of the DAQ must also be adequately trained in the use of the system. One of the important attributes of the system, as outlined in the Needs Analysis and Requirements Specifications, was usability. This means that the system will be easy to use so that the Baja team can focus on the competition as opposed to the DAQ operation. Thus, just about any engineer on the Baja team will able to use the DAQ. Only DAQ team members should exchange or modify the hardware components of the system itself.

1.4.2 Intended Use(s)

The DAQ is designed to be used by the Baja team members to evaluate various data points about the vehicle and make changes based on the data collected. To begin using the DAQ, the Baja team will have to simply turn the system on and begin running it (the procedure to run the DAQ is TBD based on the design). Once powered on and instantiated, the DAQ will begin collecting and displaying data to the users. The received data will be written to a storage device so that the Baja team can analyze it after testing or competition. During the competition, the Baja team will be able to use this data to make adjustments to the vehicle as needed. Ultimately, it is up to the Baja team to determine what is to be done with the collected and displayed data.

1.5 Assumptions and Limitations

1.5.1 Assumptions

- All components used in the design of the DAQ will be chosen such that their specifications meet or exceed the requirements of the system.
    - The wireless data transmission module(s) will exceed a range of 3 miles urban.
    - The main power source and the subsystem power sources will be chosen such that they allow at minimum 8 hours of system operation.
    - The storage medium will be large enough to accommodate all collected data
        - It is estimated that 1 GB will be more than enough to accomplish this
        - 40 bytes per line * 18000 seconds (5 hours) * 1 Hz = 720KB
- The main MCU will have enough I/O pins to be able to interface with every subsystem of the DAQ.
- The main MCU will be mounted inside of a protective enclosure to shield it from the competition conditions.

- The end product will only be used on the Baja vehicle.
- The system will be subject to inclement conditions outlined above in **Section 1.3 - Operating Environment**

1.5.2 Limitations

- The DAQ will be limited in some ways by the Baja competition rules.
    - The engine of the vehicle cannot be modified in any way.
    - The DAQ must use its own power source separate from the Baja vehicle's power source.
    - The system cannot interfere with any essential vehicle systems.
- The system shall be designed within an initial budget of $600.
- The system shall be able to withstand temperatures up to 120 degrees Fahrenheit.
- The display shall be easily readable by the driver of the vehicle.

1.6 Expected End Product and Other Deliverables

Before April 9th, 2014, the team will deliver a data acquisition system to the SAE Baja team. This system will collect, use, and display important data about the Baja vehicle to the team during the SAE Baja competition. This data includes fuel levels, suspension travel, acceleration, speed and tire pressure. This data will be written to removable media so that the Baja team can import it to a computer and analyze it as they see fit. The system will consist of two sections, the collection system mounted other vehicle (outlined in section 1.6.1), and the pit station where a readout of the collected data will be given to the pit crew (outlined in 1.6.2).

The Baja team will also be provided with a copy of each deliverable report upon completion, so that they may stay up to date on the development of the DAQ. The Baja team will also receive schematics of the system, top-level block diagrams, and data sheets and information about each component used. Additionally, they will be given a copy of all source code used in development of the project, so that future Baja teams may learn and improve on the design further.

The end product will be a stand-alone data acquisition that will collect data about the following subsystems:

- Fuel
- Suspension
- Acceleration
- Speed
- Tire Pressure

The data will be logged onto a removable memory host that can stored for later use.

In addition, there will be a signal traveling from the driver to the pit crew alerting the pit crew of low fuel and tire pressure allowing the pit crew to prepare for the drivers return.

There will also be a display of the car’s subsystem status on the vehicle for driver awareness.

1.6.1 On-vehicle Data Collection

The actual data acquisition system itself will be mounted to the vehicle. The unit will collect data about the vehicle from several sensors, store that data to a removable media device in a CSV file, and display some of that data to the driver and the pit crew. The vehicle will also have indicator lights that will warn the driver of low fuel or tire pressure. The unit will consist of the following:

- 1 - Hercules LAUNCHXL-TMS57004
- 9 - MSP430G2332IN30 Microcontrollers
- 2 - US1881 Hall effect sensors
- 1 - Forman 911-008 fuel sender
- 4 - Schrader 20398 TPMS Sensors
- 4 - TPMS Sensor readers (TBD based on modulation type)
- 1 - ADXL335 accelerometer
- 1 - XBee-PRO 900HP wireless transceiver
- 2 - $LiFePO_4$
- 1 - High-gain Dipole Antenna
- 2 - Indicator lights
    - One for fuel, one for tire pressure
- 1 - SD card module

1.6.1 Pit Unit

The pit unit will include a display for the collected information as well as mirrored indicator lights that warn the pit when the vehicle requires fuel or tire pressure. This unit will include the following items:

- 1 - Raspberry Pi (B)
- 1 – XBee-PRO 900HP wireless transceiver
- 1 - Display
- Fuel and tire pressure indicator lights

1.6.2 Deliverable Reports

During the designing of the system, the DAQ team will fulfill several milestones, three of which occur in the Fall 2014 semester. The SAE Baja team will be provided with copies of each deliverable report as they are completed. This is to ensure that the Baja team is satisfied with the progress of the DAQ and all of its components, and to ensure that the system fulfills the needs set forth by the team. The SAE Baja team will receive electronic copies of the following:

- Needs Analysis and Requirements Specifications (Completed Friday, October 17th)
- Project Proposal and Statement of Work (This document)
- System-Level Design Review (Due November 13th, 2014)

The SAE Baja team will also be provided with any other deliverable reports due in the Spring semester of 2015.

1.6.3 Documentation and Configuration Files

Along with the actual system itself, the Baja team will be provided with documentation about the implementation of the system. This includes a top-level block diagram, information about each component, and all source code for the project. Those items are outlined below.

1.6.3.1 Top-Level Block Diagram

The top-level block diagram of the system will provide the Baja team with an idea of how the system is laid out at a glance. This diagram will show each different DAQ components and illustrate how they interface with each other. The diagram will be stored as a PDF to allow for portability between platforms. This will also allow the Baja team to make comments on the document to share amongst themselves.

1.6.3.2 Component Information

The Baja team will also be provided with information about each component used in the system. For each component used in the DAQ, the Baja team will receive:

- Datasheet
- Part number
- Information about how the part is interfaced with the overall system

This information will allow this the current and future Baja teams to easily find and replace any failed components with the same components or components with similar specifications. In the event that future teams with to improve on the DAQ design, they will be able to choose new components that will be compatible with the rest of the system.

1.6.3.3 Source Code

All of the source code used to implement the system will be given to the SAE Baja team. This will allow future members of the SAE Baja team to learn from the DAQ team's implementation of the system and improve on the design further. The files will be added to a *.zip or *.rar archive and given to the team with all of the other deliverables.

2 System Design

2.1 Overview

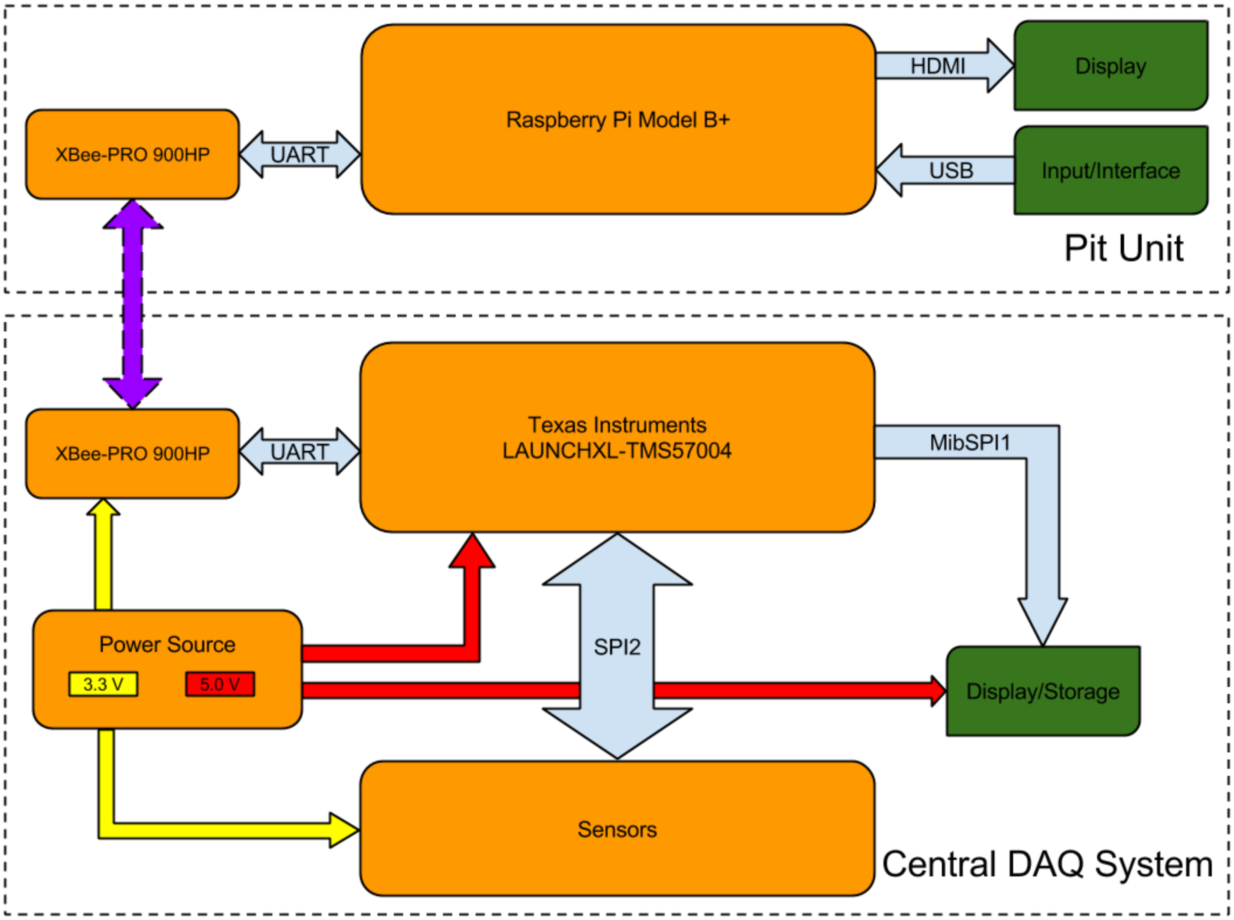


Figure 2.1a: Top-Level block diagram of the entire system

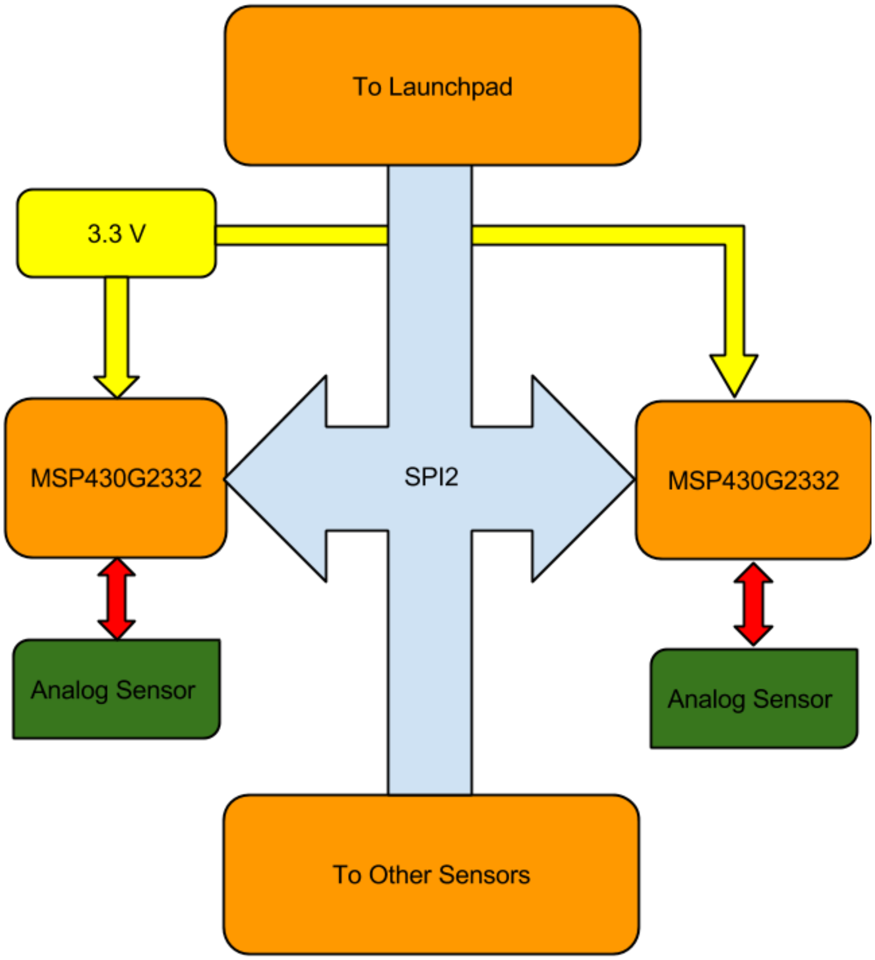


Figure 2.1b: Block diagram of the sensor network

A top-level block diagram for the overall design of the system is found above in **Figure 2.1a**. The design will have two sections, the pit unit, which allows the pit crew to monitor the vehicle remotely and the on-vehicle DAQ system, which collects, stores, displays and transmits data from the sensor network. The vehicle MCU will poll data from the sensors, format the data, write the data to an SD card, and transmit data to the pit unit via an XBee-PRO 900HP. The system will be powered by two 3.2V $LiFePO_4$ batteries connected in series. The on-vehicle display will be done using a 2.2” SPI LCD display, and will display the speed of the vehicle as well as an indicator bar showing the amount of fuel left in the vehicle.

