E.D.A.D.S: Enhanced Driver Awareness Detection System

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Project is original without sponsors or external contributors.

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1.0 Executive Summary

The Enhanced Driver Awareness Detection System (E.D.A.D.S.) was designed to assist the driver of a vehicle in navigating obstacles. The system is intended to be applied to off-road vehicles so that the driver has better information to make decisions. The system provides multiple camera views to enable wheel position/ route selection for traversing difficult terrain without the use of a spotter or leaving the vehicle. The system also provides sensors for collecting data and relaying the information to the driver. This is accessible through an in cabin visual display as well as an on-windshield heads-up display. The vehicle power supply is used for the project and necessary steps were taken to prevent interference with the factory electrical, sensor, and safety systems.

Various methods for achieving the desired functionality were examined for each section of design. The selection criteria and resulting choices are highlighted in the report that follows. Our chosen approach utilizes Raspberry Pi cameras that feed to individual Raspberry Pi modules around the vehicle then feed to a central Pi that interfaces with sensor inputs and the display. The video cameras selected are covering forward for guiding tire placement and rearward to aid in reverse travel. They are IR models with wide angle lenses. Sensors were selected primarily based upon budget and desired functionality. The sensors chosen are temperature and proximity sensors. The proximity sensors provide feedback on rearward obstacles, while the temperature sensors provide information regarding vehicle components with diagnostic and trouble shooting in mind. The information is relayed through the master Raspberry Pi to the visual display and the heads-up display depending upon the data. Video will be viewed on the main display with secondary data such as warning indicators visible on the heads-up display. The exact operations sequence is covered in the operating manual.

The system was designed with cost, capability, and manufacturability in mind. The desires for this system were in constant conflict with the project budget. This in conjunction with the time and manufacturing resources available led to the decision to develop a proof-of-concept prototype. The funding and resources needed to deliver a system capable of meeting the true needs of a comprehensive off-road spotting aid was not possible while staying within our constraints. The difference between the two being quality and number of sensors, the harsh environment survivability of components, and the number of camera feeds with our system being a scaled down version of the desired. This led to the current design that utilized components that were not ideal for the task yet allowed the group to demonstrate the concept and remain within budget.

The plan outlined in the pages that follow describes the implementation to be started once Senior Design Two begins. Over the break we plan to do some more work on the mounting design. Along with testing different placements of cameras to see how different angles around the vehicle will work.

2.0 Project Description

The following section outlines the reason behind this project. A discussion of the design objectives and goals for the outcome are laid out.

2.1 Project Motivation

Off-road travel carries its share of risks. The highways one has access to within the United States today are a testament to civil engineering. They make it easy to forget how engaging a task driving can be. Off-road travel for the sake of this report is defined as travel on unimproved surfaces. They can span the range from mild dirt tracks and fire access roads to the extreme where there are no established roads. This type of travel brings with it hazards many are spared from in their day-to-day commutes, thanks to our transportation infrastructure.

Recreational pursuits and business operations alike have reason to leave established roads. Some destinations can only be reached through these means and some journeys would not be the same if taken any other way. Off-road driving has the potential to be challenging, mentally taxing, and dangerous. Modern vehicle development has worked to helped manage these risks. Ergonomic designs have increased driver comfort and thus helped reduce driver fatigue. Improved construction has led to safer vehicles in the event something goes wrong, as well as greater reliability. Technological advances have benefited off-road travel.

Though ill advised, many venture off-road alone. Whether it be a well logger for an oil company, or the recreational explorer, it happens often. In these situations, the vehicle driver must multitask and in technical or tight situations a spotter may not be available. The role of a spotter is to protect the vehicle by guiding and relaying information to the driver. Without someone to act as a second set of eyes technical situations are made more dangerous and cumbersome involving getting in and out of the vehicle to check clearance and examine terrain. Things can be overlooked or misjudged leading to vehicles becoming stuck or damaged. Figure 1 shows an example of miscalculation and resulting damage a rock can cause to an oil pan. [1]

Figure 1 Rock Damaged Oil Pan

Most vehicles in use today do not have technology integrated into their design to meet this need. This in conjunction with a passion for off-road recreation have led to our selection of this project.

