TrackPack: Intelligent Vehicle Racing Monitor and Recording System

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Table of Contents

List of Figures

List of Tables

2.1 Project Background and Motivation

Introduction

With thousands of vehicle racetracks and millions of car enthusiasts in the United States alone, people are consistently seeking ways to measure their vehicle's performance, as well as their own performance as drivers. Vehicle racing has evolved greatly since inception in the late 1800s, and cars today are becoming extremely fast and precise machines with immense capabilities.

With the competition in mind, TrackPack was born. Looking for ways to measure, record, and share accurate vehicle statistics both on and off the track has been a challenge for years. With groundbreaking advancements in technology, we are now able to allocate advanced features in a compact design.

At the root of TrackPack is a small microcomputer with extensive processing power. In addition to the microcomputer, GPS and an accelerometer allow the user to accurately track location, speed, and acceleration. Using these parameters alone, we can accurately determine a vehicle's 0-60mph time, 0-100mph time, ⅛ mile time, ¼ mile time, and other key racing measurements such as braking distances, g-force, lap times, etc.

TrackPack doesn't stop there, however, using an onboard camera TrackPack allows you to record and save footage from the vehicle to be played back later and compared with the measured parameters. Furthermore, whether you're a casual driver, occasional spirited driver, or competitive racer, TrackPack can help you measure your vehicle's health. Utilizing the Onboard Diagnostics port in the vehicle, TrackPack allows users to measure and manage their vehicles health by gaining access to a slew of parameters directly from the vehicle's computers.

Motivation

Similar products to TrackPack currently exist on the market with certain limitations in functionality. These limitations require consumers to purchase additional accessories to read all the parameters that TrackPack will read. We set out to create an all-in-one device that consumers can use to track all this data in a single, concise, portable, and easy to use design. The market for consumer electronics dealing with vehicle performance is substantial, racing enthusiasts are always looking for a way to enhance their vehicles performance. Of course, enhancing vehicle performance yields a more spirited driving experience, but TrackPack wants to enable users to take their driving experience to the next level. By tracking the user's vehicle performance and live data from the vehicle, we can ensure that the consumer has the most accurate performance data on their vehicle.

2.2 Project Objectives

Goals

Basic goals:

- Design a module that monitors a vehicle's performance in real-time
- Provide accurate readings of the vehicle's acceleration, braking, and handling
- Help drivers understand their car's performance to optimize driving strategy and improve lap times
- Assist in identifying issues with the vehicle and point the driver in the right direction for repairs or upgrades

Advanced goals:

- Allow racers and car enthusiasts to make quick adjustments to their driving style or vehicle setup based on real-time data feedback
- Provide comparative analysis of different vehicles or setups to help users make informed decisions about improving performance
- Develop an optical design and video collection system that records a perspective closely matching what the driver sees during races and driving
- Enable users to cross-reference any issues found in the data collected to any terrain encountered.

Overall, the basic goals focus on designing a module that monitors vehicle performance, provides real-time data feedback, and assists in identifying issues with the vehicle. The advanced goals build upon these basic goals by enabling racers and car enthusiasts to make informed decisions based on comparative analysis, and by providing a more detailed and accurate perspective through the optical design and video collection system.

Objectives

The TrackPack will embody a compact, light-weight design that is battery powered. This module is OBD-II compatible where it will read vehicle performance parameters and store results on an SD card. Significant specifications such as location, will be accurately tracked using onboard GPS. An accelerometer will be implemented to measure proper acceleration to determine g-force. As a bonus, the TrackPack will include a video recorder which can serve as a dash cam and/or a way to share your experience with friends and family. The recordings will allow the viewer to see everything that the driver saw and more. The videos will also allow the driver useful feedback, having the data collected during the drive presented alongside the recording. Its objective is to provide accurate and reliable performance data for car enthusiasts and professionals who want to improve their driving skills and enhance their vehicle's performance. The data collected by TrackPack can be used to fine-tune a vehicle's performance and make modifications to improve its performance, speed, and handling.

#	Objectives
2.2.1	Plug-and-Play functionality
2.2.2	Lightweight & Portable Design
2.2.3	Low-Latency parameter tracking
2.2.4	Video Footage
2.2.5	High quality display
2.2.6	Wide angle footage
2.2.7	External data storage
2.2.8	User-friendly interface

Function of Project

Our device will be able to take the input from the OBD II port as well as use this port to supply power to the device on the vehicle to then read back the values of the emissions, fuel efficiency, etc. We will transmit this data to our microcontroller and add the data from the accelerometer and GPS. The microcontroller will have to determine when to begin reading the detailed statistics. Once the measurement has been calculated the measured value will then be displayed while continuing to collect the speed from the accelerometer. The statistics will be read out to the user on a display and the footage that is taken from the camera module will also display these statistics back to the user on an LCD display with the current statistics that the user has set to scan for. Once the data is recorded from the device the data will be transmitted to the display with the aim of a 3ms time delay, to give the data as quickly as possible to the user. All the data taken from the OBD II port will be read by the microcontroller present on the PCB along with the additional modules. To implement the image processing done by our dash cam we may need additional processing power to successfully present the entirety of the data. If the microcontroller is not sufficient on its own to have enough power to collect and read out the data as well as the images for video, an additional MCU (raspberry pi) will be used to exclusively run the imaging process.

Marketing Analysis

Devices exist that can monitor individual aspects such as race time, vehicle health, acceleration times, position, and driver POV but few solutions exist that can achieve all the above. The products that are on the market can cost upwards of $1000, which acts as a barrier to entry level racers. There are devices that support connecting external monitoring systems, but these systems will require more space within the vehicle. The goal of the TrackPack is to provide a low-cost all-in-one solution to all levels of drivers, which would fill a need market space and encourage other companies to provide a greater scope of measurements in a single device.

2.3 Project Requirement Specifications

Specification Number	Hardware Parameters	Measurements
1.1	PCB board size	10cm x 10cm
1.2	Dash Cam (FOV)	>80° to capture an even wider angle than what the driver sees
1.3	Pixel Resolution	1080p video for high-definition recordings
1.4	Video Frame Rate	Due to fast paced nature of driving a frame rate of 30 fps will limit motion blur during quick accelerations
1.5	Optical Resolution	The spot size of the on axis and off axis rays will be smaller 250 microns in radius
1.6	Optical Aperture	The optical system will be designed to achieve a f-number between f/1.8 and f/2.8 to balance light input and the depth of field
1.7	Complete device in housing size	The TrackPack will be compact and portable. 4in x 3in x 2 in
1.8	Trackable speed	0 mph to 999 mph
1.9	Power Supply	The TrackPack will be able to obtain power from the OBD II port to have no need of a separate battery support
1.10	OBD II compatible	The TrackPack will include OBD II compatibility to collect vehicle parameters such as engine pressures, engine temperatures, emissions, etc.
1.11	Weight	The TrackPack will be lightweight to support vehicle weight reduction. <= 1 lbs.
1.12	Accelerometer	i2c and SPI interface Scales of 2g to 16g
1.13	Gyroscope	i2c and SPI interface Measurement range 125 to 2000 dps Sensitivity 4.375, 8.75, 17.50, 35, 70 mdps
1.14	GPS Module	Altitude of 50,000m Max update rate 10 Hz

		Horizontal position accuracy <2.5m CEP Acquisition sensitivity -148dBm Tracking sensitivity -167dBm

Table 1: Project Hardware Requirement Specifications

Specification Number	Software Specifications
2.1	Live performance metrics
2.2	GPS Tracking
2.3	Data Logging
2.4	Experience Recording
2.5	Measure Acceleration
2.6	Trackable speed
2.7	Measure Lap Times
2.8	Measure Braking Distance

Table 2: Project Software Requirement Specifications

Specification Number	Constraints
3.1	Accuracy Limitations: limitations to the precision of measurements in certain conditions, such as on uneven or slippery surfaces
3.2	Device Placement: must be placed securely in the vehicle to ensure accurate measurements
3.3	Battery life: as a battery life of approximately four hours, which may not be sufficient for extended periods of use without recharging or connectivity to direct power source
3.4	Latency: Like any electronic device, there is a certain amount of latency associated with TrackPack

Table 3: Project Constraints

2.4 House of Quality

The House of Quality matrix is an important tool in defining customer needs and correlating these needs with the fundamentals of development. To develop a great product, it's important to identify the wants and needs of the customer and the engineering requirements. By utilizing a House of Quality matrix, we can determine how the wants and needs of the customer coincide with the engineering requirements and what level of precedence certain features hold.

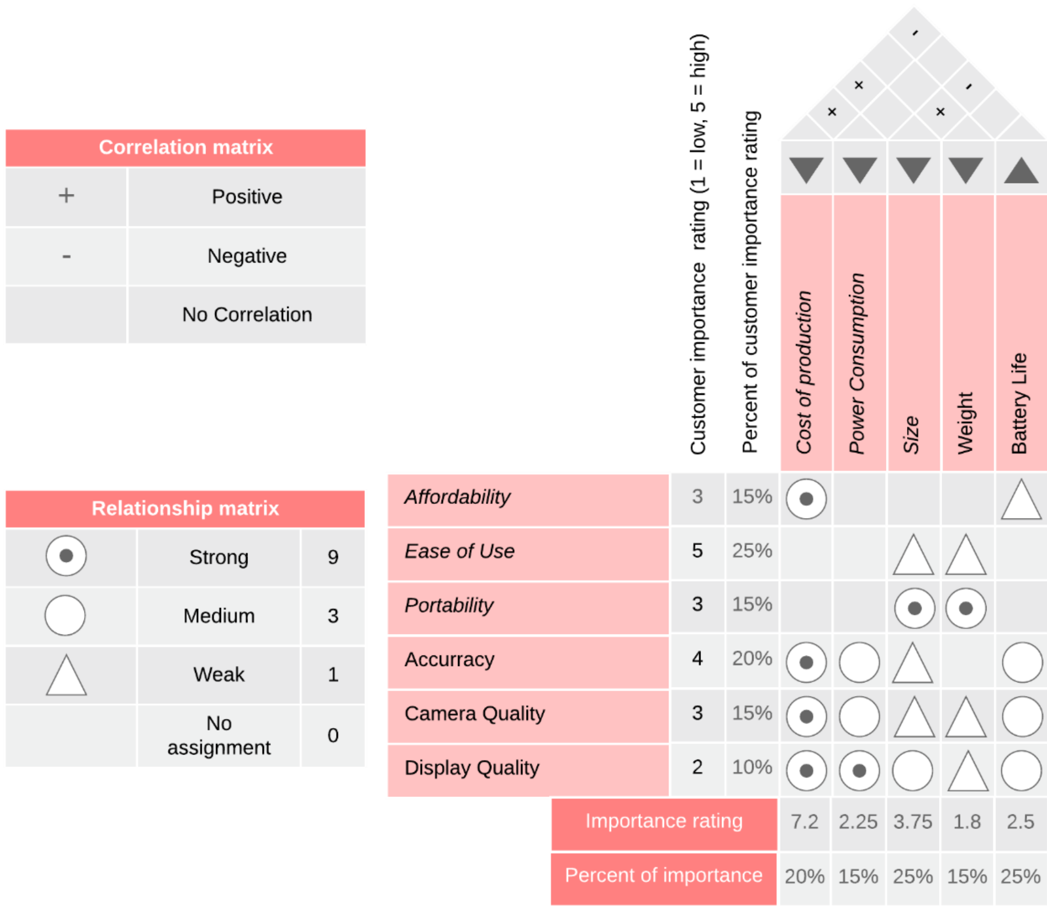


Figure 1: House of Quality

2.5 Block diagram in Hardware

Figure 2: Block Diagram in Hardware

2.6 Flowchart in Software

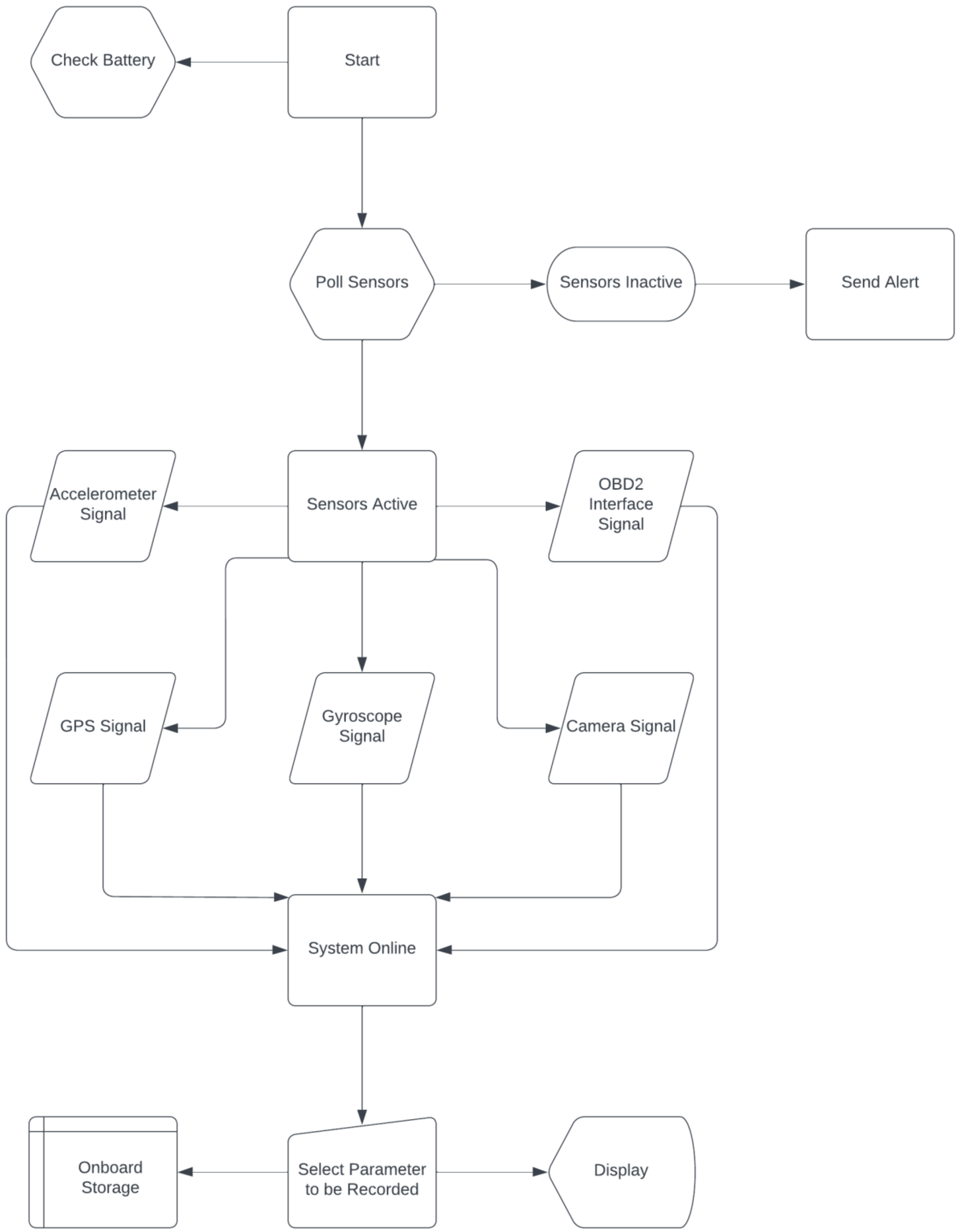


Figure 3: Flowchart in Software

Figure 3: Flowchart in Software

3 Research and Part Selection

Part selection research is crucial in various fields such as engineering, manufacturing, and construction. It involves identifying and choosing the appropriate components, materials, and parts to use in the design and production of a particular product or system. The selection process involves considering multiple factors such as cost, availability, functionality, durability, and compatibility with other parts. Our part selections are meticulously researched and compared when it comes to ensuring the high building quality that consumers will see on the TrackPack. Here we will discuss both the research done during the selection of the parts, as well as relevant technologies which make up the part selection process.