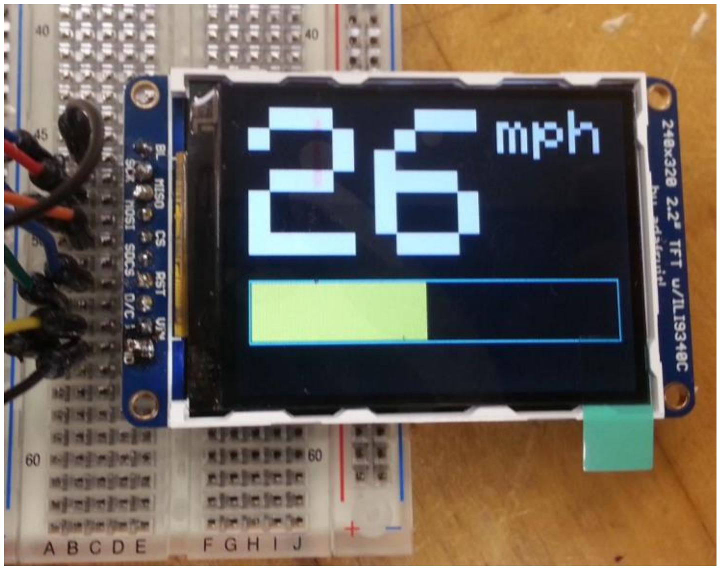


Figure 2.1c: Preliminary display layout prototype

2.2 Major Components and Component Requirements

2.2.1 On-Vehicle Data Collection Unit

The unit mounted on the vehicle will contain the main microcontroller, a power source, a sensor network, a wireless transceiver and antenna, a microSD card slot, and a display as illustrated by the top-level block diagram in **Figure 2.1a**. The main microcontroller will poll data from the sensor microcontrollers--which will be continually collecting analog outputs from the sensors they are connected to, converting the analog inputs to digital representations, and converting the digital representations to the desired units (e.g. MPH, percent of fuel remaining, m/s^2, etc.). If polled, the sensor microcontrollers will then send their final calculated values to the main microcontroller via an SPI bus. Each sensor microcontroller will be powered by the regulated power source outputs via its own connection, and will not be powered by the development board's 5 V/3.3 V regulated outputs.

2.2.1.1 Main Microcontroller

The main on-vehicle microcontroller will be the central hub of information flow for the entire system. It will collect data from each sensor via SPI and transmit or relay that data to a number of endpoints including a display for the driver, a log file on an SD card, and the remote pit unit. It will ideally perform this data acquisition and display in real time. This will provide the basis for the DAQ system and allow the system to provide the most up-to-date information to the driver and crew, and store the most useful information to the log file.

The main MCU must be fast enough to perform data collection, display, and storage in near-real-time. It must have a number of interfacing options including hardware SPI, and it must have enough GPIO and function pins to provide support for all the current DAQ functions as well as any future additions the system might have. Additionally, the MCU must be reasonably priced and should have low power draw.

2.2.1.2 Accelerometer Module

The accelerometer, along with most of the other sensors used in the system, will be connected to its own microcontroller. The accelerometer itself will output analog values for each axis of motion (generally 3 in our universe). These analog outputs will be read by the MCU's ADC and stored for calculation and conversion, as well as sent to the main MCU on command via the SPI bus. The data on the bus will be sent in a usable format - most likely m/s^2. The acceleration data will be used by the Baja team to increase performance in the acceleration portion of the competition.

Ideally the accelerometer will have a low measurement range (wheeled vehicles typically only reach accelerations of 0.4-0.6g, so a low measurement range will reduce cost and increase accuracy), offer through-hole mounting, and should be available at a reasonable price.

2.2.1.3 Hall Effect Sensor Module

Hall effect sensors increase their voltage output in the presence of a magnetic field. The Hall effect sensor will be used to measure the speed of the vehicle by affixing a permanent magnet to the drivetrain of the vehicle, and using the sensor to read when the magnet passes by a certain point. Once calculated, the speed of the vehicle will be sent to the main MCU and displayed on the on-vehicle display. The sensor will have its own microcontroller to calculate the speed of the vehicle and handle data transmission on the bus. The use of a discrete microcontroller to calculate speed is useful because polling of the sensor has to be done very frequently and at regular intervals in order to accurately determine rotational velocity, if it were to be done by the main MCU it would reduce the sampling rate of the system.

The Hall effect sensor should offer an analog output (as opposed to a switch), and should be through-hole or frame mounted. The attached MCU should be fast enough to poll the sensor at a sufficient rate to accurately determine the vehicle's speed, and the entire control flow should be fast enough to provide data to the main MCU as quickly as possible.

2.2.1.4 Fuel Level Sensor Module

The fuel level sensor module will operate much like the accelerometer module, with a discrete microcontroller measuring the analog output of a sensor and repeating its value on the SPI bus. Fuel level sensors generally act like a rheostat, with a float acting as the main actuator. This sensor will be in series with some static resistance, creating a voltage divider with an output that can be read by the ADC. This along with some rudimentary calculation and calibration will allow the MCU to read the amount of fuel remaining in the tank and report it to the main MCU on command.

The SAE Baja team will need to be consulted before any installation of a fuel level sensor can occur. The selected sensor must have a mounting option appropriate for the tank on the vehicle, and it must have a predictable impedance. It must also be an appropriate length for the tank in order to get the most accurate readings.

2.2.1.5 Tire Pressure Monitoring System Module

Tire pressure monitoring will be done by short range RF, using a transmitter/receiver pair. Battery powered sensors are placed in the tires which send data once a suitable RF signal is received. Typically this data includes some unique unit ID, the pressure in the tire, and the temperature. The data for all 4 tires can be collected by a single unit and this data can then be repeated over the SPI bus to the main MCU.

The RF transceiver for the TPMS system must be powerful enough to activate and read output from all 4 sensors from some central location on the vehicle. The attached MCU must also be able to communicate with the sensors at the appropriate baud rate.

2.2.1.6 Sensor Data Bus

The sensors and main MCU will be connected by a single data bus which simplifies programming, allows for future expansion, and reduces pin use on the main MCU. The bus used will be 4-wire SPI, using individual chip select lines to differentiate devices on the bus. For sensors, as soon as their chip select line is pulled low they will send a start code followed by their formatted data on the bus. Other peripheral devices may require input from the main MCU to be sent on the bus also.

2.2.1.7 Wireless Transceiver

The wireless transceiver will allow the on-vehicle system to communicate with the pit unit remotely, providing the pit crew with valuable data such as fuel level and tire information while the vehicle is racing. This will allow the crew to prepare for pit stops in advance and thereby reduce the overall time spent in the pit. There will be two identical transceivers (one at each endpoint), and 2 way communication will be possible (although information will primarily travel from vehicle to pit)

2.2.1.8 Display

The display will allow the driver to read important information about the vehicle such as speed and fuel level while racing. Other messages such as system errors or warnings can be displayed also. This will allow the driver to quickly determine when a pit stop is needed, and will aid the driver in dynamic competitions as performance data can be displayed in real time.

The display will have a controller which uses serial communication to write to the screen (as opposed to complex and costly parallel or dot clock screens) which will allow the main MCU to draw the interface efficiently. The display should also be low power yet high visibility. This probably means a smaller screen size would best fit the design.

2.2.1.9 Storage

Removable storage will be used to log data from the DAQ system for later analysis. The log will be stored in CSV format to allow portability and ease of reading and writing. CSV is a very simple open format which is readable by a very wide range of free and proprietary software. An SD card will be used as the removable media due to its ease of implementation and portability.

2.2.2 Pit Unit

The pit unit will collect data from the DAQ system wirelessly and allow the pit crew to read the status of the vehicle remotely. It will consist of a wireless transceiver (identical to the vehicle's transceiver) to retrieve data, and a processor to record or display that data to the crew.

2.3 Performance Assessment

Most of the requirements set forth in the Needs Analysis and Requirements Specifications should be met given the design outlined in its current state in this document. Some requirements were tabled indefinitely due to the solutions not being financially viable, while others were tabled due to, among other things, their lack of usefulness.

2.3.1 Functional Requirements

Most of the functional requirements will be met with the design in its current state as outlined in this document. The system will accurately measure and display the speed of the vehicle (**REQF-001**) and the fuel level of the vehicle (**REQF-002**). The system will accurately measure and report the linear acceleration of the vehicle (**REQF-003**) and any low-frequency vibrations (up to 50 Hz with the default accelerometer setup) (**REQF-004**). There will be visual alerts (**REQF-007**) on the displays both on the vehicle and on the pit unit, alerting the pit crew and driver of low fuel or low tire pressure (TBD based on whether or not the design team can interface with the TMPS sensors). The on-vehicle system will have an easy-to-read display that shows both the speed and fuel level of the vehicle (**REQF-009**). A preliminary prototype of this display can be seen in **Figure**. The data collected by the system will be written to an SD card in a *.csv file (**REQF-010**).

Some functional requirements were tabled due to their financial viability, their lack of usefulness, or engineering design concerns. The potential inability to meet **REQF-005** is explored below in **Section**. The suspension travel measurement (**REQF-006**) was tabled indefinitely due to the cost of implementation using market solutions. This requirement may be met if the Baja team decides to invest in the sensors, which are very costly. It was determined that designing sensors was beyond the scope of this project given the time and material cost it would take to design and manufacture suspension travel sensors. The voice communication between the driver and the pit (**REQF-008**) was also tabled due to the range concerns with the wireless transceivers. The design team met with the SAE Baja team and determined that the feature, which would have hampered the rest of the design, had limited usefulness. The Baja team determined that, if need be, a marketed voice communication system would be purchased and installed by them, independent of the DAQ team.

2.3.2 Non-Functional Requirements

Given the preliminary budget analysis and a budget of $750USD to date, the system should remain within the budget provided by the FAMU-FSU Department of Electrical and Computer Engineering, as per **REQN-001**, barring any unforeseen expenditures and given the complete mitigation of the financial risks outlined in **Section 6.1**. To date, the project is on schedule to be completed before the Auburn, AL competition on April 9th, 2015 (**REQN-002**). However, there could be setbacks that prevent the due date from being met. The on-vehicle system will be powered by its own power source, explored in detail in **Sections 3.1.3** (**REQN-003**). The user interface for the DAQ has not yet been finalized, but the selected hardware is powerful enough to support a fast and responsive UI without issues, and will be powered on or off by a switch located outside of the system's protective housing (**REQN-004**). Since most of the sensors are housed independently of each other and the main MCU box, subsystems can be taken out without affecting the operation of the overall system (**REQN-005**). However, the fact that most of them will be mounted to custom PCBs could make repairing those subsystems a lengthy procedure if extra modules are not on hand and assembled. The hardware chosen for the system is powerful enough for real-time performance, and any code written will be optimized as much as possible to ensure that the system is running as efficiently as possible (**REQN-006**).

2.3.3 Environmental and Health & Safety Requirements

The DAQ's power source should be recyclable and should last for a large number of recharge cycles (**EHS-001**). The system must not impede the function of any essential Baja systems such as brakes or

2.3.4 Usability Requirements

User interfaces for the DAQ system have not yet been finalized, but the selected hardware will be fast enough to support a fast and responsive UI without issue (**REQU-001**). The system's modular design allows the Baja team great freedom in placement of components around the vehicle, and will allow them to remove and replace system components as needed to perform vehicle maintenance or other work. The system will be powered on or off by a switch located on the exterior of the main DAQ housing so that the team can enable or disable the system as needed (**REQU-002**).

2.3.5 Reliability Requirements

The system is expected to run for many hours due to careful selection of components and battery technology (**REQR-001**) and allow for extra run-time for pre-race testing and adjustments, and also to compensate for extra power draw unforeseen by the design team. The modular design of the system will simplify component replacement in the event of component failure (**REQR-002**).

The Baja team will be consulted on system mounting locations to ensure that the system is safe and secure on the vehicle (**REQR-003)**.

2.4 Design Process

While the majority of the DAQ system design components have been planned and outlined in the documentation, there are still some major decisions left to be made.

2.4.1 Suspension

After discovering the high cost and low availability of suspension travel sensors, the team initially decided to design their own sensors using a potentiometer and steel tubing. After some discussion and research, it was determined that designing sensors was beyond the scope of this project given the time and material cost it would take to design and manufacture suspension travel sensors.

The suspension travel measurement may be implemented if the SAE Baja team decides that they wish to purchase the sensors using the Baja budget, or if they determine that one can be designed in-house.

2.4.2 Pit Crew Unit Display

The Pit Unit should display data collected from the system on a screen so that the pit crew can see the status of the vehicle at a glance. Currently, research is being done to determine the best display to use. The display should be lightweight and low power, but have high visibility. Since it is being connected to a single board computer as opposed to an MCU, the display does not need serial input capabilities but can use standard video interchanges such as composite video or HDMI.

