TrackPack: Intelligent Vehicle Racing Monitor and Recording System

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***Abstract* — TrackPack is a compact and portable device that revolutionizes vehicle performance measurement and analysis. By combining a microcomputer, GPS, accelerometer, and onboard camera, TrackPack accurately tracks parameters such as location, speed, acceleration, braking distances, g-forces, and lap times. It eliminates the need for additional accessories, providing a comprehensive all-in-one solution for car enthusiasts. Moreover, TrackPack allows users to measure and manage their vehicle's health by accessing onboard diagnostics through the OBD-II port. With its lightweight design and SD card storage, TrackPack provides accurate performance data and synchronized video recordings for optimizing driving skills and enhancing vehicle performance.**

***Index Terms* — GNSS, Microcontroller, OBD2, PCB, Performance Tracking, Raspberry Pi Model 4, Vehicle Diagnostics, Wide Angle Lens.**

I. Introduction

With the rapid advancement of technology and the ever-growing popularity of vehicle racing, the need for accurate measurement and analysis of vehicle performance has become increasingly important. Car enthusiasts around the world are constantly seeking ways to evaluate their vehicle's capabilities and enhance their driving skills. In the United States alone, where thousands of vehicle racetracks and millions of car enthusiasts exist, the demand for a comprehensive performance tracking system has reached new heights.

To address this demand, TrackPack was developed—a revolutionary device designed to measure, record, and share precise vehicle statistics both on and off the racetrack. Leveraging groundbreaking technological advancements, TrackPack offers a compact design packed with advanced features that provide accurate performance data.

At the core of TrackPack lies a powerful microcomputer, which, combined with GPS and an accelerometer, enables users to track location, speed, acceleration, and other essential racing measurements. This includes determining key metrics such as 60ft time, 0-60mph time, ⅛ mile time, 1000ft time, ¼ mile time, braking distances, g-force, lap times, and more. Moreover, TrackPack goes beyond performance tracking by incorporating an onboard camera, allowing users to capture and save footage from their vehicle for later playback and comparison with measured parameters.

Not limited to performance tracking, TrackPack also aids in assessing a vehicle's health. By utilizing the Onboard Diagnostics port and accessing the vehicle's computers, users can monitor and manage their vehicle's well-being through an array of diagnostic parameters.

TrackPack stands out from similar products on the market by offering an all-in-one solution. Unlike competing devices that require additional accessories to access comprehensive data, TrackPack provides users with a single, concise, portable, and user-friendly design to track all relevant performance metrics.

This paper aims to present the motivation behind the TrackPack project, its unique features, and the market demand for such a device. Additionally, we will discuss the technical specifications of the TrackPack, including its compact and lightweight design, battery-powered operation, OBD-II compatibility, and the integration of GPS, accelerometer, and video recording capabilities.

By providing accurate and reliable performance data, TrackPack empowers car enthusiasts and professionals to enhance their driving experience, improve their skills, and optimize their vehicle's performance. The collected data offers valuable insights for fine-tuning a vehicle's capabilities, making necessary modifications to achieve greater speed, control, and handling. With TrackPack, the next level of vehicle performance tracking and analysis is within reach.

II. System Overview

The TrackPack design can be divided into several subsystems and components. Shown below in Figure 1, is a high-level overview of the system components. Upon start up, the various sensors on TrackPack are polled to collect data from multiple locations such as the vehicle engine Control Unit (ECU), the camera, the accelerometer, etc.

Upon system activation, users will be presented with a user-friendly interface, enabling them to effortlessly choose the desired mode of operation. Within this interface, users have access to multiple mode selections, granting them the flexibility to specify the intended functionality they wish TrackPack to execute.