The main constraints we are considering when selecting our components for our system are cost and size, as we need the system to be relatively compact and affordable. Each individual component must also be entirely compatible with one another. When creating our schematic this constraint we would have to ensure that if were to pick a component to ensure the output type to see what parts we would be limited to and to look for future parts in the design process to make sure that they are also compatible.

3.1 Existing Products

Similar products to TrackPack existing on the market have their own unique features and advantages, and the best choice depends on the user's specific needs and preferences. Depending on if the consumer is more focused on accuracy, ease of use, or cost, this can dictate which product they choose. The following relevant products are beneficial to our research, it allows us to intricately analyze the advantages, disadvantages, features, etc. of each design. With extensive comparison between existing products on the market, we can use the research to support the final design and build of TrackPack.

3.1.1 Garmin Catalyst Driving Performance Optimizer - Most Relevant Product

Garmin is a company that specializes in the design of global positioning system (GPS) enabled products. Among the many items that Garmin designs and produces, they primarily make GPS navigational tools, smartwatches, fitness trackers, action cameras, and radar systems. Individuals and professionals in fields like aviation and marine navigation, search and rescue missions, and law enforcement utilize the advanced technology that Garmin offers.

The Garmin Catalyst Driving Performance Optimizer is an advanced performance data and coaching tool created especially for track drivers. It is a device that mounts to the dashboard or windshield of a vehicle and employs a mix of sensors, cameras, and GPS technology to collect real-time data on a driver's performance. This includes speed, lap times, and driving line. The device is compatible with mobile applications on Android devices and iOS devices.

Figure 4: Garmin Catalyst Driving Performance Optimizer

The Garmin Catalyst Driving Performance Optimizer has a compact, 7.84" W x 4.79" H x 0.93" D, design that includes a heavy-duty mount for the cockpit. It connects to a power source and the vehicle's OBD II port. The device features a touch screen display size of 6.0" W x 3.5" H with a display resolution of 1024 x 600 pixels. The display makes it easy to see the driver's performance information and coaching feedback. The display includes a predictive lap timer, speed, lap times, and G-forces among other data elements. The data fields that are shown on the screen can be altered by the driver to fit their preferences. All the information gathered while driving is logged onto the device and may subsequently be accessed on the Catalyst companion app. As a result, the driver can examine their performance statistics in greater detail and pinpoint areas where they can improve over time. Equipped with a high-quality camera, the Garmin Catalyst Driving Performance Optimizer records at 1080p resolution and 30 fps. The camera includes a wide-angle lens that is designed to capture a 140° field of view of a driver's performance/trip on the track.

Capabilities of the Garmin Catalyst Driving Performance Optimizer include 10 Hz multi-GNSS positioning, image processing, and built-in accelerometers to generate the driver’s racing line on the track. The device also provides an on-track driving coach where the device provides audio cues through either Bluetooth or the vehicle’s stereo. With the help of this ground-breaking technology, user's best times for each track section are combined to provide their ideal driving time based on lines users have driven. The Garmin Catalyst Driving Performance Optimizer displays the driver’s apex performance, showing how the timing of apex decisions impacts the overall performance and speed on the track. In addition to the collected data, the device also keeps track of your best lap time, adaptive delta time, number of laps and total session time.

3.1.2 Dragy

Dragy Motorsports is a company that provides performance measurement devices for consumers interested in monitoring and tracking the performance of their vehicle. The Dragy device is encased in a portable design of a 1” x 3” box weighing in at 2 lbs. which is a size that works well with being set on the dashboard of your vehicle or even stored in your glovebox when not in used.

Dragy is an independent device that works in conjunction with a smartphone equipped with Bluetooth control to the device that holds up to 10 hours of battery life. The device is connected to an application that is consistently being updated with new features, this application is accessible to both iOS devices and Android devices. The smartphone app allows users to view and share their performance data in real-time. The app also provides various features, such as performance leaderboards, video overlays, and social media sharing options.

Figure 5: Dragy

Dragy offers a video synchronization feature which allows users to combine their video footage with the performance data collected by Dragy. Dragy synchronizes video footage with performance data using its internal clock, so users can view both simultaneously. Users simply start recording video on their smartphone or camera at the same time as they begin a Dragy run.

Dragy aims to provide race precision timing so that car enthusiasts can make modifications to their vehicle accordingly to hit their peak performance. This device allows for the monitoring of a driver’s 0-60mph, 60-130mph, 100-200kmh, 1/4-mile, 1/2-mile performance, etc. Dragy gathers a vehicle’s performance parameters by using high speed GPS satellites. Some features include measuring parameters such as: acceleration, braking time, G-force measurement, and lap timer.

With the support of accurate performance readings, Dragy encourages the idea of a cost-effective lifestyle where they support consumers to spend wisely on the modifications to their vehicle instead of a costly performance measurement tool.

3.1.3 VBOX Video HD2

VBOX Video HD2 is a performance device that relays the parameters of a user’s vehicle in real-time. The comprehensive collection of data allows users to analyze the performance of their vehicle and their driving, allowing drivers to make the appropriate adjustments to their driving. The VBOX Video HD2 utilizes intelligent data logging technology, various sensors and real-time streaming to form an analysis.

The VBOX Video HD2 holds up to a six-hour battery life with a weight of 130g, which is noted to be an ideal weight. The VBOX Video HD2 is advertised to be compatible with any type of vehicle such as a car, motorcycle, bicycle, jet-ski, powerboat etc. In addition to offering compatibility with Apple dev ices like the iPhone, iPod Touch, and iPad, the VBOX Sport also comes with a Bluetooth connection, allowing for the use of the device with Bluetooth to enhance GPS reception on iOS devices, or to add GPS functionality if the devices are not equipped with GPS. The system includes and internal power backup to prevent lost or corrupted data.

The VBOX Video HD2 is equipped with a dual camera setup, with HDMI video output and 1080p 30 fps HD video. Video footage and data from the data logger are recorded along with a synchronized video from the VBOX Video HD2, allowing users to capture high-quality race footage. Some components to the video feature include multiple camera inputs and switching options, live streaming, synchronized data overlay on video footage, and customizable video overlays and graphics.

Figure 6: VBOX Video HD2

The VBOX Video HD2 is used to record GPS data such as speed, acceleration, distance, and time. Users can easily analyze the performance data that has been captured by the VBOX Video HD2 directly using the analysis software - Circuit Tools - and users can store these results directly into the SD card that is provided. Some notable features of the VBOX Video HD2 include: 10Hz GPS engine, internal GPS antenna, socket for external GPS antenna, USB charging, SD card logging, waterproof camera, and free data analysis software. The VBOX Video HD2 has advanced features such as predictive lap timing, a built-in display, and the ability to measure lateral G-forces.

3.1.4 SoloStorm

SoloStorm is a smartphone-based performance tracking app that records performance data from various sensors, such as accelerometers, GPS, and OBD-II. SoloStorm offers a camera recording option. A compatible camera must be connected to SoloStorm and configured as a video source to use the camera recording feature. After this is set up, users can start and stop the recording manually or automatically, and the footage is stored with all the user’s other session(s) data.

The SoloStorm Autocross Data Logger is only compatible with Android and the SoloStorm software must be purchased with a Bluetooth GPS receiver (SoloStorm GPS Package). At an additional cost for OBD II compliant vehicles, consumers can purchase the Bluetooth OBD II reader. With the Bluetooth OBD II reader users can log throttle position and RPM. Another addition for CAN OBD II compliant vehicles, consumers can purchase the SoloStorm RaceCapture/TrackPackage which will allow consumers to log OBD and other CAN bus channels at higher sample rates. Some vehicles that are compatible with this feature may allow consumers to log brake pressure and steering angle. For vehicles that are not OBD II compliant, SoloStorm offers the SoloStorm Race Capture/Pro Package where SoloStorm can be connected via a USB or wireless connection to standalone data acquisition systems that can connect directly to your vehicle's sensors. These systems typically include their own sensors and data acquisition hardware. This package provides consumers with features where they can run brake pressure, steering, or custom sensors with this data logger and it includes analog inputs, CAN bus connectivity, accelerometers, and gyroscopes, among other features.

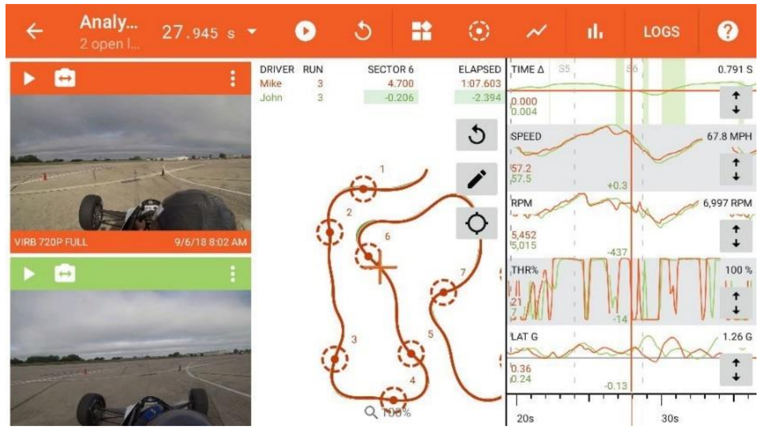


Figure 7: SoloStorm

Product Comparison				
Product	Garmin	Dragy	VBOX Video HD2	SoloStorm
Battery Life/Power Supply	up to 2 hours	Up to 10 hours	12 V auxiliary or cigar lighter socket	N/A
Connection Type	Bluetooth	Bluetooth	Bluetooth	Bluetooth OBD II/Standalone data acquisition system
iOS and Android Compatible	Yes	Yes	Yes	Android only
Dimensions	7.84" W x 4.79" H x 0.93" D	1” x 3”	178 x 143 x 35.5 mm	N/A
Built-in Display	Yes	No	No	No

Weight	~15.4 oz	~2 lbs	~870 g	N/A
Camera	Yes	No	Yes	No
Cost	$999.00	$189.00	$ 3,895.00	$304.00

Table 4: Existing Products Comparison

3.1.5.1 UART

UART works by using two wires, one for transmitting data and another for receiving data. The data is transmitted in a series of bits, with each bit representing a 1 or a 0. The bits are sent one after another, with a start bit and a stop bit framing each byte of data. The start bit is always a logic 0, and the stop bit is always a logic 1. The data bits can be any combination of 1s and 0s. One of the main advantages of UART is that it is asynchronous, which means that the transmitting device and the receiving device do not have to be synchronized with each other. This makes it easier to implement and more flexible than synchronous communication protocols, which require the two devices to be synchronized. Another advantage of UART is that it is relatively simple to implement. It only requires a few hardware components, such as a shift register and a baud rate generator, which can be easily integrated into a microcontroller or other embedded system. The baud rate is the rate at which the data is transmitted over the UART connection, and it determines the speed of the communication. The baud rate is usually set by the transmitting device, and the receiving device must be configured to match the same baud rate in order to receive the data correctly. The baud rate is usually expressed in bits per second (bps), and common baud rates include 9600, 19200, and 115200 bps. To use UART, the transmitting device sends the data serially one byte at a time. The data is sent using the start bit, followed by the data bits, and then the stop bit. The receiving device detects the start bit, and then samples the data bits at the appropriate time to receive the data. Once the stop bit is detected, the receiving device knows that the byte is complete and can be processed.

3.1.5.2 SPI

SPI works by using a master/slave architecture, where one device (the master) controls the communication and initiates the data transfer, and one or more devices (the slaves) respond to the master's commands and send data back to the master. The master device generates a clock signal that is used to synchronize the communication between the devices, and data is transmitted and received simultaneously over separate wires. SPI uses four wires for communication: a clock signal (SCK), a master output slave input (MOSI) signal, a master input slave output (MISO) signal, and a chip select (CS) signal. The clock signal is generated by the master and is used to synchronize the communication between the master and the slave devices. The MOSI signal is used by the master to send data to the slave, and the MISO signal is used by the slave to send data back to the master. The CS signal is used to select the slave device that the master wants to communicate with. SPI data is transmitted in packets, with each packet consisting of a set number of bits. The master initiates the data transfer by sending a packet of bits to the slave, and the slave responds by sending a packet of bits back to the master. The packets can be any length, and the master and slave must agree on the packet length before the communication begins. One of the advantages of SPI is its speed. SPI can operate at high speeds, up to several megabits per second, which makes it ideal for applications that require fast data transfer rates. Another advantage of SPI is its simplicity. The protocol is relatively easy to implement and requires only a few hardware components, making it a popular choice for low-cost embedded systems.

3.1.5.3 I^{2}C

I^{2}C is a synchronous, multi-master/multi-slave (controller/target), packet switched, single-ended, serial communication bus. It is widely used for attaching lower-speed peripheral ICs to processors and microcontrollers in short-distance, intra-board communication. A particular strength of I^{2}C is the capability of a microcontroller to control a network of device chips with just two general-purpose I/O pins and software. Many other bus technologies used in similar applications, such as Serial Peripheral Interface Bus (SPI), require more pins and signals to connect multiple devices. I^{2}C uses only two bidirectional open-collector or open-drain lines: serial data line (SDA) and serial clock line (SCL), pulled up with resistors. Typical voltages used are +5 V or +3.3 V, although systems with other voltages are permitted. I^{2}C has several speed modes, and we will try to use the highest that our MCU can process to send to the user. The High-speed mode (Hs) has a maximum speed of 3.4Mbit/s.

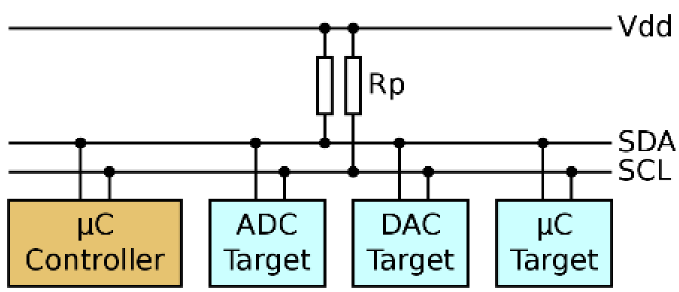


Figure 8: Example of Microcontroller using I2C

3.1.5.4 Communication Protocol Choice

Protocol	UART	I2C	SPI
Complexity	Simplest	Easy to chain multiple devices	Complexity increases as device count increases
Speed	Slowest	Faster than UART	Fastest
Number of Devices	Up to 2 devices	Up to 127	As many as needed
Number of Wires	1	2	4
Duplex	Ful Duplex	Half Duplex	Full Duplex
Master to Slave ratio	Single to Single	Multiple slaves and masters	1 master, multiple slaves

Table 5: Communication Protocol Comparison

Given the above criteria that each communication protocol met, we decided to use the I^2C. The speeds are fast enough for design requirements and mainly we are going to have several connections between our corresponding devices that are tracking the data in operation, so having a system that is easy to run multiple devices at once was the most important feature when choosing the protocol. This fact will be considered when selecting the auxiliary components of our design as we want them to be I^2C compatible.

3.1.6 PCB design

Autodesk Eagle, also known as simply Eagle, is the software program for designing printed circuit boards (PCBs) and schematics that we used for our project. For our system we will be implementing a design using the parts available in the component library as well as importing in the parts we need and adding the required footprints. With the completed file we will be able to create our unique PCB design by taking the Gerber file from Eagle and uploading it directly to the manufacturer to be produced. PCB way also provides the ability to assemble the components onto the PCB. The company offers both surface-mount technology (SMT) and through-hole technology (THT) assembly services. For our design we would like to have multiple layers to make a stronger board and try to keep the total footprint of the board to a minimum to reduce space, while keeping all the necessary components to have ample power. The disadvantages to this are a higher cost, and longer lead times, so as soon as a design is agreed upon with all auxiliary components, we will order the board immediately to ensure proper time to debug and test before the due date.