2.2 Project Goals and Objectives

The objective of this project is to provide a system to support the driver in navigating difficult terrain while providing pertinent real-time information. Modern vehicle electronics systems have become increasingly complex. This has made the challenge of adding aftermarket accessories and functionality difficult. To circumvent the challenge of attempting to integrate with factory systems a second user designed system for the management of aftermarket demands is desired. The proposed project scope covers the cameras, sensors, and the control center for these added features. The end goal is a stand-alone unit that can be mounted around the vehicle that acts as a spotter while relaying information to the driver. Additional elements besides video feed are desired. Discussion of the project is separated into the information inputs and a separate driver accessible control panel for data logging, display, and control functions.

In a monitoring system it is important to be able to efficiently display the information of the system to the user. To solve this issue, we are not only going to use a display to show the information we will also implement a heads-up display. The plan is to use an optical heads up display that will display information onto the windshield of the vehicle. The information that can be displayed on the windshield can include indicators for the proximity sensors to indicate to the driver that the vehicle is about to collide with something. Along with warning symbols for temperatures also this HUD can trigger the cameras to show the driver on the main display what is in the proximity of the v. Some challenges that we will face will be the display may be hard to read in very bright situations. This can be combated by using a polarizer and tint on the vehicle windshield. It is legal to have a strip of tint on the top portion of the windshield so this area can be utilized for clearer imaging onto the windshield. Furthermore, the optical sensors we plan on using will need some research to figure out mounting and displaying the data onto a screen. The IR temperature sensors will need to have a specific field of view and mounting position in order to ensure the proper areas are being monitored. Finally, the plan is to have cameras for monitoring the vehicle path. In off-roading this is important because the potential to hit rocks and for the vehicle to bottom out is much greater compared to regular driving. Ideally, we will take the signals from these cameras and try and stitch the camera outputs into one display for a point of view that allows the driver to quickly assess any obstacles that are being approached.

The separate control panel will perform control, data logging, and user interface functions for aftermarket components. Cameras, sensors, and indicators will provide real time feedback. It will be a wired hard mount device within the main cabin that provides diagnostic, performance, and safety features for the driver in an ergonomically accessible manner. A compact and durable screen for video and information display that allows user input will be a key component of the control center. A way to bring in information from multiple sources and organize it for display and storage is also envisioned.

Most systems that cover aftermarket demands are designed to operate in a vacuum independent of one another. The result when attempting to integrate multiple units to one vehicle often results in a wiring mess in conjunction with a fierce competition for real estate within the vehicle. Engineered to work as one system with the incorporation of multiple modifications in mind, our proposed secondary electrical system will provide a streamlined method for the integration of aftermarket electronics. The primary motivation for this project is to modify a Jeep Wrangler for overland travel. The modifications included in the design of the second electrical system are geared towards off-road self-contained travel. Weight reduction, reliability, serviceability, and a compact form factor are guiding principles of design.

2.3 Functionality

This system will enhance a driver's ability to navigate technical terrain without the use of a spotter or leaving the vehicle. The system will provide pertinent information to contribute to driver decision making.

A real-time feedback of vehicle position in relation to the surrounding terrain will be displayed on the in-cabin screen via external cameras. These cameras will show the area around the vehicle that would normally be obstructed from the driver's seat. Proximity sensors will enable the measuring of vehicles relation to objects on the sides and relay to a heads-up display when problems are detected. This warning will be paired with the camera screens in order to highlight the issue for the driver to act. Tire temperature sensors will be used to monitor the tire's ability to grip surfaces based on temperature.