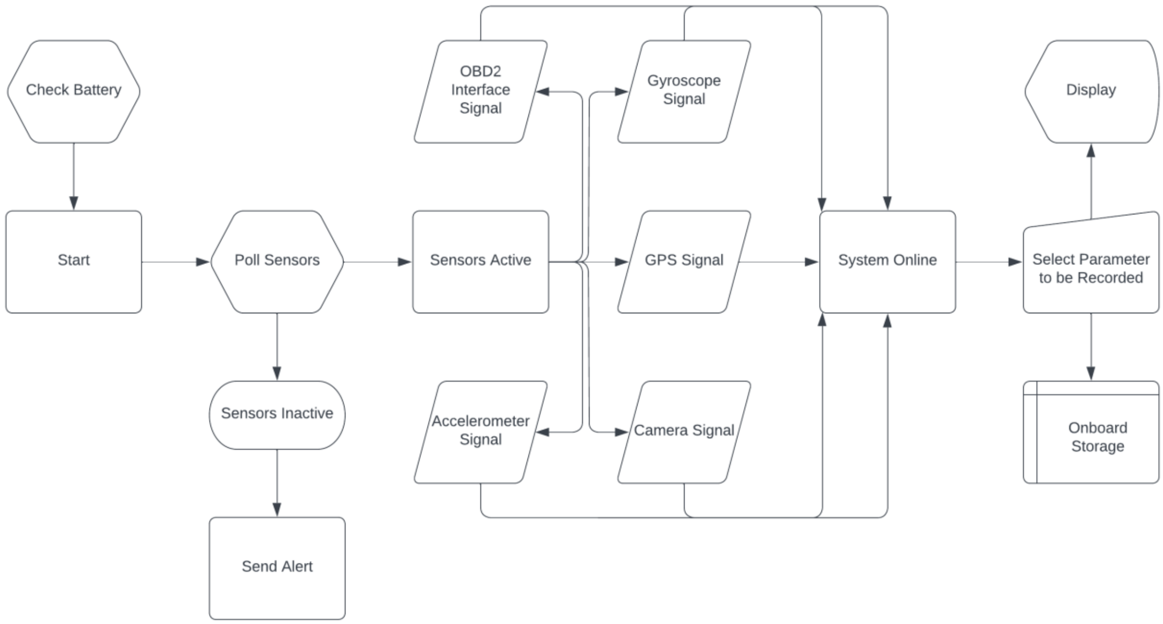


Figure 1 Block diagram of TrackPack System

III. SYSTEM COMPONENTS

The system's structure is most effectively described by its individual components, referring to the physical modules that are interconnected to form the ultimate product. This section offers a semi-technical overview of each component, serving as an introduction to their respective functionalities.

A. Single Board Computer (SBC)

TrackPack utilizes the Raspberry Pi 4 Model B as its single board computer. 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. TrackPack prioritizes energy efficiency to optimize battery life. In this regard, the Raspberry Pi 4 exhibits minimal power consumption, making it an ideal choice.

B. Global Navigation Satellite System (GNSS)

TrackPack utilizes the U-blox CAM-M8C, a GNSS module offering high-precision measurements with low latency. This capability enables effective determination of essential parameters such as distance traveled and speed. By extrapolating this data, additional parameters such as ¼ mile time, ⅛ mile time, 0 – 60 mph time, 60 – 130 mph time, lap time, etc., can be derived. The U-blox CAM-M8C is a standard precision GNSS module supporting simultaneous reception from multiple GNSS bands, including GPS / QZSS, GLONASS, Galileo, and BeiDou. This module is one of the more cost-effective options on the market and this module is especially suitable for lower voltage operation.

C. Display

TrackPack prioritizes a user-friendly interface as a key objective. To ensure ease of use and control, a careful selection was made for the device's display. The chosen approach involves a minimal number of physical buttons on the device itself, with the remaining controls and functionalities accessible through a dedicated app. The core component of the display is a 7-inch LCD screen with a resolution of 800 x 480 pixels, offering a clear and detailed view of the Raspberry Pi's output. Whether utilizing a graphical user interface or a command-line interface, this display provides optimal visibility. Notably, the display is capacitive, allowing effortless touch input recognition from the user's fingers and ensuring swift responsiveness. The display design aims to facilitate convenient device operation while maintaining an unobstructed view for users when the vehicle is in motion on the track.

D. OBD II

To establish communication with the vehicle, TrackPack leverages the OBD II port, which enables the monitoring of specific vehicle parameters. The OBD II port serves as a standardized interface facilitating communication between the vehicle's Electronic Control Unit (ECU) and external diagnostic instruments. This port grants TrackPack real-time, in-car system monitoring. To ensure a seamless user experience, a wireless scanner is employed instead of a wired alternative. Given TrackPack's requirement for detailed readings beyond basic parameters, a slightly advanced OBD II scanner is utilized. The ELM327 Bluetooth adapter is chosen for its compatibility with a broader range of devices, offering greater versatility compared to scanners with limited OBD II protocol support. As TrackPack focuses on enhancing vehicle performance rather than vehicle repairs, an average scanner is employed. This scanner effectively reads various parameters from the vehicle's ECU and vehicle trouble codes, avoiding the need for a high-end and costlier scanner with unnecessary capabilities for TrackPack's intended design.