3.1.7 Voltage Regulation

The OBD II port provides several different voltages, depending on the specific pin and function being used. Pin 16 of the OBD II connector provides battery voltage (approximately 12V) directly from the vehicle's battery, which can be used to power external devices that are connected to the OBD II port. However, other pins in the OBD II connector provide different voltages and signals, depending on their specific function. For example, Pin 2 (J1850 Bus +) and Pin 10 (J1850 Bus -) provide a differential voltage signal for communication with certain vehicle modules. Pin 4 (Chassis Ground) and Pin 5 (Signal Ground) provide ground connections for the various signals and voltages. In any of the pins available we will have to have a form of DC-to-DC conversion to function the PCB and system if we want to draw power from the OBD II port and eliminate an external power supply. The other option is to use the 12V accessory outlet to get power and have an adapter to USB to then connect to power the PCB and camera modules. This alternative will let us have an easier connection and provide easier access to the user to plug in the device as well as disassembly to move between vehicles. Another benefit of moving the power supply to the 12V accessory outlet is the removal of any cables below the steering column that could impede the driver in reaching the pedals. One flaw with this input method for the power supply is that the voltage level could be elevated to the 13.5-15V range while the engine is running, so any DC-to-DC converter must be rated to operate at this higher voltage level.

This voltage level will have to be stepped down to operate our devices without damaging them on average between 3Vand 5V values. Linear and switching DC voltage regulators are two commonly used methods for regulating voltage in electronic devices. While both types of regulators serve the same purpose of maintaining a stable output voltage, there are significant differences between them in terms of efficiency, size, cost, and performance. A linear voltage regulator operates by continuously dissipating excess voltage as heat, while maintaining a constant voltage output. This method of voltage regulation is simple and effective, but it can be inefficient, particularly when the input voltage is much higher than the output voltage. Linear voltage regulators are typically smaller and cheaper than switching voltage regulators, but they can also be less precise and generate more heat. On the other hand, switching voltage regulators use a more complex method of voltage regulation that involves rapidly switching the input voltage on and off to maintain a stable output voltage. This method is more efficient than linear voltage regulation, as the excess voltage is not dissipated as heat, but rather stored and reused. Switching voltage regulators are typically larger and more expensive than linear voltage regulators, but they are also more precise and generate less heat. One advantage of switching voltage regulators is their ability to regulate a wide range of input voltages, making them ideal for use in battery-powered devices that have fluctuating input voltages. Switching voltage regulators are also able to handle higher power levels than linear voltage regulators, making them suitable for use in devices that require high levels of power. Linear voltage regulators are simpler and more straightforward to design and use, making them a popular choice for applications that do not require high efficiency or precision. They are also less prone to noise and other issues that can affect the performance of switching voltage regulators. In summary, the choice between linear and switching DC voltage regulators depends on the specific requirements of the application, including the input voltage range, the required output voltage stability, the power level, and the cost and size constraints. While linear voltage regulators are simple, compact, and inexpensive, switching voltage regulators offer higher efficiency, precision, and flexibility in handling varying input voltages and power levels. Most of the components in our system will require an operating voltage level somewhere between the 3V and 5V values. So, we must regulate the voltage from the 12V of the OBD II port and then have a 3.3V and 5V DC-DC converter within the system. In previous courses to regulate voltage we have used the 7805 and 7815 voltage regulators to regulate to 3 and 5 Volts with an input of 5 volts, so we can implement a similar circuit in order to bring our voltage down using a similar schematic and have a voltage closer to the 3-5V range that will power the PCB and then be used by the DC-to-DC converter.

A 3.3V to 5V DCDC converter is a type of DC-to-DC converter that is used to step up a 3.3V input voltage to a 5V output voltage. This process is commonly used in electronic devices that require a higher voltage than the input voltage to operate. The DCDC converter operates by using an inductor and a switching transistor to convert the input voltage into a series of pulses. These pulses are then filtered and regulated to produce a stable output voltage. There are several different types of 3.3V to 5V DCDC converters, including buck-boost, flyback, and boost converters. The choice of converter depends on the specific requirements of the application, such as input voltage range, output voltage, and efficiency.

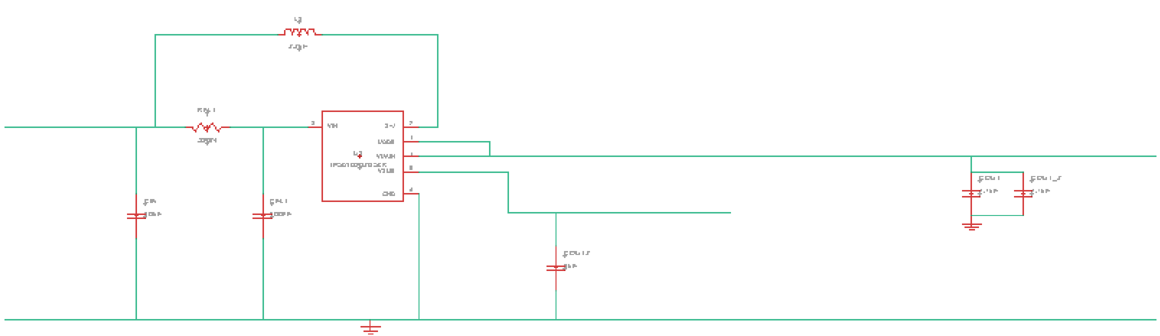


Figure 1 3.3VDCDCConverter

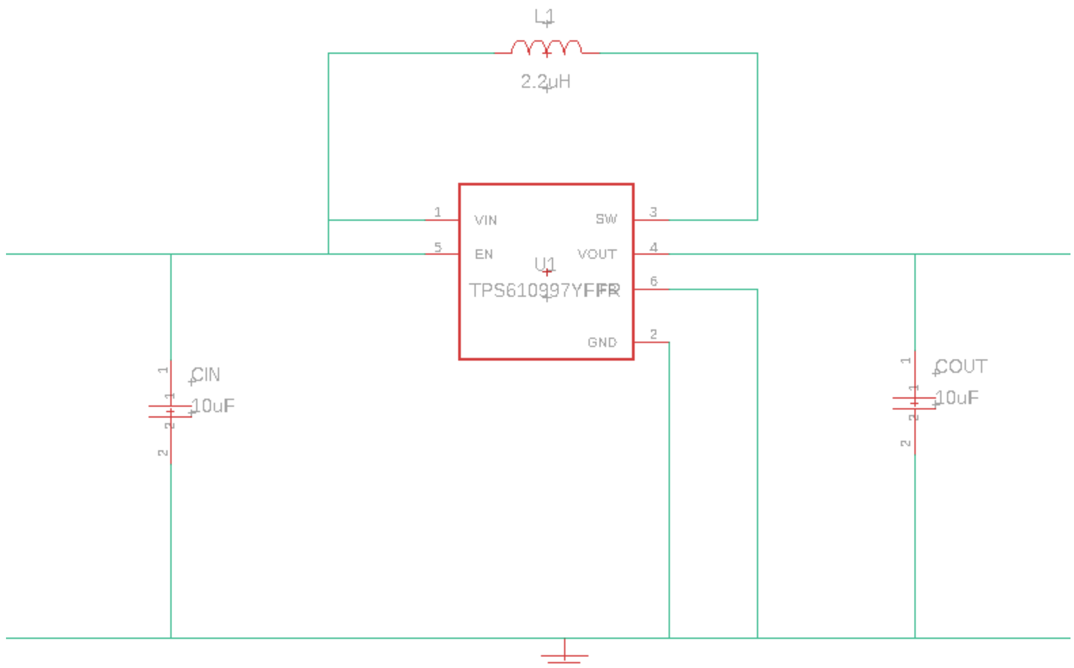


Figure 2 VDCDC Converter

One common example of a 3.3V to 5V DCDC converter is the LM2675 from Texas Instruments. This is a simple switch-mode power supply that provides a fixed 5V output voltage from a 3.3V input voltage. It has a maximum output current of 1A and an efficiency of up to 90%. Another example is the MP2315 from Monolithic Power Systems. This is a synchronous buck converter that provides a variable output voltage up to 5V from a 2.7V to 5.5V input voltage. It has a maximum output current of 1.5A and an efficiency of up to 95%.3.3V to 5V DCDC converters are widely used in a variety of electronic devices, including microcontrollers, sensors, and other low-power applications. They are typically small and efficient, making them ideal for use in portable and battery-powered devices.

3.1.8 Power Supply

Our main goal after discussing the project, was the possibility of removing an external power supply in the form of a battery and getting the power straight from the vehicle. After researching into the two options of the OBD II port, and the 12V car accessory outlet (cigarette lighter), we chose the 12V accessory due to its ease of access to the user and easier connection port. The 12V cigarette lighter socket in a car provides more than enough power to supply both the PCB and the camera module. To convert the 12V DC power supply from the cigarette lighter socket to a 5V DC power supply suitable for USB devices, a converter circuit is needed. The rectified DC output is then regulated to provide a stable 5V DC output. Switching voltage regulator technology is chosen to reduce unnecessary power consumption wherever possible. In addition to low power consumption, the switching regulator produces far less heat than the linear regulator, which is a critical consideration as the device will be sitting on top of the dash and will be exposed to external heat through the windshield of the vehicle.

To see what possible DC-to-DC converters were available we used the Webench power designer tool available from Texas Instruments. This tool allows us to select an appropriate value for our input voltage, in this case around 12V, and select the ranges we want for each output (3V or 5V) The tool simplifies the design process by automating the selection of key components such as inductors, capacitors, and switching transistors, while considering various design constraints such as size, efficiency, and cost. The user can then select a specific topology and configure it further by specifying additional design constraints such as maximum component size, output ripple voltage, and thermal constraints. Once the design is configured, the tool will generate a complete bill of materials (BOM) that includes all the necessary components, as well as a schematic and layout diagram. Using this system, we wanted to prioritize a small footprint as our highest criteria with at least an efficiency rating above 90% for both the 3V and 5V converters, as past this value there would be little change in the performance and a much larger BOM leading to higher cost and footprint of the circuit. Both schematics can then be imported into Autodesk Eagle with a schematic layout, as well as the footprint layout, if they are in the Eagle library already. Components that are not will have to be added manually by using the footprint and package numbers given from Webench.

3VDC-to-DC - LMR54410DBVR	
Efficiency:	91%
BOM Cost:	$0.72
Footprint:	112 mm^2
BOM Count:	10
Topology:	Buck
Frequency:	1.1 MHz
IC Cost:	$0.42 | 1ku

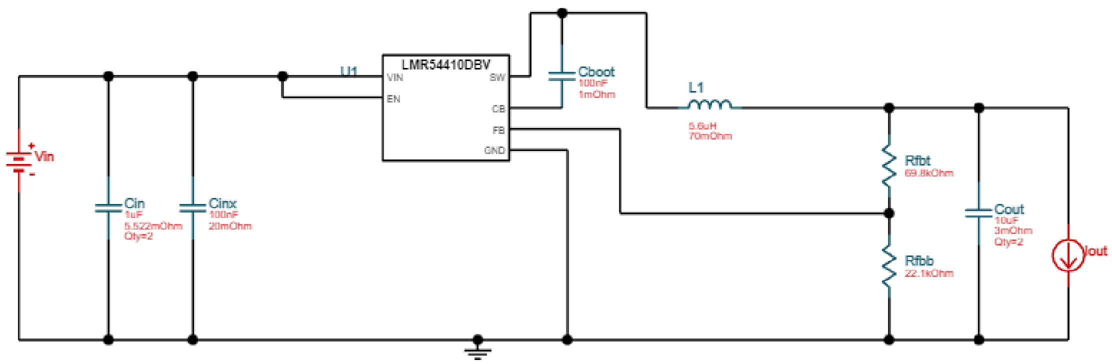


Figure3 LMR54410DBVR Topology

5V DC-to-DC - TPS562207DRLR	
Efficiency:	93.8%
BOM Cost:	$0.85
Footprint:	114 mm²
BOM Count:	11
Topology:	Buck
Frequency:	572.98 kHz
IC Cost:	$0.16 | 1ku

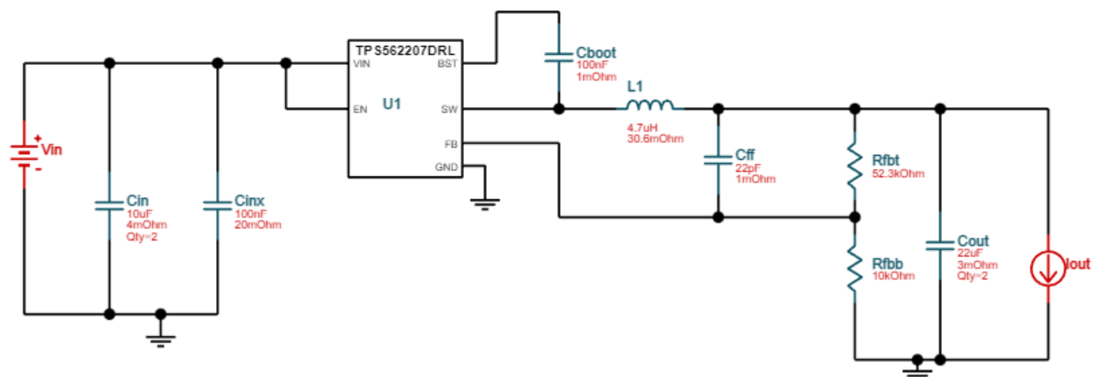


Figure 4TPS562207DRLR Topology

3.1.9 Image Processing

For our PCB we required an MCU to control and operate our system, the recording of images from the cam is too power intensive to also have it run off the PCB’s microcontroller. To process the images will have a separate MCU to run the dash cam. This will be in the form of a Raspberry Pi. The Raspberry Pi is also known for its GPIO (General Purpose Input/Output) pins, which allow users to connect various sensors, actuators, and other electronic components to the board. This makes the Raspberry Pi an excellent choice for projects. Moreover, the Raspberry Pi supports various programming languages, including Python, C/C++, and Java, which makes it easy to develop and control projects. The boards are powered by an ARM-based CPU, with various models featuring different speeds, RAM, and connectivity options. Due to its versatility, we can connect our camera and lens module to the Raspberry pi which we be strong enough to process the video. Another reason for the need of the additional MCU is the larger memory space to collect all the video taken that will be a much larger size than any of the other data transferred. This data can be stored for later viewing. One of the most common ways to use the Raspberry Pi for image processing is to connect a camera module to the board and use it to capture images or video. The Raspberry Pi camera module is a small camera that can be attached to the board using a ribbon cable. It can capture images with a resolution of up to 8 megapixels and video at up to 1080p resolution. The camera module can be controlled using the Raspberry Pi's GPIO pins, and images and video can be saved to the board's SD card. Once images or video have been captured, the Raspberry Pi can be used to process the data. This can involve using software libraries and tools such as OpenCV, which is a popular open-source computer vision library. OpenCV provides a range of functions for image processing, including image filtering, edge detection, and object detection. The Raspberry Pi's processing power may be limited compared to a dedicated computer, but it is still capable of performing many basic image processing tasks, mainly the ability for us to save the data locally on an SD card.

3.1.10 Image Ray Tracing

We would like to have a lens system that is designed to minimize the need for expensive specialty optics. To do this the lens design will be limited to spherical singlet lenses. Lenses with spherical curvature are easier to produce and cheaper than other alternatives such as parabolic lenses, which reduce spherical aberration at an increased cost.To start the lens design, the system will be designed as a single thin lens. This calculation method assumes the lens to be a two-dimensional plane, ignoring the propagation of rays that occur between the two surfaces of a lens. To calculate the focal length of the single lens needed to achieve the desired FOV we will use the equation below where d is the diagonal size of the sensor.

$$FOV = \tan^{-1}\left(\frac{d}{2f}\right)$$

Once the required focal length of a single thin lens is determined, the lens makers equation below will be used to calculate the necessary surface curvatures and thickness of the lens so that it can be input into Zemax.