The system will use the vehicle battery and be installed in a hard-mounted manner to have a compact form factor that complements factory design. This secondary electrical system will be reliable and accurate to enable driver confidence in information being relayed.

2.4 Requirements and Specifications

The below list highlights the requirements for the project and the specifications that will enable these capabilities to be met. These requirements ensure reliability, utility, and ease of use. The primary objective of this project is to deliver an end product that provides aid to the driver within the set budget.

Demonstrations of camera view, HUD function to sensor inputs, and sensor operation will be made. These are our critical points for our project and key to making it function as a system properly. With these being our main testing points of function, we will demonstrate how the sensors interact with the cameras in order to show their corresponding view on the internal display while in the proper mode. We will demonstrate all these functions on the 2016 Jeep Wrangler that we already have and will install our system prototype into. These demonstrations will show how our system could be extremely beneficial to a user to ensure the safety of components in their vehicle that are susceptible to damage such as the oil pan. This will save our users the heartache of replacing what could be costly parts of the vehicle.

The vehicle in use is shown in the figure below. It is a 2016 Jeep Wrangler JKU. The components that require special care when navigating obstacles are shown below. The mounting of cameras underneath will provide coverage of these with the lowest vulnerable point of the transfer case being the central focus.

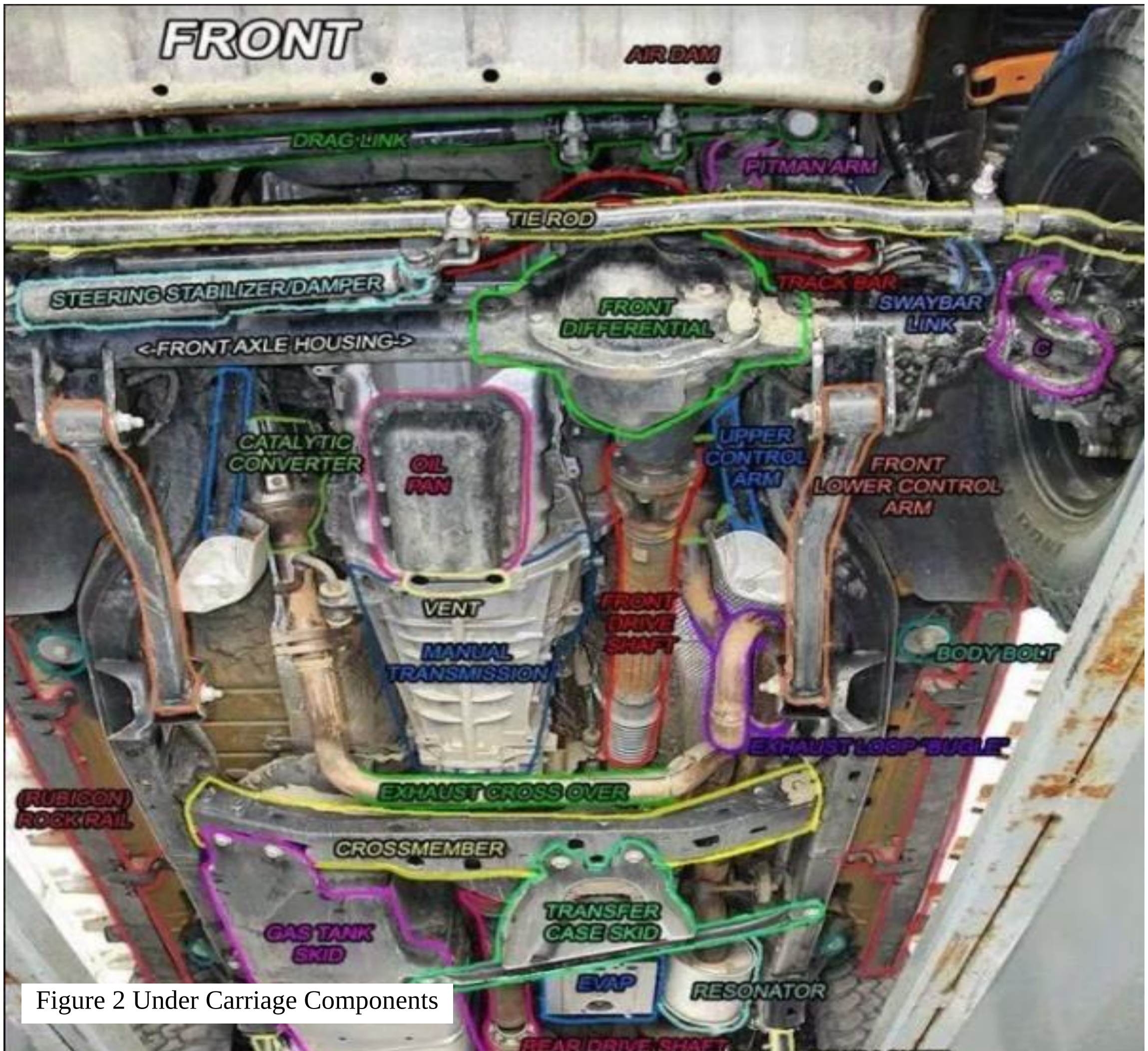