E. Inertial Measurement Unit (IMU)

TrackPack incorporates an IMU (Inertial Measurement Unit) to capture accelerometer and gyroscope metrics. The accelerometer plays a vital role in TrackPack by enabling measurement of the vehicle's acceleration forces. By detecting gravitational forces (g-forces) during acceleration, braking, and cornering, the accelerometer becomes an integral component of TrackPack. Users leverage accelerometer and gyroscope measurements to assess stability, speed, angle, and maneuverability of the vehicle. Instead of assembling individual components, TrackPack utilizes the BerryGPS-IMU GPS and 10DOF, which integrates the accelerometer, gyroscope, and GNSS module. Additionally, the BerryGPS-IMU offers the potential to gather data from its supplementary barometric sensor. While the most cost-effective approach would involve separate purchases of the IMU and GPS, the decision was made to prioritize TrackPack's small form-factor and ease of use over cost efficiency and implementing an all-in-one option.

F. Raspberry Pi High Quality Camera

TrackPack employs a Raspberry Pi 4 along with the Raspberry Pi High Quality Camera for the crucial task of image collection and subsequent processing. To capture high-quality visuals, the camera module is equipped with the Sony IMX477 sensor. This CMOS sensor boasts an impressive 12.3-megapixel resolution and measures 7.9 millimeters diagonally, ensuring clarity and precision in image capture.

When it comes to video recording, the IMX477 sensor excels in offering flexible options. It can record videos at a resolution of 2028p x 1080p, delivering rich visual details, with a smooth frame rate of 50 frames per second. For scenarios that demand enhanced fluidity, the sensor provides an alternative option of 1332p x 990p resolution at an impressive frame rate of 120 frames per second, allowing for seamless motion capture.

Considering the role of the Raspberry Pi 4 in processing the collected videos and data, the decision to use an official Raspberry Pi camera module becomes evident. By selecting an official module, TrackPack ensures compatibility and seamless integration with the Raspberry Pi platform, streamlining the video collection process and facilitating efficient data processing. The compatibility between the Raspberry Pi 4 and the official camera module is expected to simplify the development and implementation stages, enabling a smooth and effective workflow for TrackPack.

G. Storage

Selecting the most suitable storage option is crucial for TrackPack, as it aims to collect vehicle parameters and record footage effectively. Given the choice of the Raspberry Pi 4 Model B as the optimal platform for TrackPack, it is important to note that this single-board computer does not provide built-in storage. Instead, it offers a microSD slot and a USB 3.0 port for external storage connectivity.

Considering TrackPack's design priorities, the decision was made to utilize the microSD card as the preferred external storage solution. While there may be slight differences in transfer speeds between devices, these variances are deemed negligible for TrackPack's operational environment. By opting for the microSD card, TrackPack maintains a seamless and compact design, as the Raspberry Pi utilized already features a built-in microSD slot. This design choice allows users to enjoy a sleek and streamlined device without the need for an external USB drive protruding from the unit's side.

H. Microcontrollers

When selecting a microcontroller for TrackPack, several critical factors were considered, including sufficient memory, processing power, and speed to support data retrieval components. Another desirable feature was I^2C compatibility to enhance communication capabilities. The chosen microcontroller, the MSP430F168IPM, from the MSP430 series, excels in providing low-power performance for diverse applications, such as industrial automation and remote sensing.

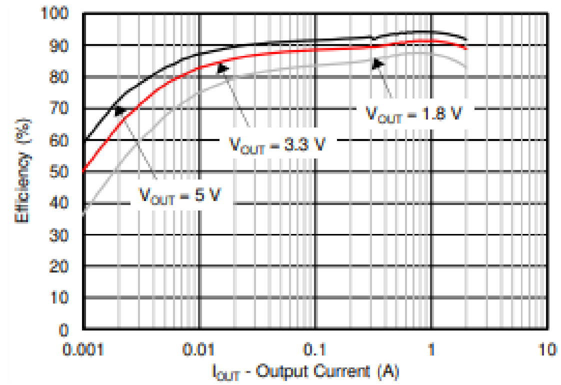
One of the standout characteristics of the MSP430 series is its remarkable energy efficiency. The MSP430F168IPM incorporates an ultra-low power consumption mode that significantly extends battery life. While it may have a lower speed compared to other available options, the MSP430F168IPM still delivers swift data transmission, meeting the requirements of TrackPack's user interface. Moreover, the microcontroller offers an ample number of I/O ports and a generous memory size, accommodating the diverse range of data statistics that TrackPack collects.