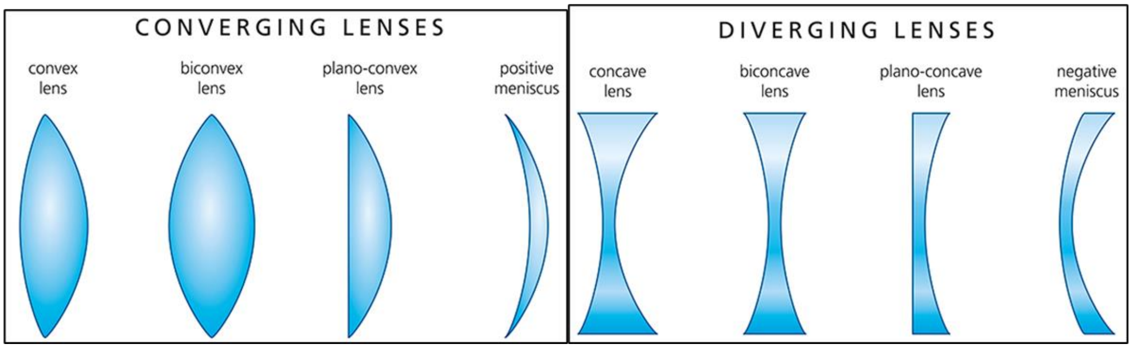
$$P = \frac{1}{f} = (n-1)\left(\frac{1}{R_1} - \frac{1}{R_2} + \frac{(n-1)d}{nR_1R_2}\right)$$

The next design step will be to split the single lens power across two or more lenses. With more than a single lens, paraxial ray tracing simplifies the process of tracing rays through multiple surfaces and can be utilized in spreadsheets to quickly determine how rays propagate as variables are adjusted. The equations for paraxial ray equation for a spherical surface and paraxial ray propagation in free space are below.

$$n_1u_1 = n_2u_2 - \frac{(n_2 - n_1)}{R}y$$

$$y' = y + u' z$$

The lens shapes that will be available for the design are bi-convex, plano-convex, bi-concave, and meniscus. Each shape bends incoming light rays in different manners and can be combined with varying lens power to capture light from the desired FOV and focus it to the correct dimensions on the imaging sensors plane. The radii of both faces determine whether the lens will converge or diverge incoming rays. An ideal converging lens focuses light from all angles to a single focal point forming a real image. An ideal diverging lens spreads light away from the optical axis and as a result forms a virtual image. In actuality, lenses have a focal depth, a range of distance that rays are focused on. Spherical aberration causes rays farthest from the optical axis to focus closer to the back surface of the lens than rays that are nearest to the optical axis. Another form of distortion that must be accounted for is field curvature. This distortion is an inherent property of spherical lenses and causes the focal plane to curve in image space. Because the sensor we will be using is a flat surface, optical design will need to be used to minimize this effect. Combinations of converging and diverging will enable the system to focus rays from the maximum incident angle to a plane as close to that of the on-axis rays. Below are examples of types of converging and diverging lenses.



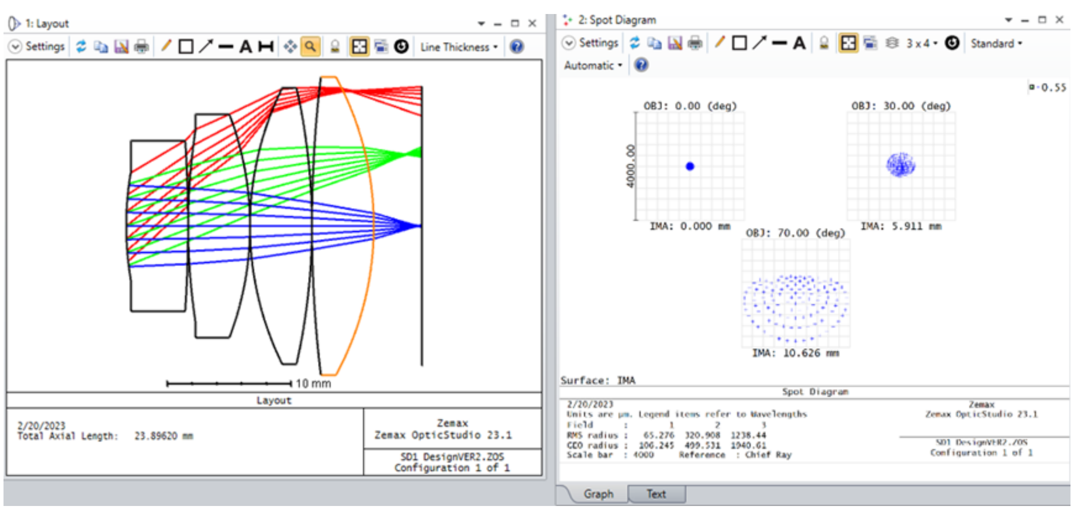
Another degree of freedom in the design is the material choice which will change the index of refraction that each wavelength experiences. Thorlabs Inc. offers lens in four different materials, N- BK7, UV Fused Silica, N-SF11, and CaF2. These materials refract light in the visible spectrum, but also outside of this range in the infrared and ultraviolet. A bandpass filter for 400 nm to 700 nm is also offered by Thorlabs Inc. and could be utilized. Finally, to reduce glare from light reflecting off the road, a linearly polarized filter will be added.

Parameter	Value
Field of View (FOV)	>110°
Image Height	4.45 mm
Resolution	2028 by 1080 pixels
Frame Rate	50 frames per second
Lens System Diameter	25.4 mm
Number of lenses	3 lenses
F-Number Range	F/1.8 - F/2.8

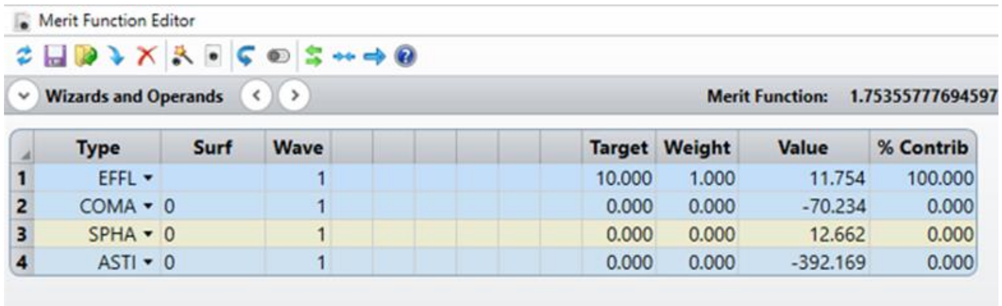
The table above shows the parameters that we are aiming for with the lens design. After researching various designs that balance the use of common optical elements, price, and desired Optical specifications we have decided to design a Cooke Triplet style lens. A Cooke Triplet system consists of three lenses, two of positive power and one of negative power equal to the sum of the two positive lenses. A Cooke Triplet is special because it can correct Seidel Aberrations more efficiently than if the system were designed without this guideline. Another key benefit of this style is that it can correct for field curvature, which at high FOV will be the main source of distortions in our system. To maximize the light collecting on the Raspberry Pi High Quality Sensor the image height will be half the diagonal length of the CMOS sensor which is 4.45 millimeters. The f-number determines two major factors in an optical system, the intensity of the collected light and the focal depth of the image. The intensity of the light is significant for our design because the shutter speed of the sensor would need to be reduced if enough light is not being collected which would lower the maximum frames per second that we could record at. Also, the focal depth of our system is important because if it is too shallow only a very small range of distance will be in focus when recording. For these reasons, a f-number between F/1.8 and F/2.8 is the goal of the optical system. A higher f-number indicates a smaller entrance pupil size which reduced the intensity of incoming light but increases the depth of field of the image. The range listed above will provide us with the proper balance of light collection while also prioritizing a larger depth of field in our system so that no autofocusing elements will be needed.

3.1.11 Zemax OpticStudio

Once the starting point is calculated for the desired specifications, the lens calculations will be transferred into Zemax OpticStudio to further optimize the ray paths through the system. Zemax is a powerful ray tracing software that quickly computes the propagation of light through optics. An important quantity that can be measured through Zemax is the spot size of incoming rays at various angles. The larger the spot size of the incoming rays, the more blur is added to the collected image. Using this software feature we can optimize the system to reduce the spot size to an area equivalent to the area of each pixel on the sensor. Zemax also has features that allow individual variables to be changed to maximize or achieve user defined characteristics such effective focal length, chromatic aberration, and spherical aberration. The ability to quickly optimize portions of the setup to achieve these specifications will ideally enable the system to use commonly available lens. The figure below is a preliminary design of the system only to demonstrate the capabilities of the Zemax software.



The window to the left shows the layout of the lens as well as the ray traces at each angle. In this image the rays are spaced at 70 degrees, 30 degrees, and 0 degrees. The window on the left calculated the RMS spot size of the focused light. The RMS spot size is a measurement of how tightly focused collimated rays of light are when they are at the back focal plane. The aim of the design is to get the RMS spot size of the on-axis ray to equal the pixel size so having this type of quantitative measurement will validate the achieved resolution of the system.


Merit Function Editor

Wizards and Operands | Merit Function: 1.75355777694597

	Type	Surf	Wave						Target	Weight	Value	% Contrib
1	EFFL		1						10.000	1.000	11.754	100.000
2	COMA	0	1						0.000	0.000	-70.234	0.000
3	SPHA	0	1						0.000	0.000	12.662	0.000
4	ASTI	0	1						0.000	0.000	-392.169	0.000

The figure shows the merit function editor within Zemax. Each row is a different quantitative measure of the system, such as EFFL which is the effective focal length. Other variables here represent other aberrations such as coma, spherical aberration, and astigmatism and Zemax has a wide variety of other functions. Merit functions can be given target values and adjust system values such as lens thickness, radius, and distances until the target values are achieved. This will also provide us with a detailed and quantitative analysis of the final lens design that can then be compared to other technologies.

3.2 Hardware Part Selection

3.2.1 Single Board Computer (SBC)

To determine which single board computer should be used for TrackPack, we need to specifically identify the demands of the hardware and match it with a suitable prospect from a list of potential candidates. It's important that we utilize a single board computer that is capable of simultaneously powering the display, sensors, image processing, and storing this information all with a low latency. Ideally, we are looking for a single board computer that has sufficient processing power and memory, while also retaining a small form factor and uses relatively low power. Using a product that is easily expandable is a significant factor also, a product with a large aftermarket hardware availability will make integrating the additional hardware substantially easier. Furthermore, a more widely used single board computer assists with the availability of resources. Should any issues arise, we hope to have a substantial number of online communities, libraries, or resources to assist with debugging.

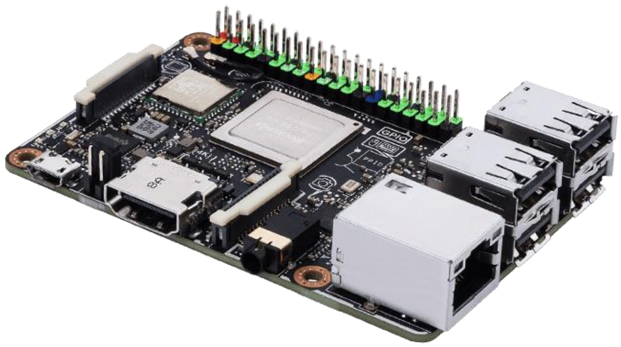
The first consideration when choosing our single-board computer will be the processing power. While the essential sensors that TrackPack will utilize (GPS, accelerometer, and gyroscope) don't require a great amount of processing power, and can typically be powered by a microcontroller, we'll require the additional processing power to implement the display, image processing, and OBD2 integration. The amount of processing power demanded by TrackPack is the simple reason why a typical microcontroller cannot be utilized.

The second consideration when choosing our single-board computer will be the form factor and power consumption. It's important that TrackPack maintains the size constraints of 8in x 5in x 3in, this size constraint is important due to the portable and mountable nature of TrackPack. It's ideal that TrackPack can be dismounted, moved, and remounted between vehicles as easily and quickly as possible. Our board selection must also remain relatively low power to extend the battery life. Typically, single board computers with similar processing power and features maintain similar power consumptions.

The third and final consideration when choosing our single board computer will be the cost, expandability, and support. It's essential that we choose a board that is cost effective. The obvious choice between two boards that boast similar specifications, but different price points is the cheaper board, however, if the cheaper board comes at the expense of lacking aftermarket expandability options and support, then the more expensive board will be our choice.

3.2.1.1 Nvidia Jetson Nano Developer Kit

The Jetson Nano is priced at $149.00 on Amazon and boasts a Quad-Core ARM Cortex-A57 CPU and a NVIDIA Maxwell GPU. The Jetson Nano comes standard with 4GB of LPDDR4 memory, and a plethora of interfaces such 4x USB 3.0, 2x MIPI CSI-2, HDMI and DisplayPort, Gigabit Ethernet, M.2 Key E, MicroSD, 3x I2C, 2x SPI, UART, and I2S. The entire assembled Jetson Nano Developer Kit comes in at 3.94in x 3.15in x 1.14in. The Jetson Nano is also capable of dual power modes where the first power mode can run with as little at 5w, while the second power mode utilizes 10w. Since the Jetson Nano was designed around AI, it also features powerful image encoding, up to 4Kp30, and powerful image decoding, up to 4Kp60. NVIDIA provides several resources and documentation on the Jetson Nano, and there are plenty of online resources, articles, and videos on using the Jetson Nano.



3.2.1.2 Asus Tinker Board S R2.0

The Asus Tinker Board S R2.0 is the next generation of the original Asus Tinker Board S. The Tinker board S R2.0 is priced at $142.99 on Amazon and features a Rockchip Quad-Core RK3288 CPU and an ARM Mali-T764 GPU. The Tinker Board S R2.0 comes with 2GB of Dual Channel DDR3. The Tinker Board S R2.0 contains an abundance of interfaces such as 4x USB 2.0, MIPI CSI, MIPI DSI, HDMI, Gigabit Ethernet, eMMC, MicroSD, 2x I2C, 2x SPI, 4x UART, and I2S. The Tinker Board S R2.0 also contains onboard 802.11b/g/n and Bluetooth 4.2. The Tinker Board S R2.0 comes in at 3.37in x 2.13in. Asus provides multiple resources and documentation on the Tinker Board S R2.0.

3.2.1.3 Raspberry Pi 4 Model B 4GB

The Raspberry Pi 4 is priced at $55.00 from any approved reseller and features a Quad-Core ARM Cortex-A72 CPU which is integrated on the Broadcom BCM2711 SoC along with the Broadcom Videocore VI GPU. The selected model of the Raspberry Pi 4 contains 4GB of LPDDR4 memory, and their standard number of interfaces including: 2x USB 3.0, 2x USB 2.0, MIPI CSI, MIPI DSI, 2x micro-HDMI, Gigabit Ethernet, MicroSD, 6x I2C, 6x SPI, and 6x UART. The Raspberry Pi 4 also contains onboard 802.11ac and Bluetooth 5.0. The Raspberry Pi 4 comes in at 3.35in x 2.20in. There are a substantial number of resources and documentation available both directly from Raspberry Pi, and other online mediums, and aftermarket part availability is considerable as well.

3.2.1.4 HardKernel ODROID-N2+ 4GB

The ODROID-N2+ is priced at $83.00 directly from HardKernel and features the ARM big.LITTLE architecture CPU with a Quad-Core ARM Cortex-A73 and a Dual-Core ARM Cortex-A53 as well as a Mali-G52 GPU. The selected version of the ODROID-N2+ contains 4GB of DDR4 memory. The ODROID N2+ interfaces include: 4x USB 3.0, USB 2.0, HDMI, Gigabit Ethernet, eMMC, MicroSD, 2x I2C, SPI, and UART. The ODROID N2+ comes in at 3.54 in x 3.54in x 0.67in. HardKernel provides a considerable number of resources and documentation, as well as additional parts for the ODROID N2+.

3.2.1.5 Single Board Computer Comparison

In section 3.2.1 we explained the predominant features that we're seeking out of the single board computer that we plan to utilize. After establishing the key features, we then delved into the specifications of each single board computer that was on our radar. In this section, we're going to directly compare each of the single-board computers that we mentioned previously to determine which is the best fit for TrackPack.