Figure 2 Under Carriage Components

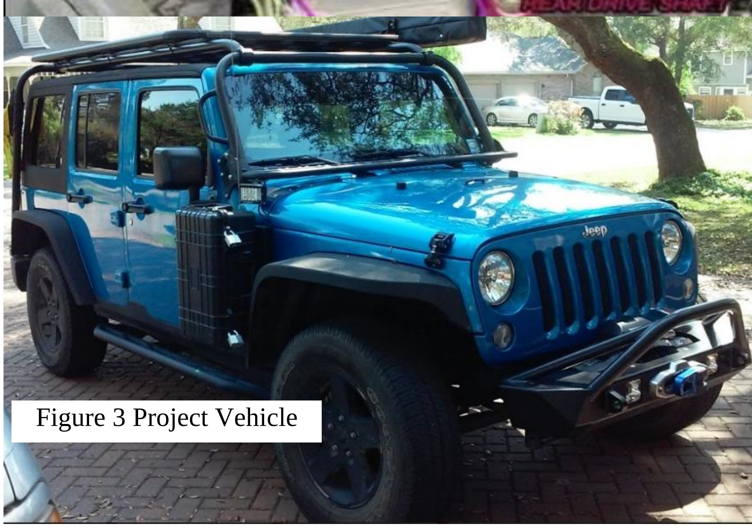


Figure 3 Project Vehicle

The project vehicle is shown at left with the front camera zone extending around each tire to cover driver blind spots. An area covering 3 meters squared from the center of the engine bay is being used to determine adequate tire coverage for the camera feeds.

The table below presents the desired requirements for a successful project and the specifications to be met in order to achieve those requirements.

Table 1 Requirements and Specifications

Project Requirements and Specifications			
Requirement	**Specification**	**Verify**	**Result**
Remain in Budget	System Cost < $800	Track Receipts	$707.34
Compact Form Factor	System Weight < 10 kg	Weigh Unit	6.85 kg
Separated from Main Electrical System	Disconnect at 12.2 V	Perform Low Voltage Disconnect test	Y
Camera Coverage	1080 P Infared FOV > 180 degrees	Mark designated grid and measure angle of camera coverage	270 degrees
Video Display in Cabin	Real time view by driver, multiple feeds	Visual Inspection	Y
Sensor Function	Proximity alerts w/in 2' , HUD warning, Camera full screen	Test according to designed procedure	Y
Sensor Function	Temperature sensor alerts via HUD if threshold is exceeded	Set temperature threshold, exceed, and examine HUD	Y
HUD Interaction	HUD is visible to Driver, Lens 2xs magnification	Visual Inspection, Measure object magnification	Y > 2xs

2.4.1 Demonstration

During the final design showcase and presentation certain requirements will be displayed for faculty to observe. The plan is to run a test course with the faculty observer in the vehicle alongside the driver. This is all contingent on COVID requirements and is written in the event in person at UCF demonstration occurs. If not at UCF a video of testing will be submitted.