Additionally, the MSP430F168IPM operates at a lower voltage supply, contributing to power optimization. It leverages various low-power modes to conserve energy when not in use, further enhancing overall power efficiency. These attributes make the MSP430F168IPM an ideal choice for TrackPack's microcontroller, ensuring efficient data processing, reduced power consumption, and reliable performance.

IV. System concepts

A. Voltage Regulation

A key component of our 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 (plus peripherals) 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. Voltage will have two rails of 3.3V and 5V DC while maintaining the ability to provide sufficient current draw. The 3.3 rail is responsible for the onboard MCU and the data peripherals, the gyroscope, accelerometer, and the magnetometer. To provide sufficient power this will have a maximum current draw of 0.5amps. accelerometer and the magnetometer as the msp430 are designed to run on very low current. The 5V rail is responsible for supplying voltage straight to the raspberry pi and camera module, which is significantly more powerful requires 3 amps to run. The use of Texas Instruments Webench power designer gave us the two following buck topology DC-to-DC converters TPS564201 and TPS563200. These chips can be designed for several specifications of input voltages and output voltages and current. Both regulators were designed using the given schematics of the chips, and simulations of RLC components to meet the requirements of our design.



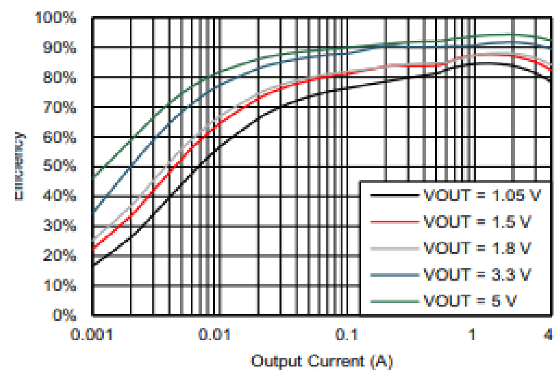


Figure 2 Efficiency vs Current of the TPS564201(bottom) and TPS563200(top)

The TPS564201 has feedback resistor values of 56.2K and 10K. The TPS563200 has values of 33.2K and 10K. Both regulators have two 10uF capacitors for Vin and 22uF capacitors on Vout. There isa 2.2mH inductor of the 3200 and 3.3mH inductor on the 4201. TPS563200 have an internal 1 ms soft-start. When the EN pin becomes high, the internal soft-start function begins ramping up the reference voltage to the PWM comparator. If the output capacitor is pre-biased at startup, the devices initiate switching and start ramping up only after the internal reference voltage becomes greater than the feedback voltage VFB. This scheme ensures that the converters ramp up smoothly into regulation point.

B. Optical Design Process

In the lens design process, a MATLAB script was written to calculate an approximate thin lens design of a Cooke triplet, a lens configuration specifically designed to mitigate field curvature when imaging wide field angles. This initial step was critical as it provided a foundation for the design process by reducing field curvature issues. The Cooke Triplet consists of three lenses: a bi-convex lens, followed by a bi-concave lens, and finally a second bi-convex lens. To account for field curvature and chromatic aberration, the center lens often incorporates a higher-index material compared to the other two lenses.

The lens prescriptions calculated in MATLAB were then transferred to Zemax, a software tool capable of performing precise ray tracing calculations. The use of Zemax enabled the rapid evaluation of multiple design variations, allowing for the manipulation of lens thickness, spacing, and the inclusion of additional lenses beyond the Triplet configuration. This approach accelerated the design process.

To further reduce aberrations, we incorporated primary lenses prior to the Cooke Triplet. These primary lenses gradually focused off-axis rays, resulting in reduced RMS spot size and ultimately sharper image capture. Zemax also includes a feature that can cross reference lenses offered by major manufacturers, ensuring the final design utilized commercially available lenses, reducing the need for custom components, and simplifying manufacturing processes. The final lens curvatures are presented in the table below. The material of each lens was N-BK7 glass with an A-coated anti-reflection coating.