2.4.3 Software Development

The team is still in the very early stages of software development. While the team can prototype code on personal hardware, code cannot be verified until final hardware is obtained. The team has drafted control flow diagrams for each processor in the system which can be found in **Section 3.1**. The Raspberry Pi was purchased and delivered, and the team is waiting on a response from Texas Instruments regarding the donation of the Hercules LaunchPad, the MSP430 MCUs and the MSP430 Dev Kit.

2.4.4 Tire Pressure

The tire pressure monitoring system, at this point, may or may not be completed. The state of the tire pressure monitoring system is explored in detail in **Section 3.1.2.6**. The TPMS had originally been tabled due to the lack of availability of marketed solutions for ATV tires as well as the lack of sensitivity of the marketed automobile sensors. The TPMS will be explored further using the donated sensors. However, the use of proprietary means of polling the sensors for their readings may lead to the TPMS to be removed from the system entirely.

3 Design of Major Components/Subsystems

3.1 Central Data Acquisition Unit

The central DAQ unit is the core of the project. It includes every part mounted to the vehicle and performs all of the tasks outlined in the requirements specification. Subsystems include the power system, the main MCU, a display, a storage device, a wireless transceiver, and all the sensors and associated controllers.

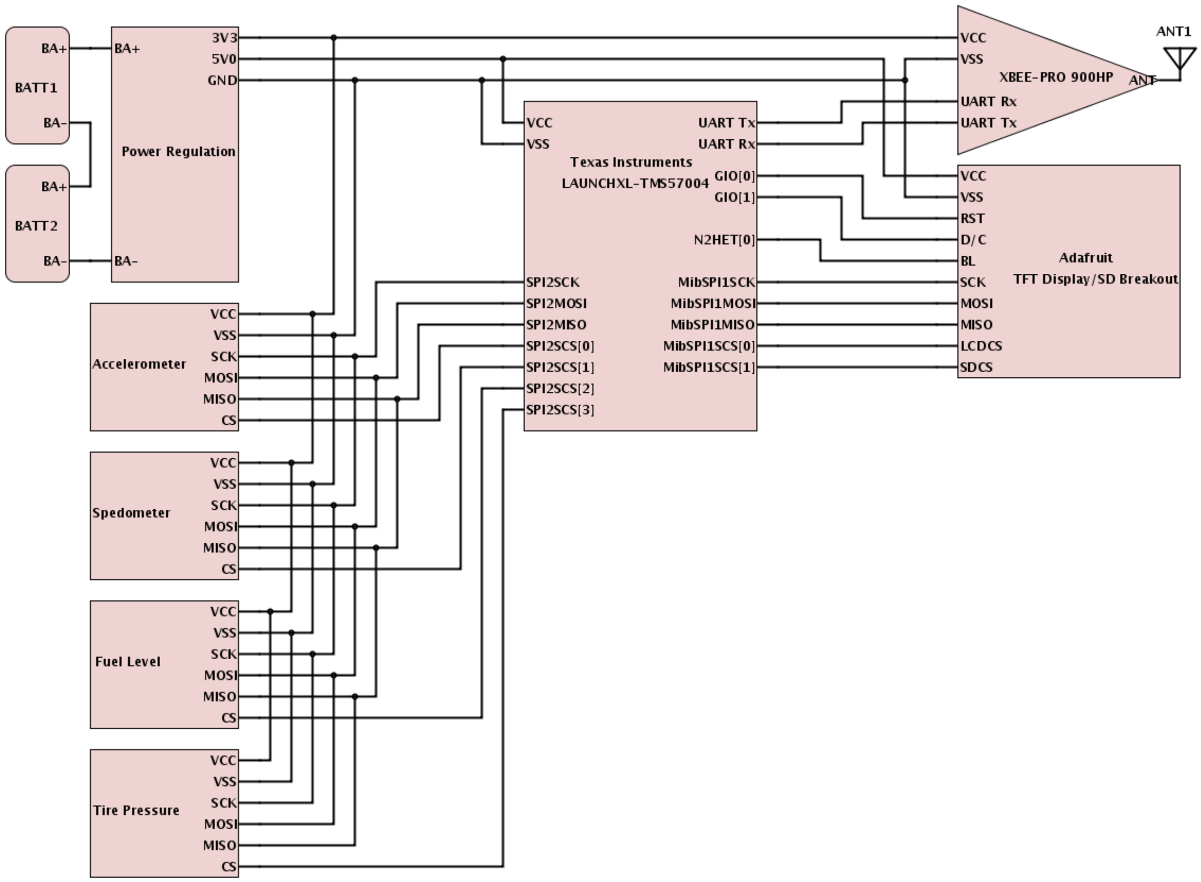


Figure 3.1a: Pin-level diagram of the on-vehicle system

Figure 3.1a, above shows all pin connections between components in the central DAQ system. Each component is expanded upon later in this section.

3.1.1 Main Microcontroller

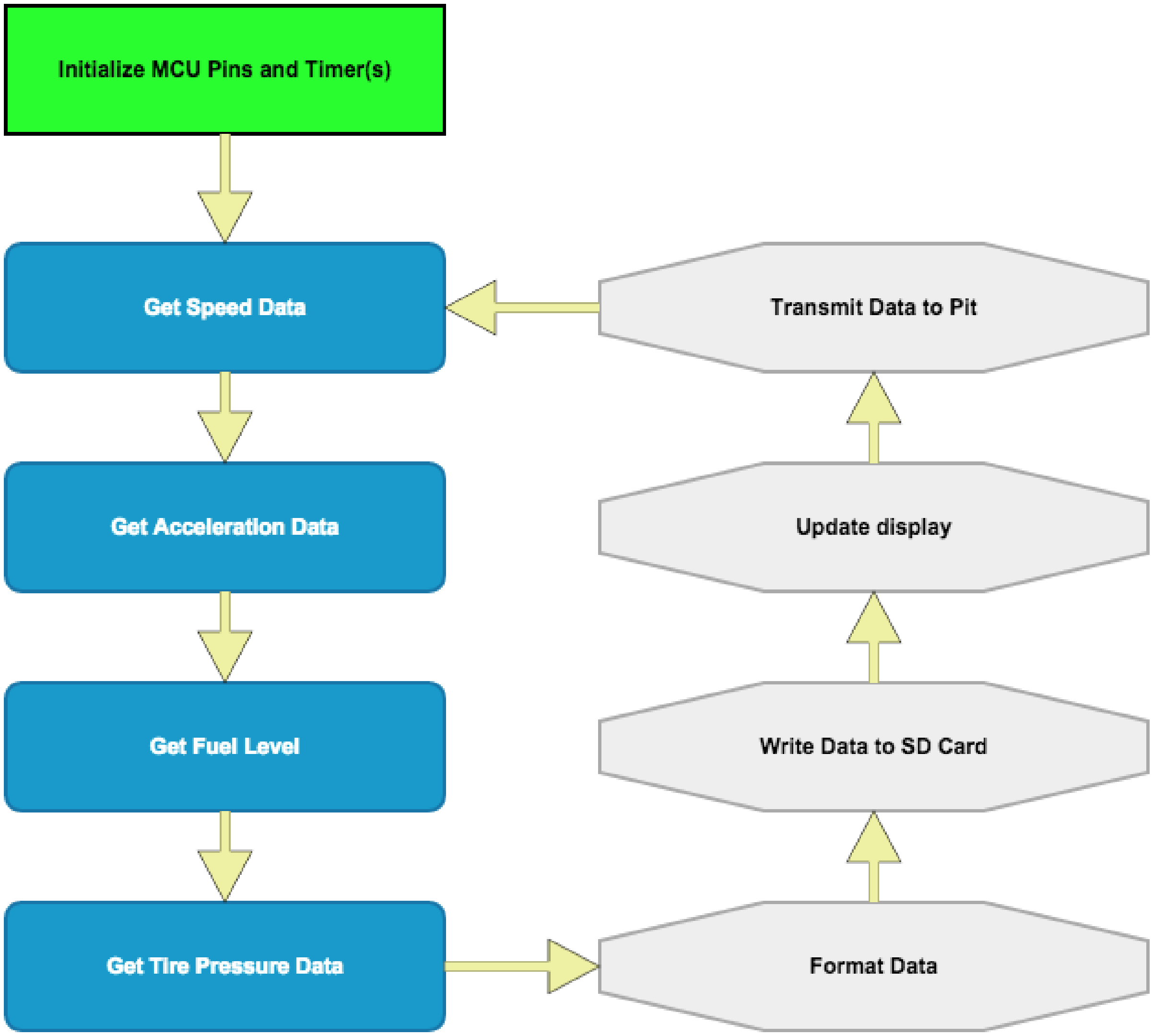


Figure 3.1b: Control flow for the main on-vehicle microcontroller

The microcontroller will serve as the central intelligence to the data collection, and well execute the control flow shown in **Figure 3.1b.** Information from the sensor bus will be sent into the MCU to be organized and stored into log file. Several criteria were considered when choosing the development board that will be used as the MCU.

Table 3.1a: Criteria used to decide which microcontroller to use for the central vehicle MCU

Criteria	**Justification**
Flash memory size	The MCU flash memory size must be large enough to accommodate software written for the DAQ
GPIO pin count	A larger amount of GPIO pins will ensure that there will be enough pins for the sensors and future project expansion.

SPI support	After deciding to use SPI for data communication, choosing an MCU with built in SPI support would shorten and simplify development.
Clock speed	The MCU should be able to collect data in real time. Higher clock speed means less time is spent performing calculations and more time can be spent collecting data.
Price	The limited project budget was considered
Power Consumption	The system will be running off a limited battery supply. Power consumption from the MCU must be kept to a minimum.

There were four development boards considered for use as the central MCU. Of those four, two had features that better suited the needs of the main MCU. These two were the Intel Galileo and the Hercules LAUNCHXL-TMS57004 from Texas Instruments. The Intel Galileo was rejected due to the high cost ($65.25) and the Hercules was chosen because of its automotive and safety focus.

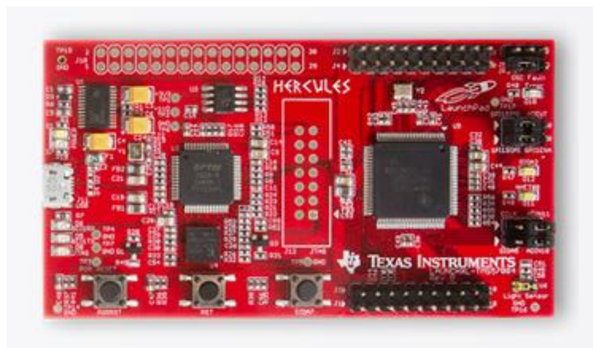


Figure 3.1c: Hercules LaunchPad

The LAUNCHXL-TMS57004 hosts a TI Hercules TMS570LS0432 MCU utilizing the ARM Cortex-R4 architecture and a 32 bit word length. It features dual CPUs in lock-step with error correction on CPU outputs and onboard memory, and can notify the system of errors via a dedicated error state pin. One of the most useful features of this MCU is Multi-Buffer SPI (MibSPI) which stores up to 128 words of queued data to be sent or received while the MCU executes other instructions. Multi-Buffer SPI also includes features such as transfer groups (which can be sent from or received to via interrupts), and interrupt outputs which correspond to successful sends/receives or transmission errors.