1. Camera coverage in term of field of view
2. HUD Function according to manual
3. Proximity sensor detection of an object within 1.5 feet of the rear of the vehicle.

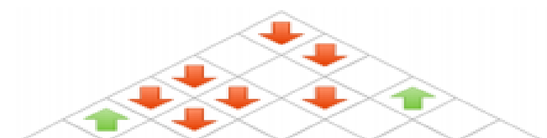
The test course will enable the observer to view camera coverage during mock obstacle navigation via technical driving around and over items. The plan being a course set up via traffic cones. The HUD display operation will be observable during operation. Proximity sensor function will be tested in a specific reverse into obstruction scenario.

The team will be in contact with faculty advisor during the senior design two period to coordinate access to a closed course to set-up the showcase testing environment. An area 20ft by 75ft is the minimum area needed to conduct this demonstration. The team will provide cones and simulated obstacles to conduct the test. One obstacle in excess of 3' x 4' x 3' is needed to test the proximity sensor function. The use of team member vehicle or cardboard boxes/ dumpsters/ building walls, or parking garage barriers are all viable options.

2.5 House of Quality

The house of quality figure shows the balance between the competing demands to be considered during the design of this project. Many items are at odds with one another. The marketing requirements tab outlines desired end functionality. The targets for engineering requirements tab represent the desired metric to ensure the completion of the marketing requirements.

Table 1. House of Quality



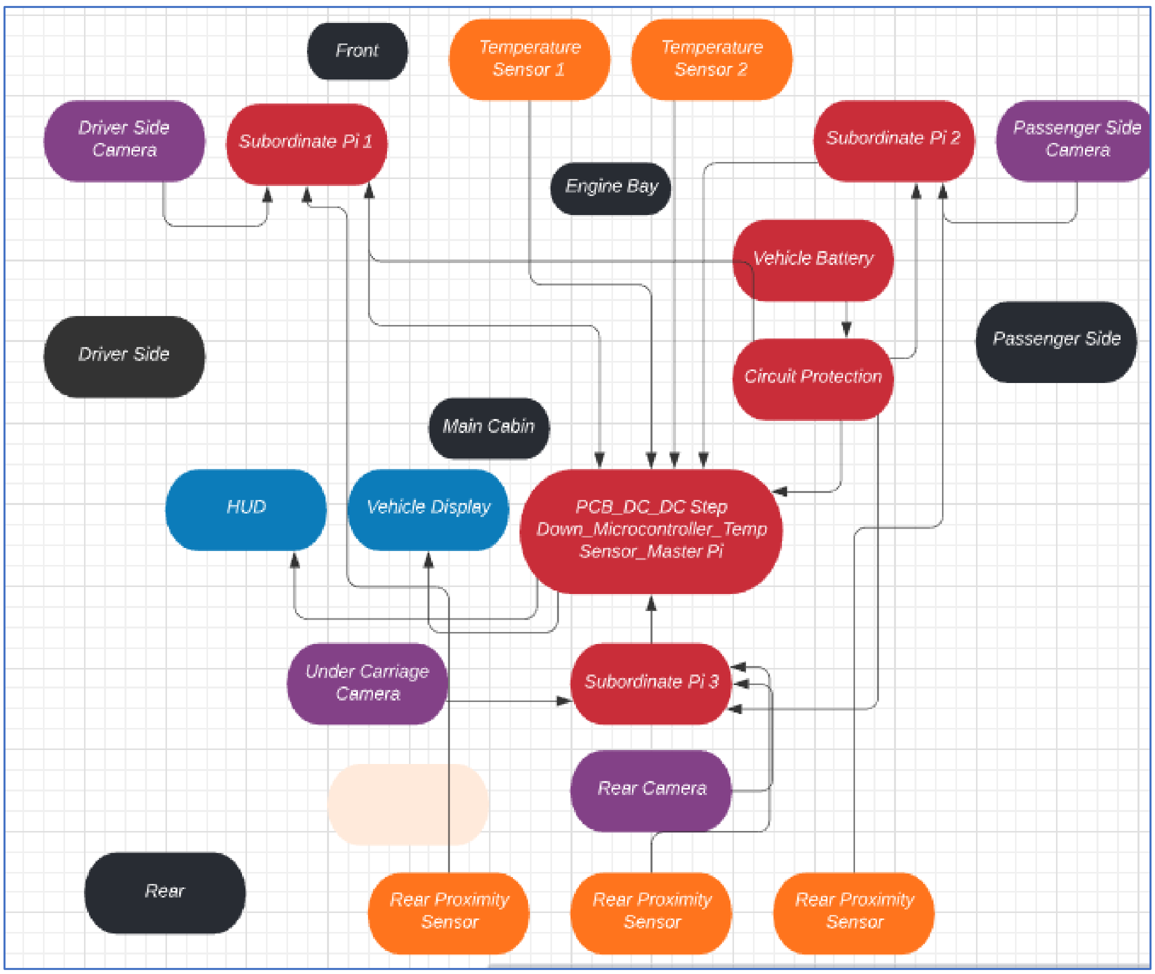
Legend	
+	Maximize
-	Minimize
↑	Pos Correlation
↓	Neg Correlation