3.2.1.5.1 Processing Power

As aforementioned, while TrackPack doesn't require a substantial amount of processing power to efficiently run the sensors, we do need additional processing power in comparison to what typical microcontrollers can provide to incorporate the display, OBD2 integration, GPS, and image processing simultaneously. Each of the CPUs and GPUs from our four single board computer choices will be evaluated.

Single Board Computer	CPU Clock Frequency	GPU Clock Frequency
NVIDIA Jetson Nano	1.43 GHz	640MHz
Asus Tinker Board S R2.0	1.8GHz	600MHz
Raspberry Pi 4 Model B	1.5GHz	500MHz
HardKernel ODROID N2+	2.4Ghz (Cortex-A73) 2.0Ghz (Cortex-A53)	800MHz

By evaluating the chart above, the clear winner is the HardKernel ODROID N2+. While clock frequency generally means the processor is faster and capable of executing more cycles per second, other factors can play a role in CPU and GPU speed.

3.2.1.5.2 Form Factor and Power Consumption

TrackPack strives to be as low power as possible to achieve the maximum battery life. In this section, we will evaluate the power requirements of each single board computer, as we'll as their power consumptions.

Single Board Computer	Recommended Voltage (V)	Recommended Amperage (A)	Power Consumption (W)	Form Factor
NVIDIA Jetson Nano	5V	3A	5W – 10W	3.94in x 3.15in
Asus Tinker Board S R2.0	5V	3A	3.5W – 5W	3.37in x 2.13in
Raspberry Pi 4 Model B	5V	3A	2.7W – 6.4W	3.35in x 2.20in
HardKernel ODROID N2+	12V	2A	2.2W – 6.2W	3.54 in x 3.54in

By evaluating the chart above, while the HardKernel ODROID N2+ has the lowest power consumption, it also has the greatest voltage demand from the power supply. The NVIDIA Jetson Nano, Asus Tinker Board S R2.0, and Raspberry Pi 4, all utilize similar power supplies, however, the Raspberry Pi 4 has the lowest power consumption. In terms of form factor, the Asus Tinker Board S R2.0 consumes the least area, with the Raspberry Pi 4 following closely behind.

3.2.1.5.3 Cost, and Support

In addition to being as low power as possible, TrackPack also strives to be as cost effective as possible. However, cost effectiveness does not directly correlate to choosing the cheaper option regardless of specification. In this section, support will not only be evaluated on how many resources can be found from the manufacturer or other resources solely, but also by the extent of the aftermarket support for each single board computer. The support evaluation will be placed on a point scale in relation to the other single board computers and used to determine the winning board in the next section.

Single Board Computer	Price	Support
NVIDIA Jetson Nano	$149.00	3
Asus Tinker Board S R2.0	$142.99	2
Raspberry Pi 4 Model B	$55.00	4
HardKernel ODROID N2+	$83.00	1

3.2.1.5.4 Final Verdict

In this section we'll grade each of the single board computers based on their placements in the four categories (processing power, form factor, power consumption, cost, and support). Depending on where each single-board computer ranked in each category respectively, they will be assigned a value between one and four to be totaled.

Single Board Computer	Cost	Support	Processing Power	Form Factor	Power Consumption/Supply	Total Points
NVIDIA Jetson Nano	+1	+3	+2	+1	+2	9
Asus Tinker Board S R2.0	+2	+2	+3	+4	+3	14
Raspberry Pi 4 Model B	+4	+4	+1	+3	+4	16
HardKernel ODROID N2+	+3	+1	+4	+2	+1	11

After carefully reviewing each single-board computer and assessing them by cross-referencing with the demands required by TrackPack, we've decided to utilize a Raspberry Pi 4 Model B 4GB. We feel that while the Raspberry Pi 4 may fall slightly short in processing power, it makes up for it substantially in the remaining categories.

3.2.2 Global Navigation Satellite System (GNSS)

GNSS Implementation is the most crucial aspect of TrackPack. It's important that TrackPack measures GNSS with a high level of precision and relatively low latency so that we can effectively find ideal values such as the distance travelled along with the speed travelled. We can use this data to extrapolate the remaining parameters we intend to measure, such as ¼ mile time, ⅛ mile time, 0 – 60 mph time, 60 – 130 mph time, lap time, etc. In this section, we'll discuss the different GNSS technologies and dive into different GNSS modules to decide which of these would be the best fit for TrackPack.

Signals Bands

It's important to understand that when people refer to GPS, they are just referring to the GNSS signal band that is typically used in North America.

There are seven major GNSS signal bands which include:

- GPS
- GLONAS
- Galileo
- BeiDou

- NAVIC
- SBAS
- QZSS

It’s crucial that the amount of different GNSS signal bands be evaluated because many of the potential GNSS modules that will be evaluated in this section are capable of concurrent reception from multiple GNSS signal bands, the use of concurrent reception improves position accuracy, position availability, and reliability.

Update Rate

Update rate in GNSS modules refers to how often the module calculates and reports its position. The update rate is measured in Hertz (Hz) and the standard rate for most devices is 1Hz, which means that the device calculates and reports its positions every second.

Position Accuracy

While we discussed accuracy briefly when introducing signal bands, each GNSS module has specifications on the level of precision their module can provide. Typically, the position accuracy is measured in CEP or Circular Error Probable. Essentially the GNSS module manufacturer will specify the amount of meters CEP, what this means it that within the specified meter diameter, there is a 50% probability that your position is within the circumference.

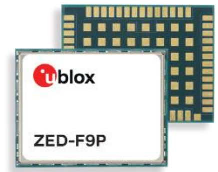
Acquisition

When it comes to GNSS, each module has a specific acquisition time whether it is performing a cold start or performing a reacquisition if the signal is lost for some reason. While substantially low acquisition times aren’t crucial due to the nature of TrackPack, reducing the acquisition time in general provides a more well-round, easy-to-use product.

Sensitivity

There are three primary types of sensitivities with most GNSS modules including: Acquisition, Tracking, and Navigation. Sensitivity is measured in dBm or decibel-milliwatts which is the power ratio in decibels in relation to one milliwatt. In relation to GNSS sensitivity, the closer the sensitivity is to zero, the stronger the signal strength is. Acquisition sensitivity refers to the minimum power level at which a GNSS module can simply get a position, commonly in a cold start situation where the module is required to initially search for all the satellites in view and connect. Tracking sensitivity refers to the minimum power level at which a GNSS module can maintain a connection to one or more satellites. Navigation sensitivity refers to the minimum power level at which a GNSS module can maintain a connection to one or more satellites to provide an accurate location while navigating. Since TrackPack will not be utilizing the GNSS module to perform and navigation but rather just calculating metrics, the navigation sensitivity will be omitted from the GNSS module evaluation.

3.2.2.1 U-blox ZED-F9P



The U-blox Zed-F9P is a high precision GNSS module capable of concurrent reception from four GNSS bands including: GPS + QZSS / SBAS, GLONASS, Galileo, and BeiDou. The U-blox Zed-F9P comes in at $199.00 from Digikey and combines multi-band GNSS with Real Time Kinematics (RTK) for extreme precision. The U-blox Zed-F9P has an update rate of up to 20Hz and a position accuracy of 0.01m + 1 ppm CEP. This reference to position accuracy correlates to the distance travelled, implying that this GNSS module is accurate to 10mm CEP with an additional 1mm CEP accuracy variation per kilometer travelled. The U-blox Zed-F9P has a cold start acquisition time of 24s and a reacquisition time of 2s. The sensitivities of the U-blox Zed-F9P are -148dBm for acquisition and -167dBm for tracking. Finally, the U-blox Zed-F9P requires between 2.7V and 3.6V and consumes 68mA at 3V.

3.2.2.2 U-blox CAM-M8C

The U-blox CAM-M8C is a standard precision GNSS module capable of concurrent reception from three GNSS bands including: GPS / QZSS, GLONASS, Galileo, and BeiDou. The U-blox CAM-M8C comes in at $27.00 from Digikey and has an update rate of up to 18Hz when only connected to a single GNSS band and 10Hz when utilizing 2 concurrent bands. The U-blox CAM-M8C has a position accuracy of 2.5m CEP and has a cold start acquisition time of 26s and a reacquisition time of 1s. The sensitivities of the U-blox CAM-M8C are -148dBm for acquisition and -164dBm for tracking. Finally, the U-blox CAM-M8C requires between 1.6V and 3.6V and consumes 28mA at 3V.

3.2.2.3 Quectel L26-T

The Quectel L26-T is another standard precision GNSS module capable of concurrent reception from three GNSS bands including: GPS / QZSS, GLONASS, Galileo, and BeiDou. The Quectel L26-T comes in at $39.68 from Digikey and has an update rate of up to 5Hz. The Quectel L26-T has a position accuracy of 1.5m CEP and has a cold start acquisition time of 35s and a reacquisition time of 2s. The sensitivities of the Quectel L26-T are -145dBm for acquisition and -162dBm for tracking. Finally, the Quectel L26-T requires between 3.0V and 3.6V and consumes 75 – 80mA at 3.3V.

3.2.2.4 GNSS Comparison

In section 3.2.2 we explained the predominant features that we're evaluating out of the GNSS module that we plan to utilize. After establishing the key features, we then delved into the specifications of each GNSS module that was on our radar. In this section, we're going to directly compare each of the single-board computers that we mentioned previously to determine which is the best fit for TrackPack.

3.2.2.4.1 Signal Bands

We've come to the consensus that access to more GNSS signal bands increases position accuracy and availability, as well as overall reliability.

GNSS Module	Number of Concurrent Bands	GPS	GLONASS	Galileo	BeiDou	NAVIC	SBAS	QZSS
U-blox ZED-F9P	4	✓	✓	✓	✓		✓	✓
U-blox CAM-M8C	3	✓	✓	✓	✓			✓
Quectel L26-T	3	✓	✓	✓	✓			✓

Evaluation of the chart above shows that not only does the U-blox ZED-F9P have access to an additional signal band in comparison to the U-blox CAM-M8C and the Quectel L26-T, but it also is able to concurrently connect to an extra band as well.

3.2.2.4.2 Update Rate and Position Accuracy

The update rate and position accuracy are some of the more important GNSS factors that we'll be evaluating. Typically, a substantially higher update rate isn't necessary unless you need to track high speed metrics where the location can change drastically in the fraction of a second. While our location won't be changing at an extreme rate, it's important that we keep the update rate on the higher end to increase precision in TrackPack's analytics. It's also important that TrackPack can track your position accurately to ensure that the measurements are as correct as possible so we can extrapolate the data we need with a high level of precision.

GNSS Module	Update Rate	Position Accuracy
U-blox ZED-F9P	20Hz	0.01m + 1 ppm CEP
U-blox CAM-M8C	10Hz	2.5m CEP
Quectel L26-T	5Hz	1.5m CEP

The chart above shows that the U-blox ZED-F9P has a substantially higher update rate, which is two to four times greater than its competition. The chart also reveals that its position accuracy is substantially greater than that of the U-blox CAM-M8C and the Quectel L26-T.

3.2.2.4.3 Acquisition Time

Acquisition time is one of the factors we're evaluating that isn't a core factor to TrackPack, however, faster acquisition times will lead to a more enjoyable, portable, and ready to use product.

GNSS Module	Acquisition Time	Reacquisition Time
U-blox ZED-F9P	24s	2s
U-blox CAM-M8C	26s	1s
Quectel L26-T	35s	2s

We can see from the chart above, that acquisition times between the U-blox ZED-F9P and U-blox CAM-M8C are relatively similar, while the acquisition time of the Quectel L26-T falls behind a bit.

3.2.2.4.4 Sensitivity

Similarly, sensitivity is another factor that is not a core factor when deciding on a GNSS module for TrackPack.

GNSS Module	Acquisition Sensitivity	Tracking Sensitivity
U-blox ZED-F9P	-148dBm	-167dBm
U-blox CAM-M8C	-148dBm	-164dBm
Quectel L26-T	-145dBm	-162dBm

The chart above shows that the Acquisition and Tracking Sensitivities are similar across all three GNSS modules, upon further research it appears that this sensitivity range is about industry standard for most GNSS modules. For this reason, sensitivity will not play a role in deciding which GNSS module will be used for TrackPack.

3.2.2.4.5 Supply Voltage, Power Consumption, Price, and Final Verdict

The last and final category evaluates the supply voltage, power consumption, and price. Power consumption and price are what we're predominantly considering in this category based on the design constraints of TrackPack.

GNSS Module	Supply Voltage	Power Consumption	Price
U-blox ZED-F9P	2.7V – 3.6V	68mA at 3V	$199.00
U-blox CAM-M8C	1.6V – 3.6V	28mA at 3V	$27.00
Quectel L26-T	3.0V – 3.6V	75 – 80mA at 3.3V	$39.68

From the chart above, we can see that the supply voltages for all three GNSS modules are similar, with the U-blox CAM-M8C being capable of operating on lower voltage. Power consumption between the U-blox ZED-F9P and the Quectel L26-T are similar, however, the U-blox CAM-M8C really sets itself forward here by being more than half as power efficient than its competition. The U-blox ZED-F9P came in between five and eight times expensive as the Quectel L26-T and the U-blox CAM-M8C respectively. After comparing each aspect of the three GNSS modules, it's clear that the U-blox ZED-F9P is a great GNSS module and has extreme accuracy and precision and relatively low power consumption, however, due to the design requirement and restraints of TrackPack, the U-blox ZED-F9P is slightly overkill in both performance and price. For this reason, we decided to choose the U-blox CAM-M8C.

3.2.3 Display

After deciding on which single board computer to use for TrackPack, it was important to select an accommodating display. During the initial inception of TrackPack, we decided that we wanted TrackPack to have as small a footprint as possible, like other products on the market. Ideally, TrackPack would contain no display and deliver all its information remotely and directly to a phone application. TrackPack would be easy to use and control with a few buttons on the device itself, and the rest of the controls and functionality to be performed through the app.

Shortly after, we decided that a small 2x16 display would assist the user to flip through menus and perform more functionality directly on the TrackPack itself as opposed to the phone application, furthermore, this would reduce the amount of development need in the mobile app. Well, as the research began and TrackPack started to come to life, the ideas grew larger. TrackPack didn't aspire to be as good as its competitors, it aspired to be greater. To alleviate the development of a mobile app to control TrackPack, we decided to incorporate a larger touchscreen digital display, all TrackPack's parameters can be accessed as easily as possible.

We decided to utilize the official Raspberry Pi 7in touchscreen LCD display. This display is easily integrable with the Raspberry Pi 4 using only two connections: power is taken from the GPIO port, and a ribbon cable connects to the DSI port. The display comes with the necessary adapter board that handles the power and signal conversion and has a display resolution of 800 x 480.

Concerns based on the size of the display have arisen. TrackPack was intended to be mounted directly on the windshield, this way the camera has a clear field of view through the windshield, and the user has a clear field of view of the display. While the large display would make parameters easy to see, concerns circled around whether the large display would hinder the driver’s field of view of the road. We won’t know with certainty if the driver’s field of view is hindered until TrackPack is assembled and mounted in a vehicle, however, to address this concern should it arise, we came up with a potential solution. Our solution is to simply mount TrackPack somewhere else, either on the side of the windshield and out of focus, or even somewhere on the dashboard of the vehicle. Mounting the TrackPack somewhere out of focus creates a new issue, the camera would not have a clear view through the windshield. This issue can easily be mitigated with the use of an external camera that can be mounted on the windshield. We’re hoping that these design concerns don’t arise because they would conflict with TrackPack’s portability aspect.