Type	Radius, mm	Thickness, mm	Radius, mm
Surface 1 (Lens 1)	∞	3.5	12.5
Surface 2	25.7	3.5	12.5
Surface 3 (Lens 2)	∞	3.5	12.5
Surface 4	25.7	10	12.5
Stop	∞	7	5.081
Surface 5 (Lens 3)	14.7	4.7	6.35
Surface 6	-14.7	0	6.35
Surface 7 (Lens 4)	-52.1	3.5	6.35
Surface 8	52.1	0	6.35
Surface 9 (Lens 5)	14.7	4.7	6.35
Surface 10	-14.7	7.421	6.35

C. Opto-Mechanical Design Process

Initially the opto-mechanical design included separated mounting disks that would have been secured onto threaded rods. The purpose of this was to allow for precise alignment of the system while allowing lenses to be securely fixed. However, this approach was overly complicated for our purposes. Since the system was designed to be used at a single focal distance with a wide depth of field, the housing could be made with fewer pieces. To design this, the CAD models provided by Thorlabs were imported into Autodesk Fusion360 and spaced according to the Zemax design. Once aligned in Fusion360, a rough casing “Blank” was created around the lenses, extending 7.4 millimeters beyond the final Bi-Convex lens, and having a diameter of 31 millimeters. This distance was purposefully less than the optimal focal length to allow for small adjustments with the lockable focusing ring on the High-Quality Camera’s CS-Mount. A hole through where the optical axis would follow was added to the model, and the CAD models of the lenses were combined with the casing blank to model their exact spacing. After, the outer diameter of the casing was reduced to one inch for a length of 8 millimeters on the side containing the half inch lenses. Threading was created along those 8 millimeters with 32 threads per inch to allow for coupling to the CS-mount. To reduce the weight and volume of the final design, The sharp edge left from where the diameter was reduced to one inch was chamfered to create a gradual change in the two diameters. Finally, to allow for the lenses to be inserted into the design, the model was split into two halves divided along a plane horizontal to the optical axis. Screw holes were created for M2.5 size screws to securely thread into the 3D printed models.

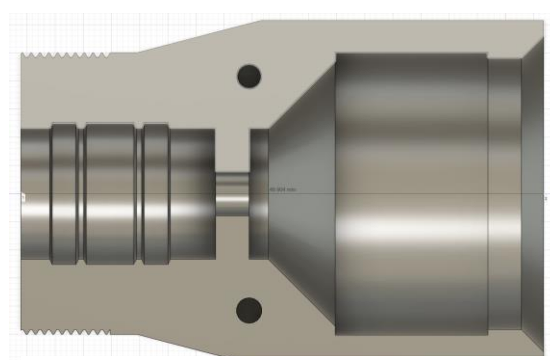


Figure 3 Cross section of lens casing

Figure 3 shows what one half of the final casing design looks like. The distance end to end is 46.904 millimeters.

D. *Optical Design Implementation*

The Raspberry Pi High Quality camera is sold as a single PCB board with the previously mentioned Sony CMOS sensor onboard. We designed a simple casing that would both protect the PCB and allow it to be mounted in the pre-existing mounting slot on the Raspberry Pi 7" case. The mounting slot was originally designed to hold the PCB of the Raspberry Pi Camera Module 3, which is 15 millimeters thinner than the High-Quality camera. The casing we designed to contain our camera sensor PCB, includes a bracket on the backside of the sensor that is the same dimensions of the Camera Module 3. However, our bracket has an angle of 15 degrees to compensate for the angle the display casing adds to the system. The two figures below show the CAD models of our designed sensor casing. The first image is the front view showing the cutout for the lens casing once attached and the second figure is the side view to show how the mounting bracket is angled. With the sensor mounted, the lens casing was threaded into the CS-Mount, and fine adjustments with the included manual focusing ring on the sensor.