	Engineering Requirements	Cost	Harsh Environment Survivable	Camera Coverage	Sensor Accuracy	Compact Form Factor	Separate Electrical System
Marketing Requirements		-	-	+	+	+	+
Cost	-	↑↑	↓	↓	↓	↓	↓
Durability	+	↓	↑↑	↑		↑	↑
Aid in Navigating Obstacles	+	↓	↓	↑↑		↓	↓
Proximity Detection	+	↓	↓	↑↑	↑↑		
Clean Install	+	↓	↑	↑		↑	↓
Targets for Engineering Requirements		< $800 Total	Exterior Comp: IP65 Interior Comp: IP44	Camera covers 3 m^2 from center engine bay	+/- 0.25 m	System Weight < 10 kg	Low voltage cutoff from battery, 12.2V

2.6 Hardware Block Diagram

The following image shows the hardware components of our system and their location on the vehicle in relation to one another. The general regions are exterior perimeter, engine bay, and the main interior cabin of the vehicle. The image can be seen as a web of outer points gathering data to be input to the center for processing. The color coding for the below diagram is to show related components type and distribution throughout the vehicle. The red corresponds to key electronics parts, orange are sensors, blue is driver interface displays, purple are cameras and black corresponds to regions of the vehicle.

Figure 4 Hardware Block Diagram Overview



2.7 Project Prototype Operating/Installation Manual

Users looking to incorporate and install our system/prototype should have general knowledge of electrical connections and a brief overview of some programming in order to be able to troubleshoot the installation of their system. The main primary display is designated to be in the cabin of the vehicle located in between the passenger and driver on the dash of the vehicle. The reasoning for having an understanding of software comes to the placement of the cameras. Where a user may have different intentions for the placement of a camera compared to our protype. In order to re-arrange our camera system the user must adjust our program accordingly to go off at different distances dependent on the location of installation of each camera, since the distance you may need to be alerted of under a vehicle could be much different than that of the sides or rear of the vehicle. If our users also wanted to add more additional cameras, they would need to incorporate another Raspberry Pi into the cluster set up and connect the Pi. This further emphasizes the need for software experience. The hardware itself is more of a commonsense affair, where the user will need to mount the cameras in the correct location and orientation, then install our proximity sensors next to it accordingly. Depending on vehicle size this could also call for adjustments in our software. The HUD installation will be right in front of the driver pointed upwards, getting a reflected image on the windshield. The windshield itself probably won't be reflective enough, and this is where you would also install a reflective film above the HUD, positioning it so it captures the reflection of the HUD display.