3.2.4 OBD II

The On-Board Diagnostics II, otherwise known as the OBD II, is a vehicle diagnosis system typically found in vehicles of the year 1996 or newer. The OBD II monitors specific parameters of a vehicle such as:

- Real-time parameters: RPM, speed, pedal position, spark advance, airflow rate, coolant temperature, etc.
- Status of “Check Engine” light
- Emission readiness status
- Freeze frame: a “snapshot” of parameters at the time a trouble event has occurred.
- Diagnostic trouble codes (DTCs).
- Oxygen sensor test results
- Vehicle Identification Number (VIN)
- Number of ignition cycles
- Number of miles driven with MIL on

The OBD II port is a standardized interface that makes it easier for the Electronic Control Unit (ECU) of a vehicle to communicate with an outside diagnostic instrument. The OBD-II port is a vital diagnostic component that enables in-car real-time system monitoring. It is often found underneath the dashboard on the driver's side of the car. In essence, the OBD II connector provides access to a vehicle's internal computer systems. A modern car's ECU handles a variety of tasks, including keeping track of the engine's performance, pollution levels, fuel economy, and several other systems.

The OBD II gathers information from several sensors and monitoring devices installed in the engine and other components of a vehicle. A standard pinout, or wiring diagram, for the OBD II port enables the diagnostic tool to connect with the car's onboard computer and gather DTCs.
Each OBD II port pin's (16 pins) function is specified by the OBD II pinout. Each pin on the OBD II port provides a different purpose. Two different types of OBD II port connectors include a wired connector and a Bluetooth adapter. When it comes to determining if a wired or wireless option is best, in the case of the TrackPack, the wireless option is preferred. The wireless connection eliminates the unnecessary restraint a cable connection would have. Consumers can move freely within and around their vehicle without being confined to the TrackPack in the vehicle.

The OBD II is important to the design of TrackPack because this is where the TrackPack will collect performance parameters from a user’s vehicle. The data collected will be passed on to the user so that they can be informed of how their vehicle is performing. This will help users determine which modifications, if any, are needed to acquire the desired performance.

A wireless communication module, memory, and a microprocessor are all parts of a Bluetooth OBD II scanner. The device's microcontroller oversees processing data obtained from the engine control unit of the car and transmits the data to the user's device, i.e., computer or mobile device. The wireless communication module transmits data wirelessly that is needed to operate the scanner, while the memory stores the software and transfers the data wirelessly to the external device.

3.2.4.1 ELM327 Bluetooth Adapter

The ELM327 Bluetooth adapter is compatible with smartphone devices and tablets. The ELM327 has a wired option depending on what the consumer would prefer. The wired option for the ELM327 adapter typically involves a USB connection that allows it to be plugged into a computer or other device. Yet, because of its practicality and use, the Bluetooth Adapter is typically more widely used. The ELM327 Bluetooth adapter has been advertised as having a primary benefit of its ease of use. The ELM327 Bluetooth Adapter is designed with extended compatibility with various mobile applications and software. Some mobile applications include Torque Pro, Car Scanner ELM OBD 2, and OBD Fusion. With its compatibility, users can read, interpret, and analyze the data gathered from the vehicle’s engine control unit.

The ELM327 Bluetooth Adapter has advanced scan capabilities compared to other Bluetooth OBD II adapters. This module specifically has comprehensive diagnostic capabilities, including the ability to reset the Check Engine Light and monitor emissions systems, as well as read and clear diagnostic trouble codes (DTCs), see real-time data, including engine speed, throttle position, and coolant temperature. Since the ELM327 Bluetooth adapter is compatible with various third-party software applications, this allows it to perform even more advanced functions such as logging data, performing custom tuning, and even displaying data on a dashboard in real-time.

The ELM327 Bluetooth Adapter is a small compact device constructed of plastic. The device has indicators such as LED lights that let users know when the device is turned on and in communication with their mobile device. Also, the adapter is made to be plug-and-play, so the mobile device does not need to have any additional software or drivers loaded to use it. The ELM327 Bluetooth adapter is best known and preferred because of its low cost and dependability.

3.2.4.2 Panlong

The Panlong OBD II scanner works similarly to the ELM327 Bluetooth Adapter. While the Panlong OBD II scanner is connected to the OBD II port, it is powered directly, so this eliminates the need for an external power source. The Bluetooth adapter is convenient to use since there are no strict restrictions on being tethered to the vehicle. Like many others, the Panlong OBD II scanner is a compact and lightweight module that can easily be stored. The module is compatible across many platforms that include Windows, Android, and iOS. Some modules on the market are restricted to either iOS platforms/Android platforms or just PC platforms.

The Panlong adapter has reading capabilities for basic information which can be useful for diagnosing simple issues with the vehicle. The Panlong adapter is a more basic OBD II scanner that is designed primarily for reading and clearing diagnostic trouble codes (DTCs It can also display some real-time data such as vehicle speed, RPM, and engine load, but it does not have the same advanced diagnostic capabilities as the ELM327 Bluetooth adapter. The Panlong scanner does not have the advanced diagnostic capabilities such as resetting the Check Engine Light, monitoring emissions systems, or performing custom tuning. This limits its usefulness for more advanced diagnostics and repairs.

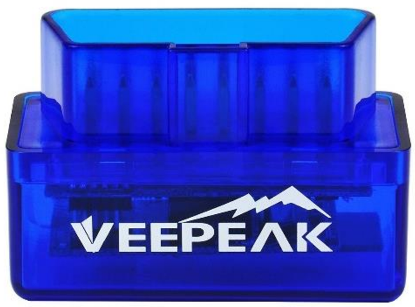
The Panlong adapter is a more basic tool that is primarily designed for reading and clearing DTCs. This module is an ideal choice for consumers that need simple and straight forward readings from the scanner. Users that have a minimal requirement of obtaining basic diagnostics on a vehicle may choose this option, especially when factoring in the affordability of this simple device.

3.2.4.3 OBDLink MX+

The OBDLink MX+ is one of the more advanced Bluetooth OBD II scanners on the market. The Bluetooth scanner carries capabilities such as enhanced trouble codes and enhanced parameters (PIDS). The scanner allows for PIDs on the supporting mobile applications to be graphed, added to the dashboard, and viewed on the data grid page. The OBDLink MX + is supported on platforms such as iOS, Android, and Windows. With secure 128-bit data encryption, the Bluetooth OBD II scanner is advertised to be hacker-proof. advanced security technology. on the OBD II scanner sets it apart from many others. Many Bluetooth OBD II scanners require a pairing pin on initial setup, the pin is typically advertised on the website, and it is as basic as 1234 or 0000. The OBDLink MX+ employs an innovative multi-layered link security mechanism that eliminates the possibility of security breaches from unapproved users.

The OBDLink MX + allows users to turn off the check engine light, and erase stored diagnostic information, read and erase stored and pending trouble codes (both generic and manufacturer-specific), access freeze frame information, display, graph, and log 90+ real-time parameters, create custom digital dashboards, measure, and display fuel economy, etc. The OBDLink MX+ is one of the more expensive scanners on the market due to the sophisticated capabilities and features it has. Unlike other scanners that are low-cost, the OBDLink MX+ can read and clear trouble codes such as ABS, airbag, transmission, body control. The scanner provides access to many other parameters and sensors that the typical OBD II doesn't offer. The mobile application that the OBDLink MX+ is supplied with the following features as advertised on their website: provides advanced diagnostics, trip logging, multi-parameter graphing, customizable gauges, 0-60 times, 1/4-mile performance, Freeze Frame, SMOG readiness, over-voltage protection to prevent electrical fires, firmware updates, and Dropbox support. The Bluetooth scanner supplies a power saving sleep mode, BatterySaver, so that users may leave their OBD II scanner plugged into the OBD II port without worrying about depleting the vehicle's battery.

3.2.4.4 Veepeak



Veepeak is a company that specializes in automotive tools and accessories. The OBDCheck VP11 is Veepeak's Bluetooth OBD II scanner. With this Bluetooth module, users can view car performance data, but there are some limitations that apply. OBDCheck VP11 is only compatible with Android devices and Windows PC only. They do offer an iOS compatible product which is the Wi-Fi version OBDCheck BLE. Accompanying the OBDCheck VP11, users need a third-party OBD II application such as OBD Fusion, Car Scanner ELM OBD2, Dr. Prius and DashCommand. Upon installing this mobile application, users then have access to the features of the OBDCheck VP11.

The OBDCheck VP11 can read, and clear fault codes related to the engine, transmission, and emission systems, and display live sensor data such as engine RPM, coolant temperature, fuel system status, oxygen sensor readings, throttle, boost, speed, fuel trim, and more. It can also perform smog tests by checking the readiness of the vehicle's emission control system. Some limitations apply such as the module may not be able to scan certain proprietary systems or modules that are not part of the OBD II standard. The OBDCheck VP11 may not be able to read ABS (anti-lock brake system) codes or airbag codes on some vehicles. Additionally, some advanced features, such as bi-directional control or programming, may not be supported.

3.2.4.5 OBD II Scanner Protocol Compatibility Comparison

We would like TrackPack to be versatile and increase compatibility possibilities. In this section, we compare each Bluetooth OBD II scanner protocol compatibility to determine which device is best.

Bluetooth OBD II Scanner Protocol Compatibility Comparison				
	ELM327	Panlong	OBDLink MX+	Veepeak
SAE J1850-PWM	✓	✓	✓	✓
SAE J1850-VPW	✓	✓	✓	✓
ISO 9141-2	✓	✓	✓	✓
ISO 14230-4 (slow)	✓	✓	✓	
ISO 14230-4 (fast)	✓	✓	✓	

ISO 15765-4 (CAN)	✓	✓	✓	✓
SAE J2411 (SWCAN)	✓		✓	
SAE J1939	✓			

Based upon the chart, it demonstrates the ELM327 Bluetooth OBD II scanner possesses the most protocol compatibility in comparison to the rest of the devices.

3.2.4.6 Build and Cost Comparison

Below is a chart comparing the overall build and cost of each Bluetooth scanner. We aim to develop a cost-effective device while also considering the support and specifications of each product.

Bluetooth OBD II Scanner Build and Cost Comparison				
	ELM327	Panlong	OBDLink MX+	Veepeak
Weight	0.81 ounces	0.64 ounces	1.2 ounces	1.12 ounces
Dimensions	1.97 x 1.18 x 0.59 inches	1.89 x 0.98 x 1.26 inches	1.97 x 1.77 x 0.91 inches	1.89 x 1.26 x 0.98 inches
Part Number	OTR-000	PL-B02	MX201	VP11
Cost	$13.99	$12.99	$139.95	$13.99

Overall, each Bluetooth scanner is quite similar in size and weight. The purpose of this comparison chart is to determine the most compact, lightweight, and cost-effective part. With this consideration, we must factor in the specifications and compatibility of each device also.

3.2.4.7 Final Verdict

In this section we'll grade each of the Bluetooth OBD II scanners based on their placements in the three categories (cost, protocol compatibility, and overall build). Depending on where each Bluetooth OBD II scanner ranked in each category respectively, they will be assigned a value between one and four to be totaled.

Bluetooth OBD II Scanner	Cost	Support	Build	Total Points
ELM327	+3	+4	+4	10

Panlong	+4	+2	+3	9
OBDLink MX+	+1	+3	+1	5
Veepeak	+3	+1	+2	6

TrackPack is meant to be a seamless, lightweight, and easy to use device. We have chosen to research Bluetooth module options for OBD II scanners to achieve ease of use for our consumers. The TrackPack requires more intricate readings than just the basics, therefore the Panlong Adapter is not the optimal choice for this build. The TrackPack requires in-depth analysis to be provided for consumers to get a well-rounded summary of their vehicle's performance. In terms of comparison with the ELM327 Bluetooth adapter and the OBDCheck VP11, they are quite similar. The performance and features of each device are comparable. The main difference is that the OBDCheck VP11 is specifically designed for use with smartphones and tablets and may be more convenient for users who prefer to work with those devices. The ELM327 Bluetooth adapter is a more general-purpose tool that can work with a wider range of devices and may be more versatile unlike the Panlong that is limited to on the OBD II protocols. With a more advanced OBD II scanner like OBDLink MX+, the enhanced features come with a significantly higher cost. The features provided with the OBDLink MX+ are not necessary to the design of the TrackPack. The OBDLink MX+ appears to gear more towards mechanics for vehicle repairment. TrackPack is made to enhance performance on vehicles, not necessarily to repair vehicles.
After the comparison of the four Bluetooth OBD II scanners, the ELM327 appears to be the ideal scanner for TrackPack, especially with the wider range of protocol compatibility and favorable cost.

3.2.5 Inertial Measurement Unit (IMU)

Aside from the GPS, an IMU is how we plan to capture the remaining accelerometer and gyroscope metrics. To further understand the metrics the IMU will be capturing, it's important to establish the fundamentals of each.

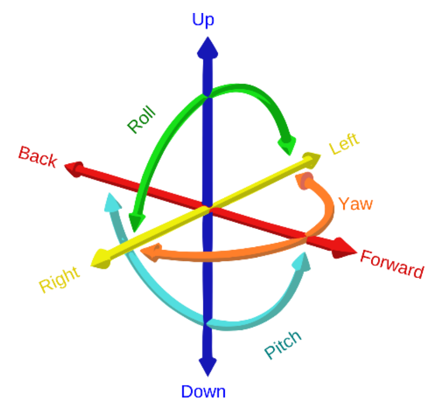
Accelerometer

An accelerometer is beneficial to TrackPack because we can measure the acceleration forces acting on the vehicle. Accelerometers measure the gravitational forces, g-forces, that act on the vehicle when accelerating, braking, and cornering. Measurement of these forces is important to determine the impact on the stability, speed, and maneuverability of the vehicle. Drivers can use these parameters to improve their driving and vehicle performance. Specifically with the measurement of the lateral G-forces during cornering, readings as such can assist the driver in determining the optimal speed and trajectory through a corner. Understanding the accelerometer readings can help vehicle builders to perform the necessary modifications needed for their vehicle to handle more predictably.

Gyroscope

Like accelerometers, gyroscopes are beneficial to racers, however, the gyroscope poses greater value to off-road vehicle enthusiasts in comparison to on-road vehicle enthusiasts.

Nonetheless, road racing vehicles can benefit from gyroscope information to accurately help them track stability, and maneuverability through corners. Furthermore, off-road users benefit from a gyroscope to accurately track the vehicles angle.



It's important to understand that an object in a three-dimensional space has 6 degrees of freedom (DOF). The object can have a translation movement or rotation movement. Translation movements are up/down, left/right, forwards/backwards. While rotation movements are pitch, yaw, and roll. These 6 degrees of motion are typically tracked using an accelerometer and either a gyroscope or magnetometer. While the three sensors do have some overlap in the parameters they can capture, this overlap helps add accuracy to the data. We know that an object in a three-dimensional space can only move 6DOF. As mentioned previously, the measured parameters from these three sensors overlap with one-another, so if each of the three sensors can determine 3DOF individually, ignoring the fact that each sensor may be calculating a degree of freedom that was already calculated by another sensor, we come to get a total of 9DOF. 10DOF IMU's simply add a barometer. So, a 6DOF IMU captures essentially the same parameters as a 9DOF or 10DOF IMU. Sensor fusion allows us to utilize more sensors in conjunction with one-another, we can mix the data from the different sensors to increase the quality and accuracy of the final measurement, which simply means that 9DOF and 10DOF IMU's are more precise.

3.2.5.1 Adafruit 9-DOF IMU

The Adafruit 9DOF IMU integrates the Bosch BNO055 9DOF sensor that features 9-axis sensor fusion by utilizing a 3-axis gyroscope, 3-axis accelerometer, and 3-axis magnetometer The integrated Bosch BNO055 operates on a voltage range from 2.4V to 3.6V and features digital interfacing through I2C and UART. The accelerometer incorporates programmable ranges ±2g, ±4g, ±8g, and ±16g. The gyroscope incorporates programmable ranges ±250dps, ±500dps, ±1000dps, and ±2000dps. The Magnetometer incorporates a typical measurement range of s ±2500µT. The accelerometer and gyroscope feature selectable low pass filters. The Bosch BNO055 features motion triggered interrupts and multiple modes of operation that give full control of each individual sensor.