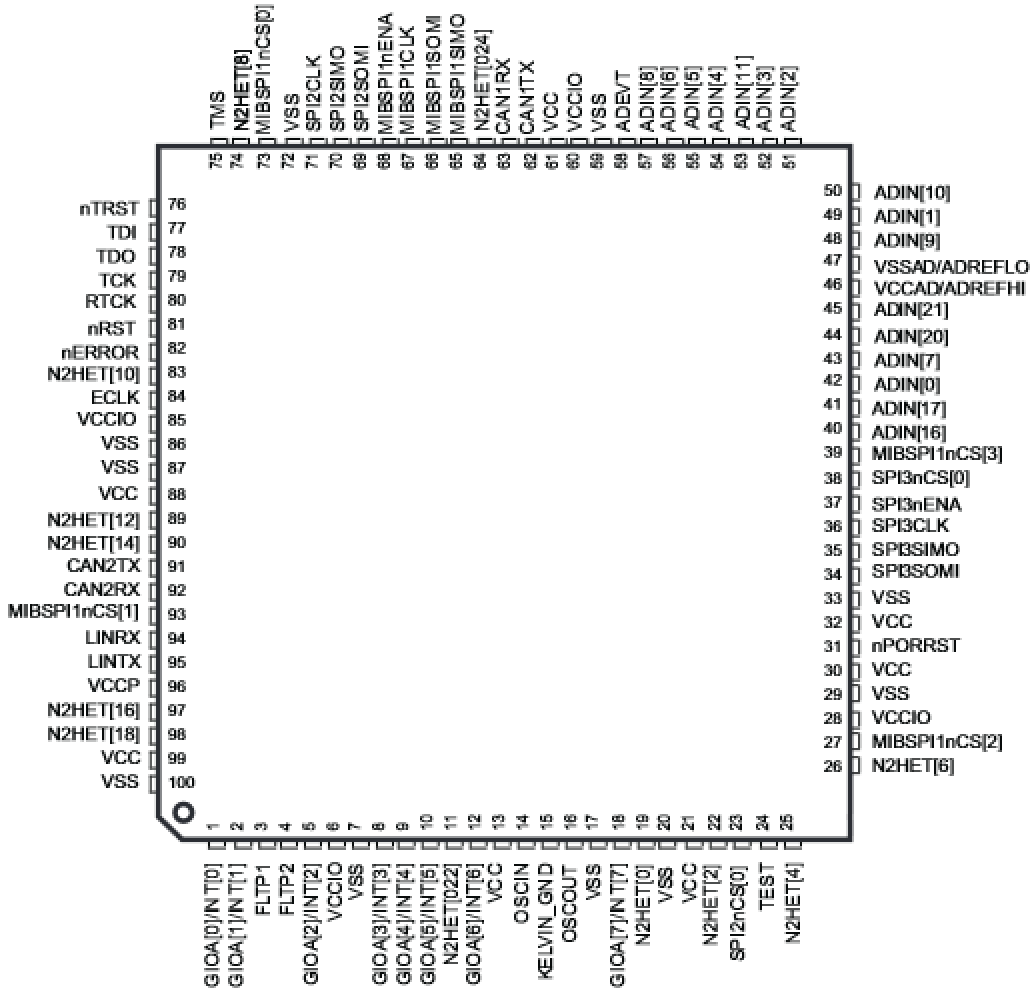


Figure 3.1d: Pin layout of the TMS570LS0432 microcontroller

Table 3.1b: Multiplexed pin assignments and control registers for the TMS570LS0432 microcontroller

100PZ Pin	Default Function	Control 1	Option2	Control 2	Option 3	Control 3
1	GIOA[0]	PINMMR0[8]	SPI3nCS[3]	PINMMR0[9]	-	-
2	GIOA[1]	PINMMR1[0]	SPI3nCS[2]	PINMMR1[1]	-	-
5	GIOA[2]	PINMMR1[8]	SPI3nCS[1]	PINMMR1[9]	-	-
8	GIOA[3]	PINMMR1[16]	SPI2nCS[3]	PINMMR1[17]	-	-
9	GIOA[4]	PINMMR1[24]	SPI2nCS[2]	PINMMR1[25]	-	-
10	GIOA[5]	PINMMR2[0]	EXTCLKIN	PINMMR2[1]	-	-
12	GIOA[6]	PINMMR2[8]	SPI2nCS[1]	PINMMR2[9]	N2HET[31]	PINMMR2[10]
18	GIOA[7]	PINMMR2[16]	N2HET[29]	PINMMR2[17]	-	-
93	MIBSPI1nCS[1]	PINMMR6[8]	EQEPS	PINMMR6[9]	N2HET[17]	PINMMR6[10]
27	MIBSPI1nCS[2]	PINMMR3[0]	N2HET[20]	PINMMR3[1]	N2HET[19]	PINMMR3[2]
39	MIBSPI1nCS[3]	PINMMR4[8]	N2HET[26]	PINMMR4[9]	-	-
68	MIBSPI1nENA	PINMMR5[8]	N2HET[23]	PINMMR5[9]	N2HET[30]	PINMMR5[10]
36	SPI3CLK	PINMMR3[16]	EQEPA	PINMMR3[17]	-	-
38	SPI3nCS[0]	PINMMR4[0]	EQEPI	PINMMR4[1]	-	-
37	SPI3nENA	PINMMR3[24]	EQEPB	PINMMR3[25]	-	-
58	ADEVT	PINMMR4[16]	N2HET[28]	PINMMR4[17]	-	-

Many needed pins such as all MibSPI pins and a number of timer and GPIO pins are already broken out on the standard 40-pin Launchpad headers, but the optional 60pin header will need to be installed in order to access the secondary SPI pins (which are also multiplexed on-chip and will require some configuration to enable).

3.1.2 Sensor Network

The sensors, each driven by their own discrete microcontroller, collect data about the vehicle and transmit that data over via a bus to the main microcontroller. Each sensor requires its own power, and each has its own required input voltage. While each analog sensor may have a different number of analog outputs, **Figure 3.1e** shows a general pin-level diagram of the connections for each sensor module that applies to all of the analog-output sensors. The sensor network will be broken down in detail in this section.

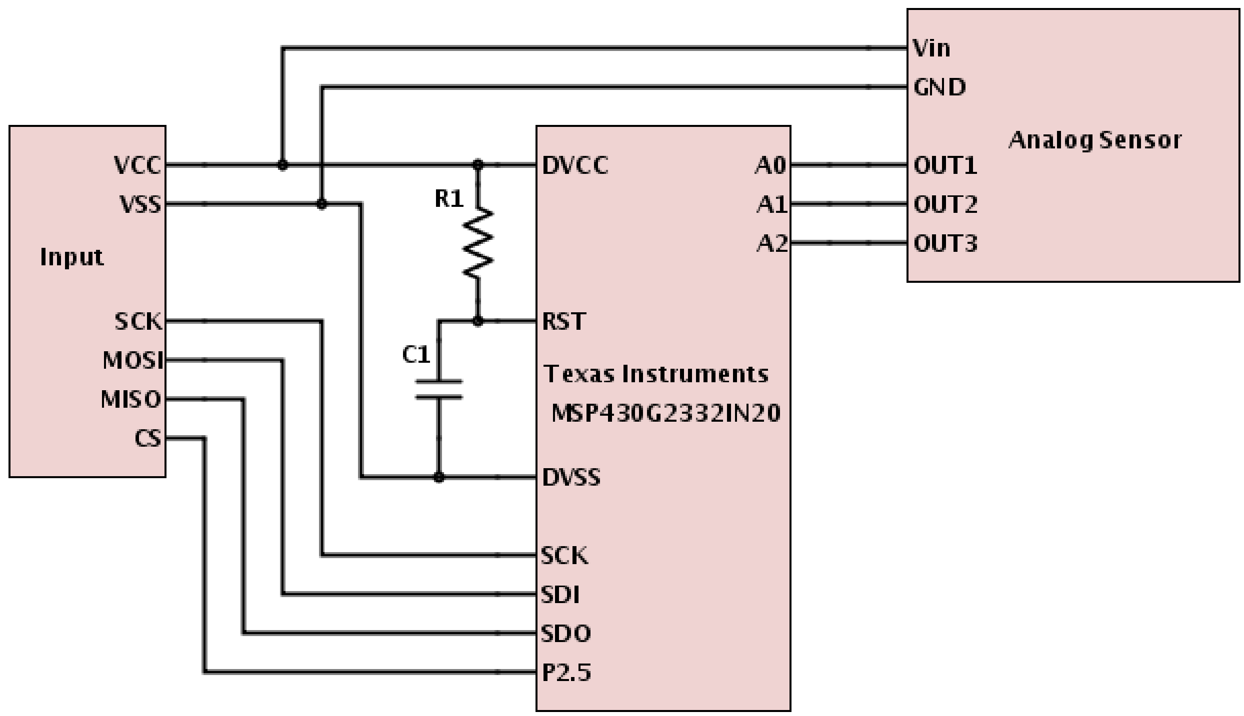


Figure 3.1e: Generalized pin-level diagram of the sensor modules

3.1.2.1 Data Transmission Bus

The data transmission bus is used to move data around the vehicle, and primarily allows the main MCU to retrieve and collect data from each sensor. The same bus type may also be used to display and record the sensor data.

Table 3.1 c: Criteria used to decide which data transmission bus to use

Criteria	**Justification**
Simple Frame Structure	A simple frame structure will simplify code and reduce unnecessary data being transmitted on the bus.
Low Pin Requirement	Conserving pins on the main MCU will allow future developers to add more to the system at a later time.
Onboard Hardware	Hardware or hybrid implementations should be available on-chip and at a low cost. Because there are many devices on the bus, adding hardware can become very costly.

A number of different serial communications standards were considered, including I^2C and CANBus, but the team chose SPI due to its simplicity in slave selection and its full duplex operation. While I2C was a main contender, its use of an addressed frame was determined to be unnecessary and costly in both code and in data transmissions (SPI's higher pin requirement was decidedly less costly than the use of an addressed frame). Additionally, CANBus requires external hardware and is very feature-heavy and could not be fully or efficiently utilized by the current system. 4-wire SPI is also supported natively in SD cards which greatly simplifies data storage.

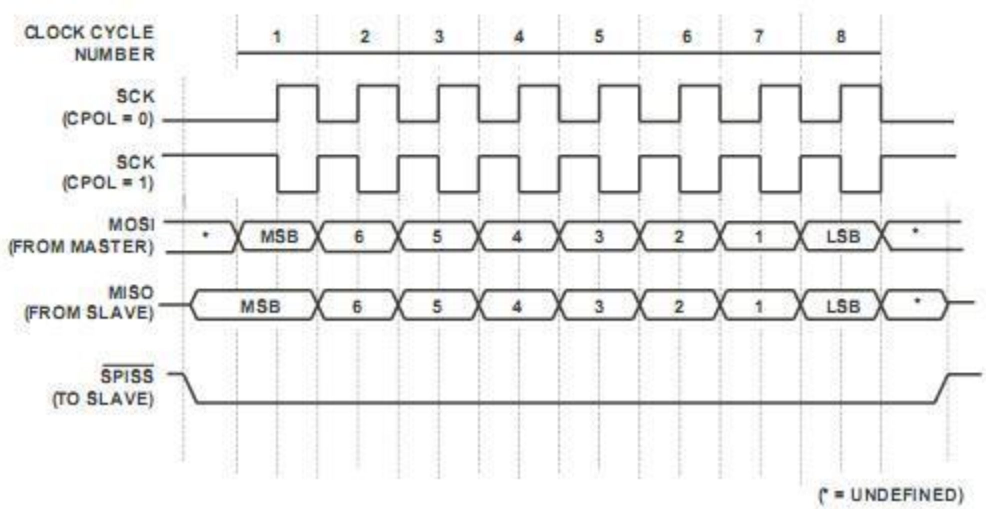


Figure 3.1f: SPI timing diagram

3.1.2.2 Sensor Microcontrollers

In deciding how to deal with the sensor outputs, the design team decided on using a data bus to reduce the number of pins used on the main microcontroller. In order to accomplish this, the analog outputs of the sensors must first be converted to their respective digital representations. For this reason, the design team decided to connect each sensor to its own discrete microcontroller, which will convert their analog outputs to digital representations, change those digital representations into the desired units, and transmit the data to the main microcontroller. In choosing this design paradigm, some of the calculations that would have been done by the main microcontroller can be offloaded onto the sensor microcontrollers.

When deciding on which microcontroller to use for this purpose, the design team was looking for a controller that was low-cost, through-hole mounted, had a minimal number of pins, and had enough flash memory to achieve the task for which it will be used.

Table 3.1d: Criteria used to decide which sensor microcontroller to use for the sensor modules

Criteria	**Justification**
Low-cost	Since there will be several of these microcontrollers, their cost should be kept as low as possible.
Through-hole Mounting	Through-hole mounting was preferred to make the milling of the PCBs in-house as easy as possible, reducing the risk of having to outsource custom PCB milling (see **6.4.2**)
Minimal Pin Count	Minimal pin count was desired again to make the milling of the PCBs in-house as easy as possible, as well as to avoid wasted features.
Flash Memory	The team wanted to be sure that the microcontroller selected had enough flash memory to hold the code that it would be programmed with to avoid wasting money.

Table 3.1e below lists the microcontrollers compared and some of their key features. Ultimately, the team decided to use the MSP430G2332 due to its small number of pins, adequate amount of flash memory, and its reasonable price. Ultimately the ATtiny85 would have been a good option, but its USI module is more software heavy than TI's and mixing MCU types would mean software would have to be developed in 2 separate IDEs.

In choosing this design paradigm, the team will have printed circuit boards milled for each sensor and MCU. There is some risk involved in this, outlined in **Section 6.4.2** of this document.