Wiring our system should probably be done by someone with experience or a professional. It incorporates many wires and systems being connected and also getting power from the battery. Power wires will be run from the battery to our main unit in the cabin, then distributed to the incorporated Raspberry Pi's. Once this is in place then come along the network cables that need to be distributed from the network switch located at the front to the main Master Raspberry Pi to the Slave/subordinate Raspberry Pi's by the cameras. The wiring could be made simpler in future revisions of our prototype where cables are all integrated into each component where all the user has to do is mount each component with the corresponding lengths.

Users looking at our system should be able to navigate and view the correct information with ease using our given button system. Our system is designed to have two designated modes, an Off-road mode and an On-road mode or a street mode. The primary use case of our project will be of use in the street mode setting, where the operator will be given alerts based on our sensors. To switch into the street mode in the event it does now boot into the street mode the user would hit our "Switch Mode" button located all the way to the right, beneath our display.

In Street mode users need to be aware that this product is not a fully safe countermeasure to safe driving and should not be used to supplement good driving behavior. We will have a warning prompt the user of this which will disappear after some time. In street mode the user will not have to provide any input to the system, such as hitting our buttons or adjusting anything. The system will operate in a manner where it will alert the user if any objects come close to the camera's and alert them via the HUD and promptly show the camera on the internal display. In this mode while the user is never prompted or does not require any input, the user can choose to open a select camera by pushing on the corresponding button for it. This will show that camera's view for a few seconds (approx. 10s) before returning to the grid of cameras. If a user selects a camera and a sensor goes off however, it will show the camera with the corresponding sensor rather than what the user selected to view. This is in fact by design, as it is more important for the user to see what is getting close in the sensor's range rather than another angle. If the user wishes for this behavior to disappear, they should instead

The Off-Road mode provides a system that is purely driven on what the user wants to see. To enter off-road mode the user must push the button to the far right underneath the internal display in the cabin. This mode provides no assistance to the driver on its own, as the sensors are disabled for this mode and will not provide feedback if something comes within the determined range of the sensors. Instead this mode requires a user to select the input camera they want to use with the buttons below the internal display. In order to view the camera, they will push the button that is labeled with their input. If a user is to add more cameras this functionality would change slightly in the fact that they would need to add more buttons. In this mode the driver HUD warnings will also be disabled, as the HUD warnings are a way of providing feedback for the user rather than displaying any of the integrated cameras. In a future revision of our product we could incorporate displaying the camera in a HUD, but this would require a larger display and reflective film than intended for our prototype. In the default view of this mode all 3-4 cameras will be shown on the display in a grid. After a user hits the button for which camera, they want to view they will be shown the camera selected. This will then stay on that selected camera until the user pushes the button to return them back to the home screen/grid of the internal system.

In all modes the user will see temperature information from the engine bay sensors located on the HUD in front of the driver. This is for diagnostic purposes of the vehicle and to ensure overheating does not occur. In both modes the temperature will be displayed in a relatively small section of the HUD, to ensure nothing gets in the way of use of the HUD. The HUDs main function is to warn the user while in drive mode and we want to make sure that this is not hindered by a clutter of diagnostics on the HUD display.

Overall, the usability of our system should be simple for users after installation. Installation will be troublesome but if a user has the knowledge of any of the for mentioned systems, they should be capable of installation of our system. Troubleshooting the system is another issue that could come up and with our current prototype phase could be complicated to figure out which component is messing up in the entire design of our product. In a future revision we could look into diagnostic codes that provide the user feedback as to which component is causing issues or signal loss. This would allow our users to diagnose the system without the need to fully understand it and all the connecting components.