3.2.5.2 SparkFun 9DoF IMU

The SparkFun 9DoF IMU integrates the TDK ICM-20948 9DOF sensor that features 9-axis sensor fusion by utilizing a 3-axis gyroscope, 3-axis accelerometer, and 3-axis magnetometer The integrated TDK ICM-20948 operates on a voltage range from 1.71V to 3.6V and features digital interfacing through I2C and SPI. The accelerometer incorporates programmable ranges ±2g, ±4g, ±8g, and ±16g. The gyroscope incorporates programmable ranges ±250dps, ±500dps, ±1000dps, and ±2000dps. The Magnetometer incorporates a typical measurement range of s ±4900µT. The accelerometer and gyroscope feature selectable low pass filters. The TDK ICM-20948 features motion triggered interrupts and multiple modes of operation that give full control of each individual sensor.

3.2.5.3 BerryGPS-IMU GPS and 10DOF

The BerryGPS-IMU GPS and 10DOF integrates the ST LSM6DSL sensor that features a 3-axis gyroscope, 3-axis accelerometer, the ST LIS3MDL sensor that features a 3-axis magnetometer, and the Bosch BMP388 barometer. The integrated ST LSM6DSL operates on a voltage range from 1.71V to 3.6V and features digital interfacing through I2C and SPI. The integrated ST LIS3MDL operates on a voltage range from 1.9V to 3.6V and features digital interfacing through I2C and SPI. The accelerometer incorporates programmable ranges ±2g, ±4g, ±8g, and ±16g. The gyroscope incorporates programmable ranges ±250dps, ±500dps, ±1000dps, and ±2000dps. The Magnetometer incorporates a typical measurement range of s ±1600µT. The accelerometer and gyroscope feature selectable low pass filters. The ST LSM6DSL and ST LIS3MDL features motion triggered interrupts and multiple modes of operation that give full control of each individual sensor.

3.2.5.4 IMU Comparison

In section 3.2.5 we described the sensors that TrackPack will be utilizing and why the measurements and level of accuracy from these sensors are important to the functionality of TrackPack. We also introduced the specifications of each IMU. In this section, we'll directly compare each IMU to determine which would be a suitable fit for TrackPack.

IMU	Adafruit 9-DOF IMU	SparkFun 9DoF IMU	BerryGPS-IMU GPS and 10DOF
Accelerometer Programmable Ranges	±2g, ±4g, ±8g, and ±16g	±2g, ±4g, ±8g, and ±16g	±2g, ±4g, ±8g, and ±16g
Gyroscope Programmable Ranges	±250dps, ±500dps, ±1000dps, and ±2000dps	±250dps, ±500dps, ±1000dps, and ±2000dps	±250dps, ±500dps, ±1000dps, and ±2000dps
Magnetometer Measurement Range	±2500µT	±4900µT	±1600µT
Voltage Range	2.4V – 3.6V	1.71V – 3.6V	1.71V – 3.6V 1.9V – 3.6V
Interfacing	I2C and UART	I2C and SPI	I2C and SPI
Low-Pass Filtering	✓	✓	✓
Motion Triggered Interrupts	✓	✓	✓

Selectable Power Modes	✓	✓	✓

Evaluation of the chart above shows that all three IMU's feature an accelerometer and gyroscope with the same programmable ranges. The SparkFun 9DoF IMU can read greater levels of magnetic fields, making it slightly more precise. The Adafruit 9-DOF IMU interfaces with I2C and UART as opposed to the competitors I2C and SPI interfacing, this breakout board also has a slightly higher minimum voltage. The primary difference is that the BerryGPS-IMU GPS and 10DOF comes with and additional barometric sensor integrated, as well as the GNSS module integrated already. If we required a GNSS module with a higher level of precision, the best idea for TrackPack would be to utilize the either of the previously mentioned 9DOF boards from Adafruit or Sparkfun, as their specifications are almost identical, along with the separate high precision GNSS module. However, seeing as we decided to go with the more affordable standard precision level GNSS module, the BerryGPS-IMU GPS and 10DOF are perfectly suitable for TrackPack and we can potentially pull data from the additional barometric sensor it provides. We would like to point out that the most cost-effective route when choosing the IMU is to purchase the IMU and GPS separately, however, we decided that the cost is worth the benefits to maintain a small form-factor and ease of use.

3.2.6 Raspberry Pi High Quality Camera

For the image collection and processing, we will be using a Raspberry Pi 4 along with the Raspberry Pi High Quality Camera. The sensor used in the camera module is a Sony IMX477 sensor. The IMX477 is a 12.3-megapixel resolution CMOS sensor and measures 7.9 millimeters diagonally. When recording video this sensor can record 2028p x 1080p resolution at 50 frames per second and 1332p x 990p resolution at 120 frames per second. The ability to record at frame rates as high as 120 frames per second will reduce motion blur in the video that would have affected the smoothness and quality of the video. The 1080p resolution will provide more value when the camera is not recording high speed races, for instance in traffic incidents the pixels per inch are more important than the speed at which images are collected. The Raspberry Pi will collect the data from the camera module and combine the data collected from the entire system with the video. The Raspberry Pi is also where the digital image filtering for field curvature distortion could be optimized as an advanced goal.

The sensor includes a C-mount and a CS-mount threaded adapter to connect a lens or lens tube to the sensor. The C-mount connector has a focal distance of 17.525 millimeters and the CS-mount has a focal distance of 12.525 millimeters. Ideally, we would design the system to interface with the CS-mounting hardware, but no commercial optics company sells lens tubes with that thread type. As a result, we chose to design an optical system to connect to the sensor with the C-mounting standards. To accommodate such a tight focal distance the mount has an adjustable focusing knob with a bandwidth of 10 millimeters. This will allow us a small window of acceptable focal lengths instead of requiring an exact value. The Raspberry Pi camera sensor can output the signal as RAW12/10/8 or COMP8 to the Raspberry Pi 4 computer over the included ribbon cable.

Since we will be utilizing a Raspberry Pi 4 to process the videos and data collected, we have chosen to use an official Raspberry Pi camera module. The goal of choosing an official Raspberry Pi sensor is to guarantee compatibility with the Raspberry Pi in the hopes that it makes integrating the video collection a smooth process. Raspberry Pi newest two varieties of sensors are the High-Quality camera sensor and the Global Shutter sensor. There are two main differences between these sensors and each has specifications suited to different applications. The High-Quality camera has a sensor resolution of 12 megapixels while the Global Shutter camera has a sensor resolution of 1.2 megapixels. The higher pixel count on the High-Quality camera will be more advantageous to our design because our goal is to collect video with a resolution of 1080p and the 12-megapixel sensor will give greater flexibility if the spot size of the light collected is larger than the pixel size. The second difference between the two sensors is the way they sample each pixel. The High-Quality sensor scans each pixel in each row one at a time to collect the final image frame. The Global shutter sensor is able to capture the data from every pixel at the same time which reduces distortion commonly found on standard sensors. The global shutter is useful for machine vision and high shutter speed photography, but after researching each sensor we have chosen to use the standard High-Quality camera sensors as the high resolution will be more beneficial to our project than the global shutter.

The Raspberry Pi High Quality camera module is available with three different mounting options for our lens array. The three types are the C-Mount, CS-Mount, and M12 mount styles each of which have slight differences. The biggest difference between all three is the flange focal distance, which simply is the distance between the deepest point of the threading and the sensor's surface. This variable plays a crucial role in our project because FOV is inversely related to the back focal length. Therefore, to achieve the highest FOV, the back focal distance should be as small as possible so that the rays with the highest incident angle can be focused within the sensors nine-millimeter diagonal size. C-Mount lenses have the longest flange focal distance of 17.526 millimeters. To accommodate this mounting style in our design, the lens array will need to have the largest magnification to focus rays from that far away to the sensor's less than one centimeter size. The next mounting style available is the CS-Mount, with a flange focal distance of 12.526 millimeters. This shorter focal distance will allow our design to use fewer optics to focus the image on to the sensor. Finally, the M12- mount has no standard flange focal distance, but with the Raspberry Pi High-Quality sensor the flange focal distance can be as low as four millimeters. This would be the most ideal mounting option if our budget was unrestricted due to the inverse relation of focal length and FOV, however it would require a more specialized design. We have chosen to utilize the CS-mounting style as it provides the best balance between the highest achievable FOV and our available budget. Another factor that affected our choice is how we will mount our lens array to the sensor. Our goal is to 3D-Print the mounts to secure each lens, and due to the CS-Mounts larger diameter it will give up greater tolerance in our design to accommodate any printing or design errors.

3.2.7 Storage

The TrackPack will be designed to collect vehicle parameters and record footage so choosing the best storage option is important. Upon selecting the Raspberry Pi 4 Model B to be the optimal choice for the TrackPack design, the unit does not provide internal storage. The single board computer offers a microSD slot and USB 3.0 port. In this section, we will discuss the two options for external storage, microSD card storage and USB drive storage.

3.2.7.1 microSD Card

The microSD card is a simple, lightweight device that is commonly used among devices such as smartphones and cameras. Since the microSD card is small, they are inherently portable and minimalistic for storing data and transferring data between devices. Considering these advantages, it's especially a favorable option for consumers since they are cost-effective. The microSD card is supported among an extensive variety of applications and requires minimal power.

Even though the microSD card seems an ideal option for consumers, there are other factors to consider like the durability of the microSD card. The storage card can be susceptible to electronic corruption, and it can easily be broken. The life span of the microSD card is finite since the technology behind the storage card is flash memory where there are limited read/write cycles, even though they are designed to last for a theoretical limit of 30 years. Consumers may view these disadvantages as miniscule, especially since the lifespan of the storage card is extensive, never mind the cycle limitations. The microSD card is not the fastest on the market when it comes to data transfer speed, but consumers typically don't notice the difference between the speed of microSD card and that of a USB drive.

3.2.7.2 USB Drive

The USB drive is like a microSD card in terms of ease of use and portability. The USB drive can be easily stored for travel, and they are a simple and effective way to save and transmit data. The USB drive may offer more durability compared to the microSD card. The USB driver is encased with either a plastic or metal housing which protects the internals of the USB drive. There are marginal differences between the USB drive's read and write speeds. The USB drive does perform at a fast rate of up to about 40 GB/s depending on which model USB drive consumers use. The USB drives are more resistant to damage, and they are resistant to corruption and data loss. Like any other technology, the USB drive can be more prone to failure over time. USB drives use flash memory technology, so since there are limits on their rea/write cycles, the external storage unit can wear out over time.

3.2.7.3 External Storage Comparison

The microSD cards and USB drive are popular storage devices, with notable differences. Both external storage devices differ in size, the microSD card being the smaller device. Some consumers may prefer the smaller storage device because it may be more convenient to use with portable devices. Other consumers may prefer the USB drive since the transfer speed of data is higher than the microSD card and the USB drive is more durable. Depending on the application, consumers would have to decide which external storage device is best for them. In the case of TrackPack, we chose to utilize the microSD card as our external storage simply due to the seamlessness of the device. We see the difference in transfer speeds between the devices to be negligible since this is a device that will be in an active environment. The Raspberry Pi we will be using has a built in microSD slot and we would like consumers to have a sleek and compact design rather than a USB drive hanging out the side. Since we chose a storage device that gets stored internally, this eliminates the possibility of possible breakage from the USB drive, since it would be open and more susceptible to breaking off. Since the use of TrackPack will be in an extremely active environment, the USB drive would not be ideal.

Interface	Storage Type	Data Transfer Speed
Default	SD, SDHC, SDXC, SDUC	12.5 MB/s
High	SD, SDHC, SDXC, SDUC	25 MB/s
UHS-I	SD, SDXC, SDUC	50 MB/s
UHS-II	SD, SDHC, SDXC, SDUC	312 MB/s
UHS-III	SD, SDHC, SDXC, SDUC	624 MB/s
SD Express	SD, SDHC, SDXC, SDUC	985 MB/s
	USB 2.0	480 MB/s
	USB 3.0	5 GB/s
	USB 3.1	10 GB/s
	USB 3.2	20 GB/s
	USB 4	40 GB/s

MicroSD Card and USB Drive Comparison				
	SanDisk 64GB Extreme PRO MicroSD	SanDisk 256GB Ultra Luxe USB	SanDisk 256GB Extreme PRO MicroSD	SanDisk 256GB Ultra Luxe USB
Cost	$13.69	$10.23	$33.90	$21.99

Dimensions	0.04 x 0.59 x 0.43 inches	1.57 x 0.62 x 0.23 inches	0.04 x 0.59 x 0.43 inches	1.57 x 0.62 x 0.23 inches
Weight	0.176 ounces	0.279 ounces	0.176 ounces	0.279 ounces
Item Number	SDSQXCU-064G-GN6MA	SDCZ74-256G-G46	SDSQXCD-256G-GN6MA	SDCZ74-256G-G46

3.2.7 Microcontrollers

Researching into available MCUs that would have the I²C compatibility and enough processing speed left two options between a MCU from the Texas Instruments MSP430 series and the ATMEGA328.

3.2.8.1 MSP 430

The MSP430 series of microcontrollers (MCUs) is a popular family of 16-bit MCUs developed by Texas Instruments. The series is designed to provide low-power performance for a wide range of applications, including industrial automation and remote sensing. One of the key features of the MSP430 series is its low power consumption. The series includes several low-power modes, including standby and shutdown modes, which help to extend battery life in battery-operated devices. The MSP430 also features an ultra-low power consumption mode that can be used to prolong battery life even further.

3.2.8.2 ATMEGA328

ATmega328 is an 8-bit, 28-Pin AVR Microcontroller, manufactured by Microchip, follows RISC Architecture, and has a flash-type program memory of 32KB. Atmega328 is the microcontroller, used in basic Arduino boards i.e., Arduino UNO, Arduino Pro Mini and Arduino Nano.

3.2.8.3 Microcontroller Comparison and Selection

We decided to choose the MSP430F168IPM as though it has less speed, it is still significant to relay the information back to the user fast enough for our product. It also has more I/O ports and more memory size for all the different data statistics it will read, and requiring a lower voltage supply with the addition of low power modes to conserve power when not in use and requires a lower Voltage supply than the ATMEGA. From previous courses, we also have experience using the development environment for the MSP430 series, and the language that the MSP430 uses.

	Microcontrollers	
Name	MSP430F168IPM	ATMEGA328P-PU DIP28
Core Size	16-Bit	8-Bit

Speed	8MHz	20MHz
Connectivity	I²C, SPI, UART/USART	I²C, SPI, UART/USART
Peripherals	Brown-out Detect/Reset, DMA, POR, PWM, WDT	Brown-out Detect/Reset, POR, PWM, WDT
Number of I/O	48	23
Program Memory Size	48KB (48K x 8 + 256B)	32KB (16K x 16)
Voltage - Supply (Vcc/Vdd)	1.8V ~ 3.6V	1.8V ~ 5.5V

4 Design Constraints and Standards

TrackPack has set forth to follow a relatively strict set of standards and design constraints relating to both the hardware and the software.

4.1 Standards

Section	Standard
4.1.1	PCB
4.1.2	Soldering
4.1.3	12V Car Outlet Power
4.1.4	USB Communication
4.1.5	Optical Mounting Hardware
4.1.6	CSI
4.1.7	HDMI

4.1.1 PCB Standards

For our PCB design we will be following the IPC-2221 standard. This standard covers acceptable circuit board design, interconnections and how to correctly mount components. The most significant topics covered in this standard include how to properly space conductors and how large the traces on the board should be. When placing conductors on the PCB the distance between the two components would need to be spaced a certain distance. The way these components are spaced is based on two measurements, clearance and creepage, which can be seen on the figures below. Ideally the space between the conductors will be as much as possible without becoming redundant. These are defined in international standards IEC 950 and EN 60950.

4.1.2 Soldering Standards

J-STD-001 is a standard issued by IPC for soldered electrical and electronic assemblies. The standard specifies material specifications, process requirements, and acceptability criteria. Joint industry-standard(J-STD-001) is the industrial specification for electronics and electrical assemblies that are grouped according to the product classes. Electronic products are classified into three groups according to manufacturability, performance requirements, process control regulations, and verification testing.