Table 3.1e: Comparison of potential sensor microcontrollers

	Atmel ATtiny85	**TI MSP430F5132**	**TI MSP430G2332IN20**
Word Length	8-bit	16-bit	16-bit
Operating Frequency	20 MHz	25 MHz	16 MHz
# of pins	8	40	20
Flash Memory	8 KB	8 KB	4 KB
Cost	$0.73/unit	$3.35/unit	$1.86/unit

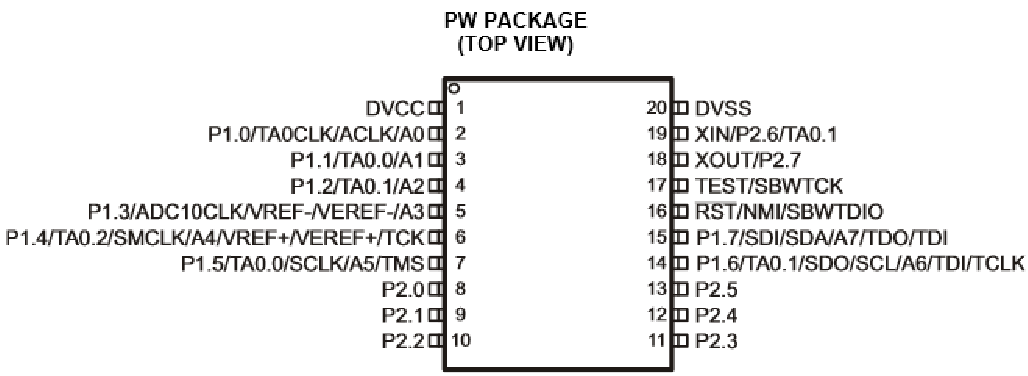


Figure 3.1g: Pin layout of the MSP430G2332 microcontroller

3.1.2.3 Accelerometer Module

The accelerometer module is to measure (most importantly) the linear acceleration of the vehicle, allowing the Baja team to tune the vehicle to their liking for the specific terrain/event. If the Baja team desires, the accelerometer module could also be used to measure low-frequency vibrations (up to 50 Hz). The accelerometer module will execute the control flow shown in **Figure.** When looking for an accelerometer, the design team considered the characteristics outlined in **table.**

Table 3.1f: Criteria used to decide which accelerometer to use for the accelerometer module

Criteria	**Justification**
Mounting Style	Through-hole mounting was preferred. As with the other PCB-mounted components, using surface mount components was not viable for the in-house PCB milling. See **6.4.2** for associated risks.
Bandwidth	The bandwidth determines how often an accurate acceleration measurement can be taken. The bandwidth should be high enough such that the acceleration can be accurately represented without being
Sensitivity	The sensitivity of an accelerometer determines range of accurate acceleration measurement. Given that the vehicle will likely not reach anywhere near 1g, accelerometers with excessively high sensitivities were ignored, as they are generally more expensive with less sensitive accelerometers.
Cost	Accelerometers can be very expensive and have a wide range of price points. Given the fairly slim budget of the project, the chosen accelerometer was fairly low-cost.

The accelerometer, along with most of the other sensors used in the system, will be connected to discrete MSP430G2332 microcontrollers. Each sensor microcontroller will execute the control flow found below in **figure**. The ADXL335 accelerometer will output three analog signals, one for each axis. These analog outputs will be read by the MCU's ADC and stored for calculation and conversion. The acceleration values will then be sent to the main microcontroller, where it will be written to the log file and sent to the pit unit for display. An option will also be available for the linear acceleration to be displayed on the on-vehicle display, that way the Baja team can measure the vehicle's linear acceleration without having the pit unit present, allowing them to tune the vehicle to maximize acceleration for that portion of the competition. The two accelerometers considered are outlined in **Table.**

Table 3.1g: Comparison of potential acceleromets

	ADXL335	MMA7455
Sensitivity	3g	2g/4g/8g/10g
Bandwidth	Up to 600 Hz (50 Hz default)	125 Hz
Mounting	Through-hole (pin headers need to be soldered on)	Through-hole
Cost	$14.95	$29.99

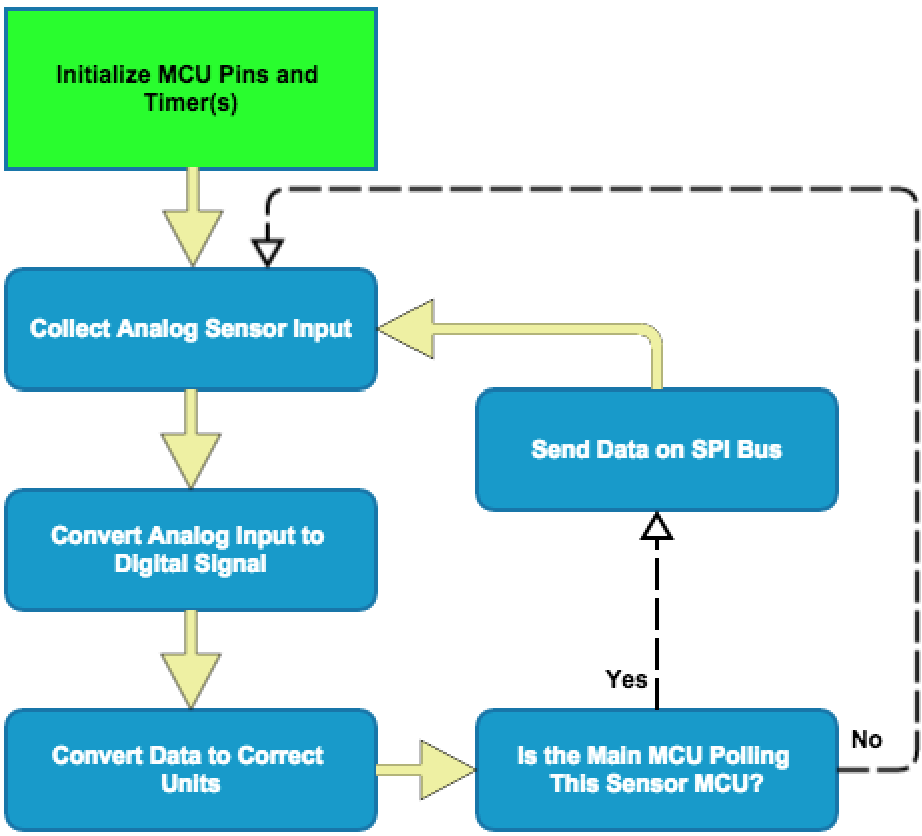


Figure 3.1h: Control flow of the accelerometer module

3.1.2.4 Hall Effect Sensor Module

Hall effect sensors increase their voltage output in the presence of a magnetic field. The Hall effect sensor will be used to measure the speed of the vehicle by affixing a permanent magnet to the drivetrain of the vehicle, and using the sensor to read when the magnet passes by a certain point. The Hall effect sensor MCU will execute the control flow found below in **Figure 3.1i**.

Once calculated, the speed of the vehicle will be displayed on the on-vehicle display. A preliminary layout of the on-vehicle display can be found in **Figure 2.1c**.

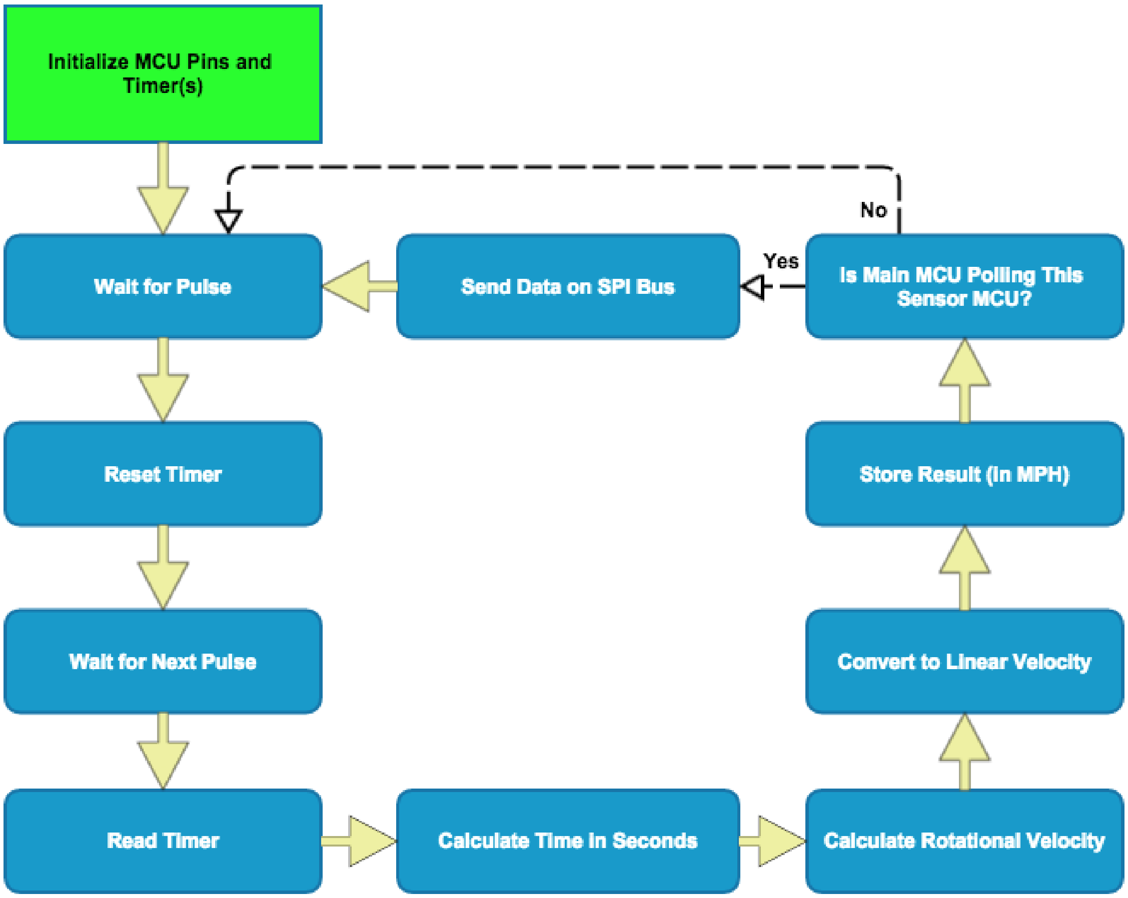


Figure 3.1i: Control flow executed by the Hall effect sensor microcontroller

When considering different Hall effect sensors, the design team considered different sensors based on the criteria outlined in **Table 3.1h** below.

Table 3.1h: Criteria used to decide which Hall effect sensor to use

Criteria	Justification
Through-hole or Frame Mounting	Like the other sensors and sensor MCUs considered, through-hole mounting was desired in order to simplify the milling of custom PCBs due to the risk outlined in **6.4.2**
Analog Output	Some components that are called "Hall effect sensors" are actually switches, which are switched "on" with the presence of a magnetic field, and switched "off" again when the presence of a magnetic field is detected again. The design team desired a Hall effect sensor that output an analog voltage whenever a magnetic field was detected.

Cost	Hall effect sensors can be very expensive depending on how robust (durable) they are as well as the type of output they produce. Industrial Hall effect sensors can cost up to $40/unit.

3.1.2.5 Fuel Level Sensor Module

The fuel level sensor module will measure the amount of fuel remaining in the vehicle. This information will be sent to the main MCU, where it will be displayed on the vehicle's display similar to the prototyped display layout shown in **Figure 2.1c**. The fuel level sensor MCU will execute the control flow outlined in **Figure 3.1h.** Fuel level sensors vary in layout, price, and documentation. When considering which fuel level sender to choose, the design team considered the criteria outlined in **Table 3.1i.**

Table 3.1i: Criteria used to decide which fuel level sensor to use

Criteria	**Justification**
Documentation	It was important in choosing a fuel level sensor that the particular chosen sensor was well-documented. Without knowing the full and empty resistances, the sensor is essentially useless. Having a well-documented sensor will decrease development time.
Length	The Baja vehicle has a fairly small gas tank (exact measurements have not been taken yet), so a somewhat compact fuel level sensor was needed to produce the correct fit for accurate fuel level measurement.
Connections	Some fuel level sensors, namely those designed for specific automobiles, come with wiring harnesses that fit factory connections for plug and play operation. The design team was looking for a sensor that had loose wires so that it could be easily connected to the MCU PCB.

When deciding on which sensor to use, the design team originally decided on one of two cheap arm-operated fuel level sensors, which had little to no documentation associated with them. Upon further research, the team decided to use the WEMAUSA SSS/SSL Liquid Level Sensor, which has no vehicle-specific wiring harness and uses a standard SAE 5-hole pattern for mounting. The SSS/SSL sensors are also well documented, with the resistance range being given on the product page. Additionally, the sensors come in lengths of 4" to 18.5", allowing the design team to purchase a sensor of optimal length for accurate fuel measurement. **Table 3.1j** below outlines a comparison between the three sensors considered.

Table 3.1j: Comparison of potential fuel level sensors

	Dorman 911-008	Marshin	WEMA SSS/SSL
Documentation?	No	No	Yes
Wiring harness	Yes	Yes	No
Setup	Lever arm	Lever arm	Magnet float
Cost	$22.20	$9.99	$40.00

Despite its high cost, the WEMA fuel level sensor will be used, as it is high quality, guaranteed to fit in the tank, and well documented. Since inefficient refueling was one of the largest controllable issues with the team's success in previous years, it is worth the extra cost to obtain a high-quality sensor that will be easy to use.