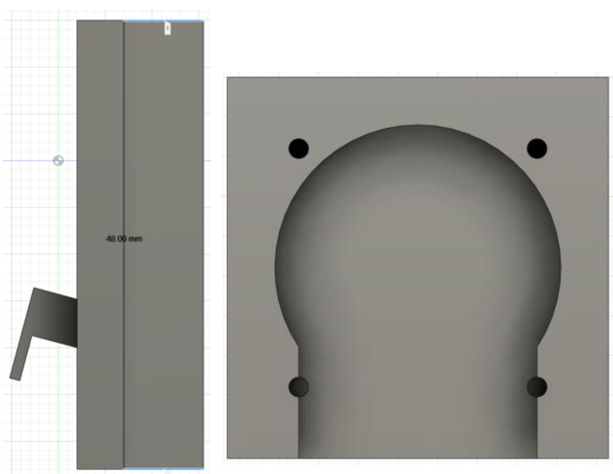


Figure 4 and Figure 5 Sensor Casing

E. *System Software Concept & Design*

The software interface design aims to achieve a minimalistic approach, prioritizing ease of use and enhancing the overall user experience. The initial interface upon loading the TrackPack GUI is the Mode Selection interface, allowing users to choose their desired mode of operation. To ensure usability on the Raspberry Pi 7-inch Touch Screen Display, all interfaces, including the Mode Selection interface, feature large buttons and clear headings. The entire GUI application is implemented in Python3, utilizing the available Python libraries.

In the OBD-II Data mode, the software interacts with a connected OBD-II Bluetooth adapter to read and display essential vehicle parameters and diagnostic information. Selecting the OBD-II Data button leads to the OBD-II live data interface. Upon startup, TrackPack establishes a connection to the Bluetooth OBD-II scanner. Once the Bluetooth connection is successfully established, TrackPack can present the primary OBD-II live metrics to the users in the OBD-II Data mode. Additionally, within the OBD-II Data mode, users have the option to access a subsection labeled "View More Data Parameters" to explore more in-depth parameters. Another subsection within the OBD-II Data mode is labeled "View Diagnostic Information," where potential diagnostic information and fault codes can be displayed to the user.

In the Parameter Logging mode, TrackPack prepares the GPS, accelerometer, gyroscope, and camera for recording sensor measurements. After initializing the sensors, the user is presented with the option to start recording. TrackPack displays a countdown timer when the driver begins their run. For precise measurements, the system code polls the velocity every millisecond, which also facilitates the calculation of total distance. As the user progresses through the track, the logging screen continuously updates the current elapsed time. Using the vehicle's speed, the system calculates various parameters such as the 60ft time, 0-60mph time, ⅛ mile time, 1000ft time, and ¼ mile time. Additional parameters, including current vehicle speed, acceleration, and direction, are also derived. The fundamental equation for calculating these parameters is:

$$distance = velocity \times time.$$

Upon completion of the test, TrackPack automatically stores the data for future review. By selecting "Review Stored Data," users can access and choose specific sets of stored data for display and review. After computing all racing data, the results are appended to a list and stored in a text file. Each data log is assigned a unique ID, allowing TrackPack to easily reference and distinguish between different logs.

TrackPack Specifications		
Power	Rails	3.3V-0.5A 5V-3A
Camera	Resolution	2028p x 1080p
Camera	Frame Rate	50 fps
Camera	Field of View (FOV)	>80°
System	Dimensions	8” x 4.5” x 1.75”
System	Weight	<1lb
Enclosure	Portability	Can be mounted or used as a tablet

V. Hardware Detail

A. PCB

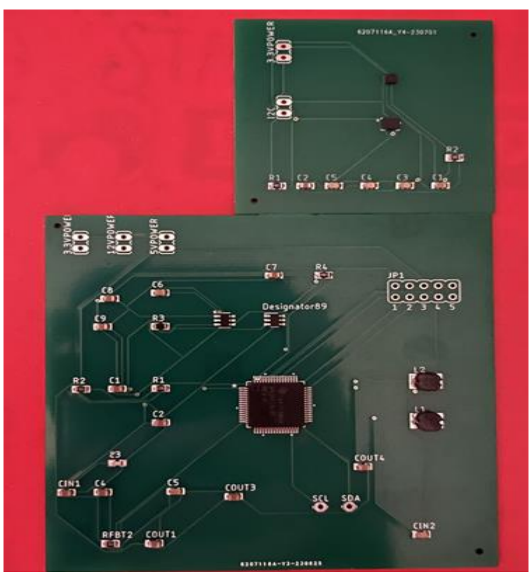


Fig 6. Realized PCB of TrackPack Design.