Class 1: general electronic products

Class 2: service electronic products

Class 3: High-performance electronic products

The latest version of this document is J-STD-001 H. These standards outlines materials, methods, and verification criteria for making high-quality soldered interconnections (lead and lead-free). This certification includes a thorough explanation of the following elements:

- Material, component, and equipment
- Soldering and assembly requirements
- Terminal and wire connection
- Through-hole mounting
- Surface mounting of components
- Cleaning and residue requirements
- Coating, encapsulation, and adhesives

4.1.3 12V Car Accessory Outlet Standard

Standard for 12 Volt Cigarette Lighters, Power Outlets, and Accessory Plugs J563_200902. This standard is intended to cover cigar or cigarette lighters as well as power outlets based on the form and dimensions of the cigar lighter, and accessory plugs for use in these devices. Components covered herein are designed to work in nominal 12 VDC systems. This standard is a full performance specification. It includes dimensional and operational parameters as well as performance characteristics which must be met when submitting a cigar lighter assembly, power outlet assembly, or plug for production approval. This standard constitutes an acceptance specification for these devices.

This standard covers the operational, reliability, durability, acceptance, and testing requirements for a cigar lighter (also referred to as just “lighter”) for installation in the passenger compartment of production vehicles. This standard covers power outlets that are based on the form and dimensions of the lighter receptacle intended for installation in the passenger compartment of production vehicles. This standard also covers plugs designed for insertion into the power outlet. Associated components supplied as part of, or with the lighter or outlet are also covered. Additional requirements may be added for these devices when mounted outside the passenger compartment of production vehicles.

Testing shall be done on part families (i.e., lighter receptacles and related knob-elements), as opposed to separate piece-parts, as directed by the appropriate purchasing agreement. Lighter knob-elements and lighter receptacles are not intended to be interchangeable when manufactured by different suppliers.

4.1.4 USB Standard

IEEE 1394 like USB 2, is a high-speed serial I/O (Input/Output) technology that can be found on many peripheral devices. Currently, the newest USB version, or specification, is USB 4.0, and it is contained within USB Type-C cables. It replaces USB 3.2 and 3.0 and enables data transmission speeds of either 40 Gbps or 20 Gbps. The Thunderbolt standard 3 and 4 use a USB-C connector.

Battery Standards

guidance for an objective evaluation of lithium-based energy storage technologies by a potential user for any stationary application is provided in this document. IEEE Std 1679-2010, IEEE Recommended Practice for the Characterization and Evaluation of Emerging Energy Storage Technologies in Stationary Applications is to be used in conjunction with this document. Secondary (rechargeable) electro-chemistries with lithium ions as the active species exchanged between the electrodes during charging and discharging are included in the category of lithium-based batteries for the purposes of this document. Lithium-ion, lithium-ion polymer, lithium-metal polymer, and lithium-sulfur batteries are examples of secondary lithium-based batteries. Primary (non-rechargeable) lithium batteries are beyond the scope of this document. A technology description, information on aging and failure modes, a discussion on safety issues, evaluation techniques, and regulatory issues are provided in this document. Sizing, installation, maintenance, and testing techniques are not covered, except insofar as they may influence the evaluation of a lithium-based battery for its intended application.

4.1.5 Optical Mounting Hardware Standards

The Raspberry Pi camera module is equipped with a C-mount threaded connection. To install and align each optical element we will C-mount threaded lens tubes. Using Edmund Optics as a reference, the necessary lens tube comes in a range of lengths from 5.6 millimeters up to 24.2 millimeters and can be threaded to make longer lengths of tube. The diameter of compatible lenses also ranges from 3 millimeters to 25.4 millimeters which will be a limitation on the maximum lens diameter. Spacer rings and retainer rings will secure the elements in the desired locations.

4.1.6 Camera Serial Interface (CSI)

Camera Serial Interface (CSI) is the standard for communication between sensor modules and its managing computer. CSI has three sub-standards being CSI-1, CSI-2 and CSI-3. CSI-1 was introduced as the first standard communication language with a minimal feature set. CSI-2 expanded on the features available in CSI-1 by including support for RAW-16 and RAW-20 color depth and as of September 2019 introduced support for RAW-24 color depth. Other features that are currently available in CSI-2 version 3 are Smart Region of Interest, End-of-Transmission Short Packet and Unified Serial Link. Unified Serial Link reduced the number of transmission lines needed for CSI communication which increased the maximum speed of data transmission. CSI-3 is the most recent version of CSI and is designed to facilitate communication between multiple cameras and computers, while also increasing the speed of video and image transmission. The computer controlling the image sensor uses the Camera Command Set (CSS) to send instructions to the sensor. All the above standards were created by the MIPI Alliance to facilitate the communication of sensors and computers in mobile computing. CSI-2 will be utilized when sending and receiving signals from the Raspberry Pi 4 Model B to the Raspberry Pi High Quality Camera Sensor (Sony IMX477R).

4.1.7 High-Definition Multimedia Interface (HDMI)

High-Definition Multimedia Interface (HDMI) was first introduced in 2002 with the goal of decreasing the connector dimensions and implementing a signal path for audio to be transmitted. The HDMI standard has a bit rate of up to 48 gigabits per second which will provide more than enough bandwidth for us to output video signal from the Raspberry Pi to the display. HDMI 1.0 is capable of outputting 1080p video at 60 frames per second. HDMI has five standard connector variants, the three most important for our project being Type A, Type C (HDMI mini), and Type D (HDMI Micro). All three types contain 19 pins for data transmission with the major difference being the form factor. Type A and Type C have the same pin assignment while Type D has a separate pin arrangement. The HDMI mini connector is used on smaller displays which potentially will be used to connect to the Raspberry Pi's HDMI Type A connector.

4.1.8 SD Card

The Secure Digital (SD) cards are a type of external storage that can be used to store music, videos, photos, documents, etc. It was introduced in 1999 through the collaboration between SanDisk, Panasonic, and Toshiba. The goal was to provide a memory storage device that could improve customer experience. Considering the size, portability, and capacity for data storage of an SD card, this made the SD card a preferred and popular choice for many devices such as cameras and smartphones. SD cards and microSD cards share the same standards of: SD, SDHC, SDXC, and SDUC and microSD, microSDHC, microSDXC, and microSDUC. The SDHC and SDXC are the more popular stands for both the SD card and microSD card. With the help from an adapter, the microSD card can be used in devices that support only SD cards. The storage capacity can range from 2GB (SD) to 32GB (SDHC) to 2TB (SDXC). SD cards use flash memory to provide nonvolatile storage, this allows the retention of data even without a connected power source. The flash memory technology in SD cards allows fast data transfer rates, low power consumption, and enhanced security.

4.2 Project Constraints

Section	Constraint
4.2.1	Safety
4.2.2	Economic
4.2.3	Ethical
4.2.4	Time
4.2.5	Processing
4.2.6	Equipment

4.2.1 Safety Constraints

As our user will be behind the wheel of a vehicle, the safety of the driver is the most important thing. Two key areas we want to avoid are the driver's access to the pedals, and the driver's view. To keep TrackPack and least invasive and as portable as possible, we utilized a Bluetooth OBD-II dongle to eliminate the safety hazard that can be caused by operating a motor vehicle at high rates of speed with wires running across the driver. By using 12V accessory outlet, commonly found near the center console, we want the connection to the device to be as thin as possible to avoid getting in the way of the driver's ability to reach any input they may have in their vehicle on that center dash, such as the radio or air conditioning system. The second main safety feature we want to consider is the driver's visibility. TrackPack intends to be mounted to the dashboard of the vehicle. For this reason, we want to make the system (camera and display included) as small as possible so as not to take away from the driver's view of the road. Taking this into consideration, the display screen should be small enough to not block the driver's field of view, but still large enough so that the driver can look and quickly read their statistics from the driver's seat and immediately return their view to the road. The system must also be robust as our project goal is for our final design to see actual track use. Therefore, the system must be able to handle the quick acceleration and turns a user might take. The housing must also remain still and securely mounted to the windshield as dislodging in motion could break the system or distract the driver and cause an accident. As important as it is that the device is compact, it also needs to be neatly put together and connections between the PCB, Raspberry Pi (camera module), and the power supply need to be encased entirely in the housing and show none of the interior components, for protection of the device, as well as the appeal to the user.

4.2.2 Economic Constraints

As this is not a sponsored or endorsed project, we would like to keep our total cost as low as possible. On major components we will emphasize the budget towards those hardware components that ensure quality, reliability, and success of implementation with minimal problems debugging, if there is not a substantial price difference. If any of these components also require a much earlier arrival date for the team's success, (i.e., the PCB) shipping costs will be allowed to ensure an earlier arrival date. On smaller components we will look to use any assets available to us already or the option to buy in bulk if multiples are required. Many of the parts that we've selected for TrackPack are in high demand, since we are currently recovering from a chip shortage, many of these parts of out of stock through the normal vendors. We would like to manufacture TrackPack and keep the total cost under $500 to mitigate the amount that each member must contribute monetarily and keep TrackPack as an affordable replacement to other similar products on the market.

4.2.3 Ethical Constraints

A notable ethical constraint also factors in a safety constraint of TrackPack. TrackPack is intended to be a device for off-road use only. The device can be used to analyze simple parameters while driving on the public road, but TrackPack is designed with advanced features beyond that of everyday driving. TrackPack can detect many other parameters of a vehicle which require generating high-speed metrics on the public road. Considering the legality and safety concerns of this, these tests should only be conducted on a closed course. Recognizing the importance of our safety while testing, we will not test the functionality of the device on the public road. Accompanying the driver, we will also have a passenger present to analyze the device so the driver can focus on the road while reaching the required statistics we would like to measure and record. Since TrackPack has a video feature, we have also considered only having videos saved and to be watched later to avoid the driver looking at video while driving and causing unsafe conditions.

4.2.4 Time Constraints

Throughout the design and build of TrackPack, there are time restrictions we should consider and be aware of. Since the development of TrackPack is marked by a deadline at the end of the Senior Design II semester, there are personal oriented and class oriented deadlines we need to follow. As time being one of the constraints on completion, time can also impact the quality of our model. We aim to complete the design of TrackPack to follow closely among the devices existing on the market. At this point, this is where team dynamics and careful planning play a vital role when developing TrackPack. The time restrictions imposed on this project determine the outcome and design of the project. It is critical to examine time restrictions realistically. If one approach may provide a higher quality design but it exceeds the time limits, another approach should be chosen to fulfill the deadlines instead. Depending on the parts we selected to assist with the project design, ensuring and verifying stock availability and delivery time of the parts can impact our deadlines. In the case of unavailability of parts or extremely delayed delivery, we may need to devise an alternative. Delay in parts arrival can reduce the time we have to assemble TrackPack and debug any issues that may arise during the testing and build of the device. To avoid this hurdle, ordering the parts earlier than we need may be ideal. This is to mitigate the issue of parts becoming out of stock and/or the delay in parts' arrival.

4.2.5 Processing Constraints

Since we will be utilizing a Raspberry Pi for image processing and to compile all the data into one location, we must understand the capabilities of this computer. The Raspberry Pi, while a high performing computer for its size, is still limited to a clock speed of 1.5 GHz and a total RAM memory size of 4 gigabytes. Due to this, we will need to closely monitor how we are using the computers' resources so as not to overload it without proper cooling. Alternatively, we could include a cooling system for the Raspberry Pi, but this will increase the total cost and does not provide us with unlimited processing power. Also, because Raspberry Pi computers run on a Linux based operating system we are limited to software that can operate on the operating system we chose. Linux software can be poorly optimized which will lead to excess processing power being used compared to software that has greater support for optimizing image processing programs.

4.2.6 Equipment Constraints

Considering the amount of hardware that TrackPack features, there are a few equipment constraints. The design of the housing will need to protect the components from excessive temperatures that it may potentially experience while the device is not in use. For example, if the car is parked in the sun while TrackPack is mounted but not in use, the processors within the unit cannot operate above a certain temperature threshold and may even be permanently damaged if immediately powered on without cooling. This can also be considered a safety constraint as well due to the potential fire hazard electronics pose in hot environments. Furthermore, finding an ideal OBD-II Bluetooth connector that meets both newer and older standards while remaining cost effective is a restraint. To accomplish this, we much choose an OBD-II Bluetooth connector that supports protocols from 1996 to 2023. A major drawback with a Bluetooth adapter that can scan all major years, makes, and models, is that if we want to remain cost effective on the Bluetooth connector, we'll have to sacrifice some of the OBD-II functions that come with the higher priced connectors. Scanning additional computer modules such as SRS and ABS are a luxury that is accompanied by the more costly OBD-II connectors. Luckily, scanning these additional modules does not provide any additional useful information for TrackPack.

4.2.7 Environmental Constraints

Environmental constraints are subset constraints that can tie together with ethical constraints. Our primary environmental constraint is that to test TrackPack effectively, it requires a relatively large amount of driving to ensure all the hardware is working correctly and tracking the data appropriately. The downfall to the amount of driving required is the increased amount of vehicular pollution. It's common that performance vehicles already generate and higher amount of pollution in comparison to the typical economic vehicle due to the high output engines, and commonly the removal of the vehicle's catalytic converter. It's difficult to test TrackPack functionality while not physically in a vehicle, and TrackPack's primary operation will require us to adjust the recording of the data to account for any latency issues to ensure that the data displayed to the user is as accurate and correct as possible. With this constraint in mind, we will mitigate it by keeping the physical vehicular testing time of TrackPack to a minimum and dialing in proper sensor functionalities as much as we can without utilizing a vehicle.

7.1 Project Budget

Item Number	Component	Quantity	Estimated Cost	Total
4.1	Completed PCB	1	$50.00	$50.00
4.2	IMU	1	$71.20	$71.20
4.3	Camera module	1	$50.00	$50.00
4.4	Lenses + mounting tube	4	$30.00	$120.00
4.5	Housing	1	$24.95	$24.95
4.6	MSP430 Microcontroller	1	$19.03	$19.03
4.7	OBD-II Connector	1	$13.99	$13.99
4.8	Jumper Wires	1	$6.98	$6.98
4.9	Pin Headers	1	$5.73	$5.73
4.10	12V to 5V - 3A Adapter	1	$8.99	$8.99
4.11	Display	1	$60.00	$60.00
4.12	MicroSD	1	$8.20	$8.20
4.13	Raspberry Pi 4 4GB	1	$55.00	$55.00
Total Estimated Budget:				$494.07

Table 4: Project Budget

7.2 Milestones

The implementation, design, and build of TrackPack will extend through two semesters, Spring 2023, and Summer 2023. Primarily, the first semester i.e., Senior Design I will focus on research and documentation to further support the team in the following semester. In the second semester i.e., Senior Design II, the team will begin executing the design and creation of TrackPack.

Milestone	Date	Members
SENIOR DESIGN 1		
Project Selection	1/17/2023 – 1/25/2023	Group 6
Divide and Conquer Report	1/26/2023 - 2/3/2023	Group 6
Divide and Conquer Revised Report	2/6/2023 -2/17/2023	Group 6
Research camera module	2/18/2023	George Gruse
Design lens array	2/20/2023	George Gruse
Research OBD II Integration	2/27/2023	Anjali Jodharam
PCB layout	2/28/2023	Myles Musanti
Test OBD II software	3/7/2023	Myles Musanti
Research Accelerometer Integration	3/15/2023	Kevin Singh
Order optical components	3/31/2023	George Gruse
60-page Draft	2/13/2023 - 3/24/2023	Group 6
Research GPS Integration	3/30/2023	Anjali Jodharam
60 page Revised & Upload to Website	3/27/2023 - 4/7/2023	Group 6
Research Gyroscope Integration	4/14/2023	Kevin Singh
PCB/electrical schematic	4/15/2023	Myles Musanti
Final 120-page Report	4/8/2023 - 4/25/2023	Group 6
SENIOR DESIGN 2		
Order Parts	4/16/2023	Group 6
Build Prototype	5/2023	Group 6
Testing and Redesign	6/2023	Group 6
Finalize Prototype	7/2023	Group 6
Final Report/Presentation	7/30/2023	Group 6

Table 5: Senior Design I & II Tasks