3.1.2.6 Tire Pressure Monitoring System

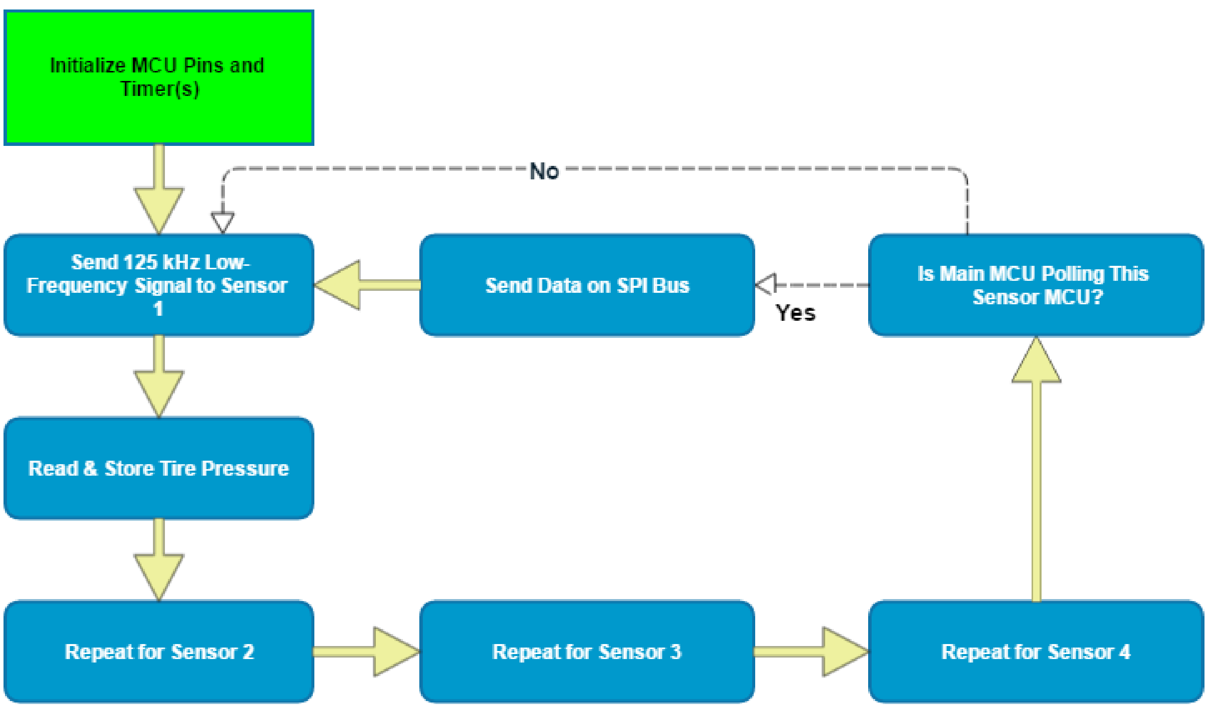


Figure 3.1j: Control flow executed by the tire pressure monitoring system microcontroller

When researching the TPMS for the vehicle, the design team found that there were no viable marketed sensors for ATV tires. Since automobile tires are inflated to around 35 PSI, the team thought that the sensors marketed for automobiles (which are fairly expensive, around $25 per sensor minimum) would not be sensitive enough to measure small pressure drops under 10 PSI, the pressure at which the Baja vehicle's tires are inflated. However, a technician at a Dodge/Chrysler/Jeep/RAM Dealership in South Florida tested a set of spare sensors and found that their readings at 6 PSI matched exactly that of a conventional dial tire gauge. Those sensors were ultimately donated to the team. The sensors, along with basically all other automobile TPMS sensors, are activated using proprietary methods. In order to implement the TPMS, which was originally tabled due to the research mentioned above, the design team will have to reach out to the manufacturers in hopes that they will give the team information regarding the activation of the sensors. If the information is not given by the manufacturers, the team will have to do an extensive amount of tinkering and reverse engineering in order to attempt to get the TMPS working properly. This subsystem may still be shelved for future iterations of the DAQ. See **6.4.1** for a detailed analysis of the design risk associated with this subsystem.

3.1.3 Power System

The DAQ system will need its own power source, as per competition rules. The DAQ's power system will consist of two Lithium Iron Phosphate batteries and a circuit to regulate the battery voltage to 3.3 V and 5 V outputs for use by the other subsystems. The block diagram in **Figure 2.1a** shows the voltages that each subsystem requires, and this system is also shown in the pin level diagram in **Figure 3.1a**.

When considering which battery technology to use, the team considered several factors to make the decision. Since the batteries are the most expensive components of the entire system, it was vital that the team considered all available options and made the right choice first time. The criteria used to evaluate battery technologies is outlined below in **Table 3.1k.**

Table 3.1k: Criteria used to evaluate potential battery technologies

Criteria	Justification
Safety	Some battery technologies are infamous for having catastrophic failures. For example, Lithium ion and Lithium polymer batteries are subject to explosion or fire if they are overcharged, overdrawn, or connected improperly. Lithium polymer batteries come in pouches, and as such are prone to crushing and puncture, which can lead to a catastrophic failure. Safety is of the utmost importance in the Baja competition. As such, safety factored heavily into the decision.
Price/Capacity	Batteries are very expensive. The batteries will be the most expensive components in the entire system. As such, the $USD/capacity also factored heavily into the decision.
Nominal cell voltage	Nominal cell voltage was a fairly important part of the decision. Some batteries had nominal cell voltages that were far too low or far too high to be viable for the voltage requirements of the components of the system.

The team considered several battery technologies for use in the on-vehicle system. Those technologies are outlined and compared below in **Table 3.1l**.

Table 3.1l: Comparison of the considered battery technologies

	Nickle-metal Hydride	Lithium Ion	Lithium Polymer	Lithium Iron Phosphate
Energy/$USD	2.74 Wh/$	2.5 Wh/$	2.5 Wh/$	Up to 3 Wh/$
Nominal Cell Voltage	1.2V	3V-4V	3.3V,3.7V	3.2V
Safety Concerns	Minimal	Can be dangerous	Can be dangerous	Minimal
Energy Density	140-300 Wh/L	250-720 Wh/L	150-730 Wh/L	220 Wh/L

The team ultimately decided to use Lithium Iron Phosphate batteries. They come in small form factors, provide a large capacity for a good price, and eliminate all of the safety concerns associated with Lithium ion and Lithium polymer batteries. While the size of the batteries has not been decided yet, a preliminary power analysis has been completed and can be found below in **Table 3.1m**.

Table 3.1m: Preliminary power analysis

Component	Active (mW)	Passive (mW)	% Active	# of Components	Average Power Draw
Hercules	445.45		100.00%	1	445.45
MSP430G2332IN20	13.86		100.00%	4	55.44
ADXL335 Accelerometer	1.122		100.00%	1	1.12
Xbee-PRO 900HP	709.5	0.00825	30.00%	1	212.86
Honeywell SS49E Hall effect sensor	19.8		100.00%	1	19.80
Adafruit LCD Display	340		100.00%	1	340.00
SD Card	330	33	30.00%	1	122.10
			Total Average Power Draw (W)		1.20

3.1.4 Wireless Communication

An RF transceiver pair will be used to create a wireless link between the pit unit and on-vehicle DAQ system. The on-vehicle MCU will send serial data to the transceiver and that data will be repeated on the other end by the paired module and displayed by the pit unit.

Figure 3.1k: XBee-PRO 900HP

The team chose to use the XBee-PRO 900HP due to its long range and low transmit power draw (as compared with its output power). This device operates in the 900 MHz band and offers both serial communication via UART and I/O pin mirroring capabilities. Models are available that offer mesh networking, or simple Point-Multipoint operation. The DAQ system will be using the point-multipoint model and communicating with the XBee via UART on both ends. The XBee can be seen in the pin level diagram in **Figure 3.1a**, which shows all necessary connections to the vehicle MCU.

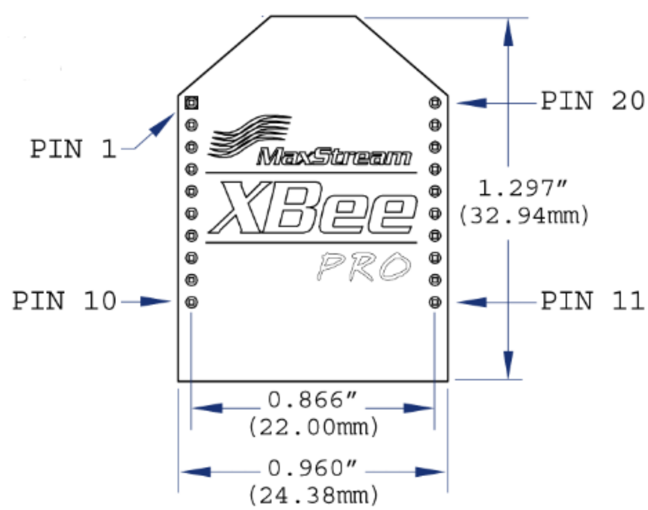


Figure 3.1l: XBee-PRO 900HP pin layout

Table 3.1n: Pin assignments for the XBee-PRO 900HP

Pin #	Name	Direction	Description
1	VCC	-	Power supply
2	DOUT	Output	UART Data Out
3	DIN / **CONFIG**	Input	UART Data In
4	DO8*	Output	Digital Output 8
5	**RESET**	Input	Module Reset (reset pulse must be at least 200 ns)
6	PWM0 / RSSI	Output	PWM Output 0 / RX Signal Strength Indicator
7	PWM1	Output	PWM Output 1
8	[reserved]	-	Do not connect
9	DTR / SLEEP_RQ / DI8	Input	Pin Sleep Control Line or Digital Input 8
10	GND	-	Ground
11	AD4 / DIO4	Either	Analog Input 4 or Digital I/O 4
12	**CTS** / DIO7	Either	Clear-to-Send Flow Control or Digital I/O 7
13	ON / **SLEEP**	Output	Module Status Indicator
14	VREF	Input	Voltage Reference for A/D Inputs
15	Associate / AD5 / DIO5	Either	Associated Indicator, Analog Input 5 or Digital I/O 5
16	**RTS** / AD6 / DIO6	Either	Request-to-Send Flow Control, Analog Input 6 or Digital I/O 6
17	AD3 / DIO3	Either	Analog Input 3 or Digital I/O 3
18	AD2 / DIO2	Either	Analog Input 2 or Digital I/O 2
19	AD1 / DIO1	Either	Analog Input 1 or Digital I/O 1
20	AD0 / DIO0	Either	Analog Input 0 or Digital I/O 0

3.1.5 Display/Storage

Once the main MCU collects and processes information from the sensors, the data is sent through a multi-buffer SPI bus (MibSPI) into a storage unit and an LCD display. An illustration is shown below.

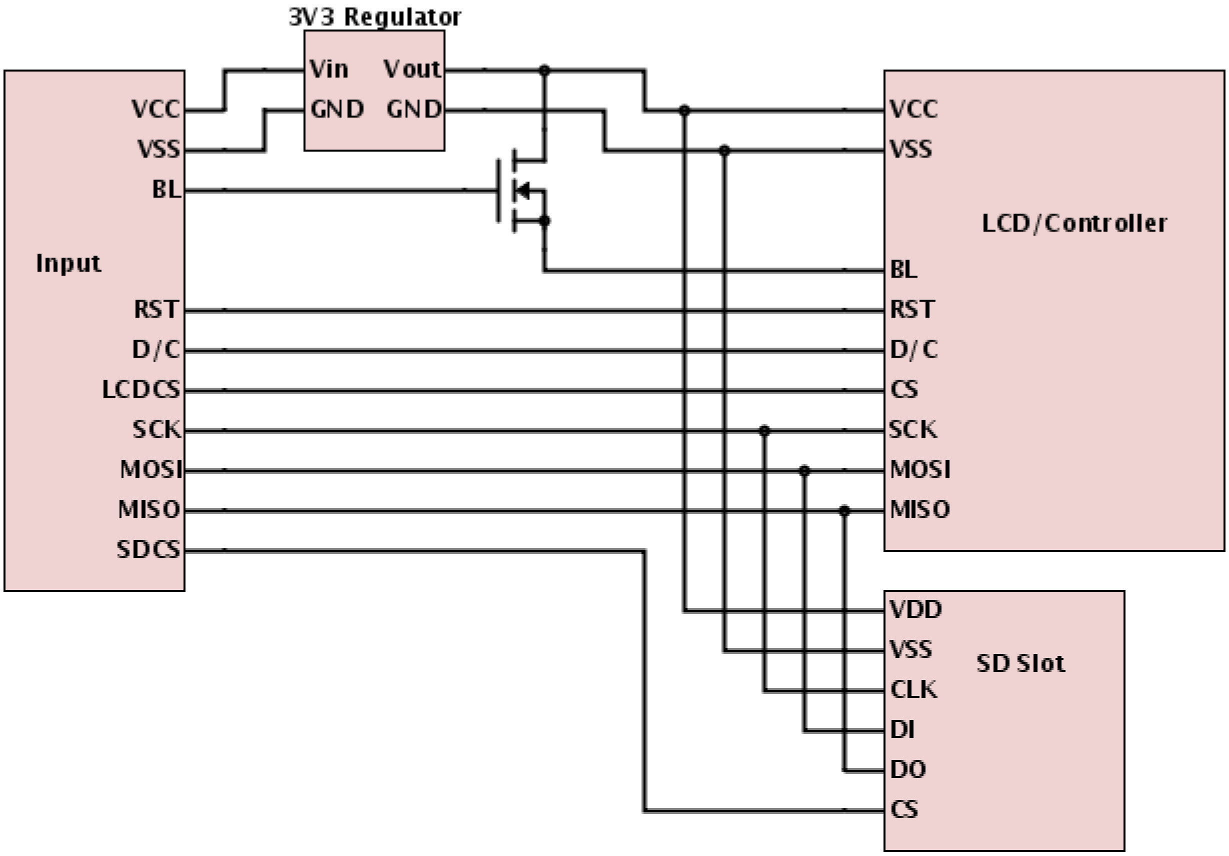


Figure 3.1m: Pin-level diagram of the display/storage module

3.1.5.1 Display

The display will be mounted onto the body in the direct line of vision of the driver and will read the speed and the fuel level from the main MCU. To meet the needs of this portion of the DAQ, the display will need to have the following characteristics.