These two boards have dimensions of 80mm * 79.7mm and 46.7mm * 44.4mm with a 1.6mm thickness. The two boards are compact enough to fit into our display case and provide room for the connections to pass without crimping wires. 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. The larger board contains the two voltage regulators and the MSP430 microcontroller. The section on the board labeled JP1 is for the programming of the microcontroller on the board. Using the MSP-FET device and the corresponding connections from MCU we can program the device on the board as opposed to programing it once and then having to solder it to the board without the ability to adapt. The FET runs the code straight from the Code Composer IDE terminal. The USB interface connects the MSP-FET to the computer, while the 14-pin connector provides access to the MSP debug emulation port which uses a standard JTAG interface. The three jumpers on the top left correspond to the Vin of 12V from the car accessory port and the 3.3 and 5Vout. A two wire (power and ground) adapter are used to plug into the 12V port, which connects into the 12V jumper which is then connected to the Vin pins on each of the regulators. The SDA and SCL pins will connect to the pins of the same name on the smaller board as well as the display for I^2C communication between each device.

B. Peripherals

On the smaller board there is a connection for the 3.3Vin to supply the LSM6DSL (gyroscope/accelerometer) and the LIS3MDL (magnetometer). The LSM6DSL is a system-in-package featuring a 3D digital accelerometer and a 3D digital gyroscope. The LSM6DSL has a full-scale acceleration range of ±2/±4/±8/±16 g and an angular rate range of ±125/±250/±500/±1000/±2000 dps. To operate the LSM6DSL in choosing the function we want gyroscope or accelerometer that the ODRs for both must be active. For the LIS3MDL as well as the LSM6DSL, to run in I^2C mode as opposed to the SPI protocol, pull down resistors of 10K are suggested. To operate in the I^2C mode the CS pin of each device must be programmed to be as 1 to activate it and disable SPI. When the I^2C interface is used, the SDO/SA1 pin must be connected to Vdd_IO or GND. In the fast mode we can run the communication between the accelerometer and magnetometer to the MSP up to 400KHz signal speed. The transaction on the bus is started through a START (ST) signal. A START condition is defined as a HIGH-to-LOW transition on the data line while the SCL line is held HIGH. After this has been transmitted by the master, the bus is considered busy. The next byte of data transmitted after the start condition contains the address of the slave in the first seven bits and the eighth bit tells whether the master is receiving data from the slave or transmitting data to the slave. When an address is sent, each device in the system compares the first seven bits after a start condition with its address. If they match, the device considers itself addressed by the master. Just as the voltage regulators, the datasheets provided info on RC components used for stability of the system and to reduce noise were followed. The LIS3MDL requires one external capacitor (C1 = 100 nF) connected between pin 4 and GND. The device's core power supply line (Vdd) needs one high-frequency decoupling capacitor (C3 = 100 nF) as near as possible to the supply pin, and a low-frequency electrolytic capacitor (C2 = 1 µF). For the LSM6DSL the device core is supplied through the Vdd line. Power supply decoupling capacitors (C1, C2 = 100 nF).

VI. ENCLOSURE

The primary objective during the inception of TrackPack was to create a device that is both lightweight and compact. Throughout the development process, efforts were made to adhere closely to the size constraints imposed on TrackPack. The physical enclosure of TrackPack measures 8 x 4.5 x 1.75, reflecting a design that effectively balances functionality and form. To ensure optimal visibility for the driver, the enclosure is accompanied by a windshield suction cup mount, allowing for convenient positioning within the vehicle. The windshield mount is designed to be detachable, functioning as a separate entity that is independent of our size constraints, and it should be treated and referenced as such.

The total volume of the camera sensor and lens system is 48 millimeters by 48 millimeters by 65 millimeters. The mounting bracket used to attach the camera to the case has an angle of 15 degrees to compensate for the angle the driver will position the screen to maintain the proper viewing angle with the display.

VII. CONCLUSION

Throughout the past two semesters our team has conducted extensive research, part selection, and design to create a system capable of capturing valuable in high-speed racing environments. Our compact and lightweight design surpassed initial expectations, resulting in an all-in-one system that records both diagnostic and performance data. This data can be used by drivers to identify areas for improvement in their vehicles and optimizing their performance in real races.

In summary, our efforts have led to the successful development and execution of a compact and race data capturing system. By providing drivers with meaningful insight after races, we aim to enhance both their experience and performance.

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