- Portable
- LED Backlight
- Low-Priced
- SPI Compatible

The Adafruit TFT LCD 2.2" 18-bit color display and the TFT SPI 2.2" Serial LCD Module Display from Amazon were chosen for consideration. Both screens had the characteristics desired for the on-vehicle display so the deciding factor was the brand as well as the open-source libraries to make writing to the display easier.

The Adafruit LCD display was chosen because of its selection of libraries and examples on the manufacturer's website. This will save time integrating the display into the DAQ by allowing the team to immediately begin interfacing.

Figure 3.1n: Adafruit 2.2" SPI TFT LCD Display

3.1.5.2 Storage

Once data has been collected and processed by the MCU, the data will then be written to a storage medium to be used for offline reference. The two storage options considered for this block were USB Mass Storage and Secure Digital (SD).

The benefits and drawbacks of both had to be weighed considerably as they both are well suited to complete this task. Below is a summary of the features of both storage options as they apply to the DAQ storage needs.

Table 3.1o: Criteria used to evaluate potential storage methods

Criteria	USB Mass Storage	SD
Compatibility	Can be used on any modern machine	Many computers do not have built in SD card readers
Portability	Flash drives portable. Longer flash drives can break under stress	Small and portable. Can be easily lost or broken.
Implementation	Requires a host controller	Built in SPI capability

As seen above, one of the downsides to using USB Mass Storage is that host controller is required to communicate between the MCU and the USB device. This could be costly in finances as well as extra development time and complexity. SD supports SPI natively which is also found in hardware on the MCU, greatly easing the hardware development and design.

It is also worth noting the LCD display chosen comes with a built in SD card slot which will save the team some time in development by reducing hardware components, and allowing both the SD card and LCD display to be accessed on one SPI bus using the chip select line on the display.

3.1.6 Central MCU Housing

The center of the on-vehicle system will be housed in a Plano Molding polycarbonate waterproof case. These cases are reasonably priced at $30 and the clamps and waterproof seal will hold up to the harsh operating environment outlined in **Section 1.3**. The housing for the sensor modules has yet to be determined, although smaller versions of this box are being considered as well as custom-made enclosures or generic project boxes. The method for attaching the housings to the vehicle is also to be determined, pending discussion with the SAE Baja team.

When choosing a project box, cost and size were the main factors. Many of the boxes large enough to accommodate the system (at least 10" long and 4" deep) were very expensive, and many boxes in the same price range as the Plano box were far too small. The box will be altered to allow for secure mounting to the vehicle as well as the connection of wires from the DAQ subsystems.

3.2 Pit Unit

The pit unit will be run with a Raspberry Pi B+. It will receive transmissions from the main MCU either constantly or whenever the vehicle is in range (see design risk **6.4.2**). The pit unit will run a GUI application that displays all of the pertinent data about the vehicle, which will be received via wireless transmission between the XBee-PRO 900HP modules.

This unit will serve as a supplement to the onboard vehicle data acquisition. As there is minimal design involved, the parts chosen for this module were more straightforward.

3.2.1 CPU

During competition there will be a CPU located in the pit crew station that will receive data wirelessly from the main MCU on the vehicle. This CPU will take the form of a SoC based single board computer to simplify the display of collected data.

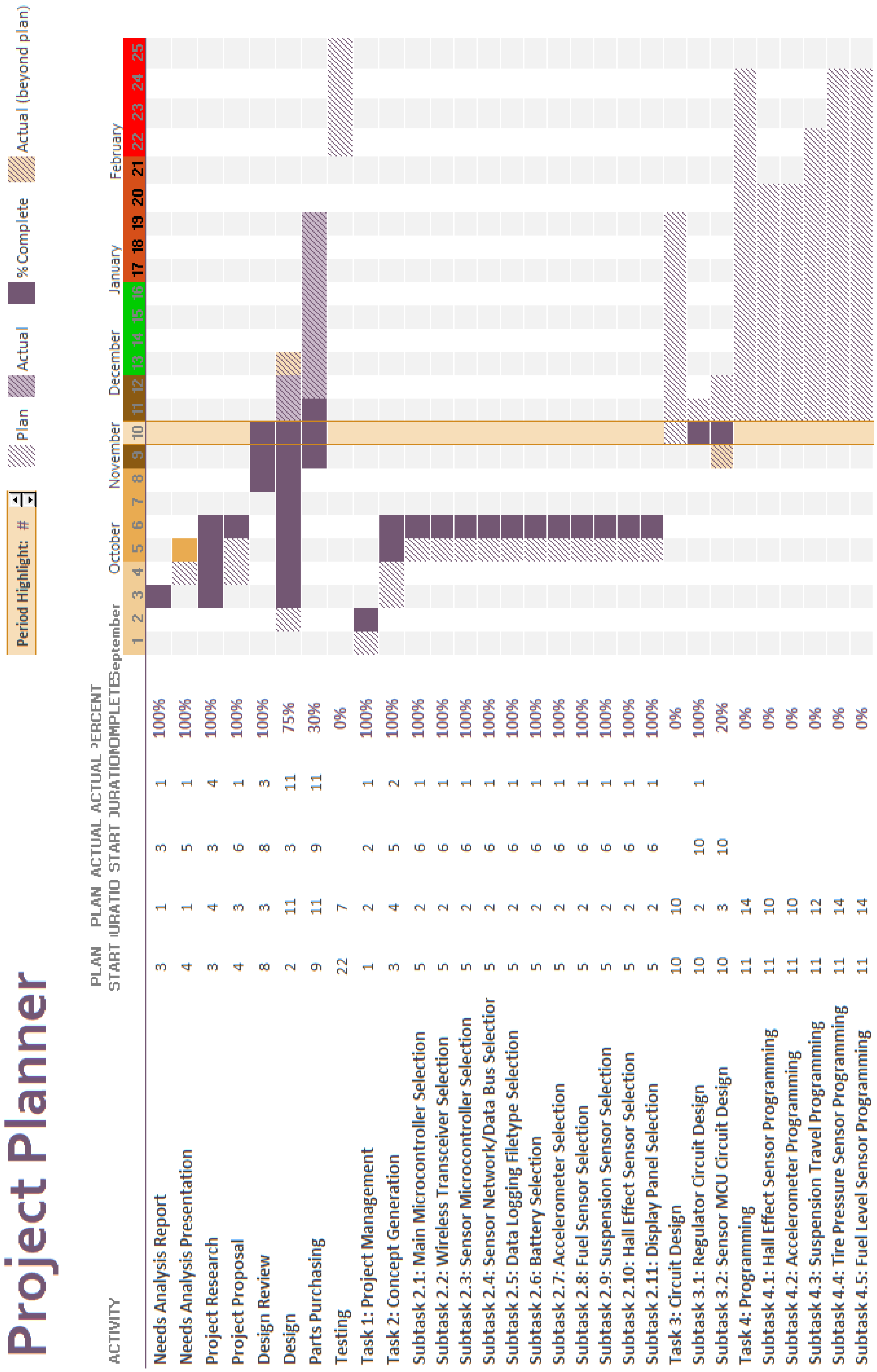
The decision to use the Raspberry Pi B+ as the pit crew CPU was made when comparing development boards for the main CPU. The features were impressive but with its optimization for graphic applications, the Raspberry Pi was not a match for what was needed as the DAQ main MCU. Since the pit crew module relies heavily on the display of data to the sideline team members, it was determined that the Raspberry Pi was better suited for this module.

3.2.2 Display

The pit crew will have a display that will output data from the receiving end of the XBee. During competition, teams are assigned an area on the spot that will serve as their pit crew station. Due to this instability, the display will need to be lightweight and energy efficient for portability.

The display will be connected to the CPU by a standard RCA audio/video cable for quick implementation.

4 Schedule



ACTIVITY	PLAN START	PLAN DURATION	ACTUAL START	ACTUAL DURATION	PERCENT COMPLETE
Needs Analysis Report	3	1	3	1	100%
Needs Analysis Presentation	4	1	5	1	100%
Project Research	3	4	3	4	100%
Project Proposal	4	3	6	1	100%
Design Review	8	3	8	3	100%
Design	2	11	3	11	75%
Parts Purchasing	9	11	9	11	30%
Testing	22	7			0%
Task 1: Project Management	1	2	2	1	100%
Task 2: Concept Generation	3	4	5	2	100%
Subtask 2.1: Main Microcontroller Selection	5	2	6	1	100%
Subtask 2.2: Wireless Transceiver Selection	5	2	6	1	100%
Subtask 2.3: Sensor Microcontroller Selection	5	2	6	1	100%
Subtask 2.4: Sensor Network/Data Bus Selection	5	2	6	1	100%
Subtask 2.5: Data Logging Filetype Selection	5	2	6	1	100%
Subtask 2.6: Battery Selection	5	2	6	1	100%
Subtask 2.7: Accelerometer Selection	5	2	6	1	100%
Subtask 2.8: Fuel Sensor Selection	5	2	6	1	100%
Subtask 2.9: Suspension Sensor Selection	5	2	6	1	100%
Subtask 2.10: Hall Effect Sensor Selection	5	2	6	1	100%
Subtask 2.11: Display Panel Selection	5	2	6	1	100%
Task 3: Circuit Design	10	10			0%
Subtask 3.1: Regulator Circuit Design	10	2	10	1	100%
Subtask 3.2: Sensor MCU Circuit Design	10	3	10		20%
Task 4: Programming	11	14			0%
Subtask 4.1: Hall Effect Sensor Programming	11	10			0%
Subtask 4.2: Accelerometer Programming	11	10			0%
Subtask 4.3: Suspension Travel Programming	11	12			0%
Subtask 4.4: Tire Pressure Sensor Programming	11	14			0%
Subtask 4.5: Fuel Level Sensor Programming	11	14			0%

5 Budget Estimate

A preliminary budget analysis was completed in the Project Proposal and Statement of Work, which is found in **Table 5a**. An updated budget analysis is found in **Table 5b**.

Table 5a: Preliminary budget analysis from the Project Proposal and Statement of Work

A. Personnel					
Engineer		**Billable Hours**		**Base Pay**	**Total Pay**
Tyler Dudley		384		$30	$11,450.00
Hebe Perez		384		$30	$11,450.00
Christopher Riker		384		$30	$11,450.00
Dewey Williams		384		$30	$11,450.00
				Personnel Subtotal	**$46,080.00**
B. Fringe Benefits				29%	**$13,363.20**
C. Total Personnel					**$59,443.20**
D. Expense	**PN/Description**	**Distributor**	**Qty**	**Per Unit**	**Total Price**
Hercules MCU	LAUNCHXL-TMS57004	Texas Instruments	1	$19.99	$19.99
Sensor MCUs	MSP430G2332IN20	digikey	10	$1.86	$18.60
SD BoosterPack	SD Launchpad BoosterPack	43oh	1	$9.99	$9.99
Accelerometer	ADXL335	sparkfun	1	$14.95	$14.95
Fuel Sender	Dorman 911-008	CAE_Services	1	$25.00	$25.00
XBee-PRO 900HP	XBP9B-DMST-002	Parallax	2	$39.00	$78.00
LiFePO4 Battery	LiFePO4 Battery Packs	All-battery.com	2	$40.99	$81.98
Battery charger	LiFePO4 Charger	Batteryspace	1	$19.95	$19.95
Magnets (x30)	Bundle	Amazon.com	1	$6.88	$6.88
Hall effect sensor	US1881	Amazon.com	1	$4.49	$4.49
Blank PCB	5.9in x 5.9in	Jameco	3	$3.95	$11.85
LCD Display Module	2.2" Serial TFT SPI LCD	TBD	1	$10	$10.00
Pit Computer	Raspberry Pi (B)	Allied Electronics	1	$35	$35
				Extra Parts	$50
				Shipping	$150
				Expenses Subtotal	**$536.68**
E. Total Direct Costs				Total Personnel + Expenses	**$59,979.88**
F. Overhead Costs				45% of Total Direct Costs	**$26,990.95**
G. Total OCO					**$86,970.83**

Table 5b: Up-to-date budget analysis

A. Personnel					
A. Personnel					
Engineer		Billable Hours		**Base Pay**	**Total Pay**
Tyler Dudley		384		$30	$11,450.00
Hebe Perez		384		$30	$11,450.00
Christopher Riker		384		$30	$11,450.00
Dewey Williams		384		$30	$11,450.00
				Personnel Subtotal	**$46,080.00**
B. Fringe Benefits				29%	**$13,363.20**
C. Total Personnel					**$59,443.20**
D. Expense	**PN/Description**	**Distributor**	**Qty**	**Per Unit**	**Total Price**
Hercules MCU	LAUNCHXL-TMS57004	TI	1	$19.99	$19.99
Sensor MCUs	MSP430G2332IN20	Mouser	10	$1.86	$18.60
Accelerometer	ADXL335	SparkFun	1	$14.95	$14.95
Fuel Sensor	WEMA SSS/SSL	WEMA USA	1	$40.00	$40.00
XBee-PRO 900HP	XBP9B-DMST-002	Digi	2	$39.00	$78.00
LiFePO4 Battery	LiFePO4 Battery Packs	All-battery.com	2	$26.99	$53.98
Battery charger	LiFePO4 Charger	Batteryspace	1	$19.95	$19.95
Magnets (x30)	Bundle	Amazon.com	1	$6.88	$6.88
Hall effect sensor (x5)	US1881	Amazon.com	1	$4.49	$4.49
Blank PCB	5.9in x 5.9in	Jameco	3	$3.95	$11.85
Adafruit LCD Display	2.2" Serial TFT SPI LCD w/ SD Breakout	Adafruit	1	$24.95	$24.95
Pit Computer	Raspberry Pi (B+)	SparkFun	1	$39.95	$39.95
5V Voltage Regulator	ROHM 5V LDO Voltage Regulator	Mouser	2	$1.76	$3.52
3.3V Voltage Regulator	ROHM 3.3V LDO Voltage Regulator	Mouser	2	$2.17	$4.34
20-DIP Socket	3M 20 pin DIP socket	Mouser	8	$0.42	$3.36
Micro SD Card	SanDisk 8GB Micro SD Card	Amazon.com	2	$6.55	$13.10
Headers - 2.54mm		SparkFun	3	$1.50	$4.50
10-pin Headers- 2mm		SparkFun	4	$1.00	$4.00
XBee Explorer USB	WRL-11812 ROHS	SparkFun	1	$24.95	$24.95
XBee Breakout Board	BOB-08276 ROHS	SparkFun	2	$2.95	$5.90
On-Vehicle MCU Enclosure	Plano 146000 Waterproof Case	Plano	1	$21.60	$21.60
MSP430 Dev Kit	MSP-EXP430G2	TI	1	$9.99	$9.99
				Extra Parts	$50
				Shipping	$150
				Expenses Subtotal	**$628.85**
E. Total Direct Costs				Total Personnel + Expenses	**$60,057.05**
F. Overhead Costs				45% of Total Direct Costs	**$27,025.67**
G. Total OCO					**$87,082.72**

6 Overall Risk Assessment

6.1 Financial Risks

6.1.1 *Financial Risk 1: Component Destruction*

Description: Electrical components are very sensitive to the presence of static electricity, and can be permanently damaged by a static discharge. Being mounted on an off-road vehicle, some components could potentially be destroyed by a vehicle roll-over or inclement weather conditions. Components could also be destroyed if they are connected incorrectly, e.g. if a component is connected to the wrong voltage levels or draws more current than it is rated for. The Destruction of any components of the DAQ could potentially consume a large portion of the budget (depending on which component is destroyed) and/or prevent the team from delivering the fully functional system on time.

Probability: High

While destruction by static shock is the least likely situation to occur, it is still a potential problem. Being mounted on an off-road vehicle that will likely be rolled over frequently, components could potentially be crushed depending on where they are mounted on the vehicle. This is the most likely scenario for component destruction.

Consequences: Tolerable to Serious

The consequences of component failure vary depending on which component is destroyed. Destruction of an XBee, a Raspberry Pi, or one or both of the batteries would be catastrophic, as they are the most expensive components in the system. The XBee and the batteries will be mounted on the vehicle. As such, they are the most expensive, most vulnerable components in the entire system. On the contrary, destruction of a small sensor or some other cheap component would have tolerable consequences, as their financial impact is minimal.

Strategy:

When choosing housings for the components found on the vehicle, the structural integrity of the enclosures will be carefully considered, as will their mounting points. Components will be mounted in places that are less likely to bear the full weight of the vehicle upon a roll over. Since components could also be destroyed by static shock, anti-static wrist bands will be worn whenever expensive electrical components are handled. Additionally, special care will be taken when connecting components to power sources to ensure that they are not overloaded with voltage or current.

6.1.2 *Financial Risk 2: Component Failure*

Description: At any time, electrical components can fail for a variety of reasons related to manufacturing defects or heavy use. As with component destruction, component failure could potentially consume a large portion of the budget and/or prevent the team from delivering the fully functional system on time.

Probability: Low
Electrical components are manufactured to be very reliable and seldom fail spontaneously under normal use. However, considering the project's intended operating environment, it may be possible for a component's longevity to be affected by heat or vibration.

Consequences: Tolerable to Serious
For the same reasons as component destruction, the consequences of component failure vary from tolerable to serious depending on which of the parts fails. Failure of expensive parts could heavily impact the project budget, while failure of inexpensive parts would have minimal impact. Any failed part will affect the project's progress and may negatively affect its completion time.

Strategy:
Since component failure would be caused by manufacturing defects, mitigation of this risk is near-impossible. The design team has no control over the manufacturing of the components used. The only mitigation strategy relating to overuse would be to limit excessive component use, although the amount of use required to cause a spontaneous is very high. As such, failure due to overuse is extremely unlikely.

6.1.3 *Financial Risk 3: Project Cost Overrun*

Description:
There is a potential that the actual cost of the project may be above that of the preliminary estimations. As with any project, unforeseen issues and changes can occur during project development which could cause the project to cost more than anticipated.

Probability: Low
The preliminary budget estimate came very close to the originally allotted $600, and did not take into account, among other things, pin headers, voltage regulators, component housing, mounting hardware, programmers or antennae. The final budget was increased to $750, but overrun could still occur due to unforeseen expenses or component replacement.

Consequences: Serious
Budget overrun would require the team to explore other funding options to complete the project. If extra funding is not found, or the funding is insufficient then features may have to be cut, or

project specifications may not be fully met. If an overrun is anticipated, the team will begin seeking external funds as soon as possible to avoid a delay in project progress.

Strategy:
The preliminary budget analysis was done using a worst case scenario, providing some monetary cushion in case unexpected expenses arise. The team has taken steps to attempt to procure some components from Texas Instruments for free, potentially eliminating some of the costs of the project.

6.3 Safety Risks

6.3.1 *Safety Risk 1: System Mounting Failure*

Description:
It is possible that the system could become detached from the vehicle via a mounting failure. This poses a safety risk to not only the driver of the FAMU-FSU Baja car, but every driver in the competition as well as spectators of the competition.

Probability: Low
As there are no components that are particularly heavy or bulky, mounting is expected to be simple and secure. Even so, unexpected complications can occur, and given the operating environment of the vehicle and the location of some subsystems mounting could prove to be more difficult or precarious than anticipated.

Consequences: Catastrophic
The safety of the Baja team's driver as well as the other competing drivers is of the utmost importance in the SAE Baja Series. A system mounting failure could pose potential safety risks to all of the drivers in the competition. As such, a system mounting failure should be avoided at all costs.

Strategy:
In order to mitigate this risk, the team will work closely with the SAE Baja team when working on mounting hardware and mounting points. If necessary, a member of the Baja team will provide welding services in order to ensure that the system is safely and securely mounted to the vehicle at all times. Additionally, all screws used will be secured with thread locking adhesives.

6.3.2 *Safety Risk 2: Water Damage*

Description:
During competition or in testing, the Baja car may be used in inclement weather or in situations that require navigation of a water hazard. Water poses certain risks to electronics and electrical

systems and steps must be taken to ensure the safety of the system and anyone working on it in such conditions.

Probability: Low
The components of the DAQ system will be housed in water resistant housings to prevent water or other materials from interfering with the DAQ's performance. Components will be placed with care to maximize the safety of the components and prevent unnecessary exposure to physical risks.

Consequences: Catastrophic
Water damage to any subsystem could cause it to become inoperable or in the worst case, cause electrical damage to other parts of the system as a whole. Water present in the system may pose safety risks to the vehicle operator or any crew working on the vehicle including electrical shock, fire, or chemical leaks from the batteries. Additionally, this damage may be irreversible and could pose a financial risk as well.

Strategy:
In order to mitigate the risk of water damage, great care will be taken to properly house and protect all components. Fuses will be placed in key locations of the power system to prevent any electrical damage or overall system failure in the event of a short circuit. Additionally, great care must be taken by the Baja and DAQ teams when disassembling or modifying any electrical systems on the vehicle.

6.4 Design Risks

6.4.1 *Design Risk 1: Tire Pressure Monitoring System*

Description:
The team found during their research of potential solutions for the Baja TPMS that there exists virtually no marketed solutions for ATV tires. While the project team was donated 4 automobile TPMS sensors, there is a chance that the team will be unable to interface with the sensors, as they require a certain command to be sent in order for the sensors to return their 69-bit long data stream. If the team is unable to get the sensors provided to return usable data, the TMPS may have to be scrapped, as designing custom TPMS sensors would require more time and money that the design team does not have.

Probability: High
The sensors that were donated to the team, as well as basically any other commercially available automobile TPMS sensors, were designed using a proprietary activation code. As such, they will require a significant amount of reverse engineering and guess work in order to interface with

them properly. If the team is not able to successfully interface with the sensors, the tire pressure measurement may be shelved entirely

Consequences: Tolerable

The tire pressure monitoring is one of the less important subsystems of the DAQ. The Baja team rarely has problems with the tires that are not immediately evident by the driver based on the feel of the car, or the pit crew based on visual inspection - even from a distance. The tire pressure monitoring system on the Baja vehicle was almost scrapped completely upon learning that the sensors available on the market may not be sensitive enough to measure below 10 PSI. With that in mind, failure to produce this part of the system would not be detrimental to the project.

Strategy:

The team is in contact with representatives from a company that manufactures replacement TPMS sensors, and has gathered some information regarding data types and frame information. The team will continue to reach out to industry professionals and companies in order to find a workable solution.

6.4.2 *Design Risk 2: Wireless Vehicle-to-Pit Communication*

Description:

The team was hard-pressed to find information about the urban data transmission range using the 2.1 dB dipole antenna. The XBee-PRO 900HP is capable of a 4-mile line-of-sight with a 2.1 dB antenna at 200 kbps, but no information was given about the urban range. If the transmission range does not meet the requirements, the pit may only get a transmission once per lap, or whenever the vehicle is in range. Depending on the topology of the endurance course, this could last anywhere from seconds to minutes.

Probability: Moderate

When considering wireless transceivers, the design team came across a benchmark for a wireless transceiver module—the XTend—that listed a 28-mile line-of-sight range using a 2.1 dB dipole antenna, which gave optimism to the team when considering the needs and requirements of the project. During component selection, however, the design team found that the specific model that was rated at 28 miles LOS was very expensive, well beyond the means of the project given the provided budget. Given that, the design team had to choose a less-powerful XBee module, which is only rated at 4 miles LOS, leading to concerns about the unit’s ability to reach the required 3-mile LOS range that was given in **CONS-005**, outlined in the Needs Analysis and Requirements Specifications.

Consequences: Tolerable

Since the 28-mile range modules are very expensive--$180 per unit--they are out of the range of attainability for the design team. The modules would cost almost half of the given $750 budget.

Even if the team were to obtain outside sponsorships, receiving the amount that is needed to use the XTend modules is unlikely. As such, the team will have to simply work with the hand they were dealt. If the XBee-PRO 900HP does not reach the proper range, the pit crew may only receive data transmissions once per lap, or only when the unit is in range.

Strategy:
If the XBee-PRO 900HP does not give the design team the required range, the pit unit may only be able to receive data transmissions once per lap, or whenever the vehicle is in range. Due to the unknown topology of the endurance courses, whether the transmissions occur once per lap or during the whole race will remain unknown until the time of the race. Unless the design team can receive funding for ~$400, the team will simply have to live with what the XBee-PRO 900HP gives in terms of range and transmission accuracy.

6.4.2 *Design Risk 3: In-house Sensor MCU Printed Circuit Boards*

Description:
The team has decided to buy discrete MCUs for each sensor and fabricate custom PCBs for each one. If the PCB milling is not possible or fails in-house, the team may have to use perfboard to make their own circuits, which would be fairly time consuming, or seek outsourced manufacturing, which could potentially add a significant amount of cost to the project.

Probability: Moderate
There is a chance that the PCB milling facility at the FAMU-FSU College of Engineering will be unable to fulfill the requirements of the design team. The traces may be located too close together in the CAD design for the milling machine to mill the PCB without issues. Additionally, surface mounting components is not possible at the in-house PCB milling facility.

Consequences: Tolerable
Failure to have the PCBs created in-house could have a large financial impact on the project. This financial impact could be mitigated by changing the design paradigm of the system, which could ultimately affect the timely completion of the project. If the in-house PCB milling is not possible, the design team will be tasked with deciding whether to pay a potentially large sum of money to have PCBs manufactured elsewhere or to build the circuits using perfboard.

Strategy:
The actual milling of the printed circuit boards is out of the control of the design team. However, the circuits will be designed so that they are as easy to mill as possible, making it more likely that the in-house PCB milling facility can fulfill the needs of the team. If the in-house milling is not possible, the design team will first look into outsourced manufacturing before deciding to build the circuits by hand on perfboard or change the design paradigm.

7 Conclusion

The design for this data acquisition system involves sensors boards with microcontrollers placed in various parts around the vehicle. The sensors will send data over an SPI bus to a main MCU for data processing and storage. All the data will be stored on an SD card and sent wirelessly from the vehicle to the pit crew. The speed and fuel level values will be displayed on an LCD screen within line of sight of the driver. The pit crew system will contain a CPU that listens for the wireless communication and displays that information during race time.

The hardware design for these modules are nearly complete with the exception of those outlined in section 2.5. Each module has been carefully chosen to suit the needs of the task it was meant to perform. The portability and energy efficiency are important characteristics for a project of this nature and has been taken into consideration for all hardware chosen for each module.

Project risks have been weighed for the DAQ system with the majority of them stemming from what will be the DAQ systems operating environment. As such, the team is prepared to take precautions in protecting the components against environment wear and tear and will have a plan outlined to handle the consequences of component failure.