3.0 Project Research

The following section covers the problem and potential solutions explored by the team. Beginning with an analysis of similar items on the market, potential features, sample end goals, and methods are discussed. These were then reviewed to help formulate a listing of requirements and constraints to our design. This enabled a vision for a completed system and the researching of applicable standards. With an idea of what the end solution should look like we proceeded to determine how it would be reached.

3.1 Market Research

An examination of existing products on the market was undertaken at the start of this project to provide a better picture of what a potential solution could look like. There are commercial and DIY options that address portions of our problem. Some are much more involved in their implementation than is possible for our team as discussed latter on in the constraints section. Others were more comprehensive in their function list, going into far greater detail or being much more flexible than the scope of this project would allow. Though none were exact, they all provided insight into potential solutions that guided the research that followed. The highlights from each system are discussed as well as system specifications and design elements that are worth noting. These were used to help decide upon realistic design criteria to meet.

3.1.1 Existing Commercial Products

This area is divided into the various aspects this project touches on. Amongst these are information display, sensor capture, cameras, and vehicle integration. Gages and displays covers products that perform data collection and relay it to the driver in order to guide his decision making. The cameras section covers various options that aid in driver navigation beyond simple parking assist features. Sensors covers supplemental vehicle sensor packages outside of OEM equipped units. Aftermarket integration discusses some solutions to the form factor requirements when heavily altering the electrical system within a vehicle.

3.1.1.1 Gages/Displays

When it comes to data logging, monitoring, and active display feedback the Superchips TrailDash2.0 [2], and DiabloSport T2 [3] come to mind. A sample page from the Superchips unit is shown here. Having been engineered to interface with the CANBUS to communicate directly with the vehicle these units take their data from factory systems and sensors. The Controller Area Network Bus is a communication network between the various components in the vehicle.

These tuning units require unlocking of the Power Train Control Module (PCM) of the vehicle when working with 2016 Jeep Wranglers so that modifications can be made (This is the primary control for the vehicle engine). Units that are monitors/ data loggers only do not require this step. Once connected, data the vehicle collects such as transmission temp, TPMS values, and other information not normally available to the driver.

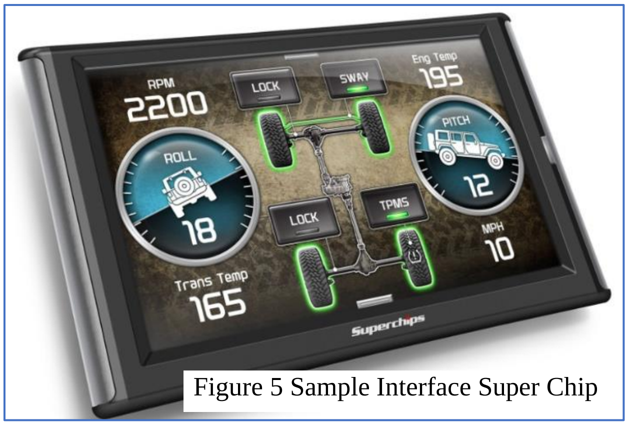


Figure 5 Sample Interface Super Chip

Diagnostic codes are also displayed and able to be read with ease. These allow the driver to be a part of the decision-making process alongside the vehicle computer. This information is relayed to a separate 5" screen/processing unit that can be mounted to suit user preference. The layout of the screen itself is also user customizable in terms of content and appearance. They retail in the $600 to $650 range for the tuning modules and $450 for only data monitoring.

Autometer is a major aftermarket gauges company [4]. The unit is shown below. They handle replacements that interface with OEM systems as well as supplemental gauges added by the end user. Covering electrical to mechanical gauges, sensors, and displays their portfolio is broad. The LCD competition dash is one of their products that provides an extensive vehicle monitoring

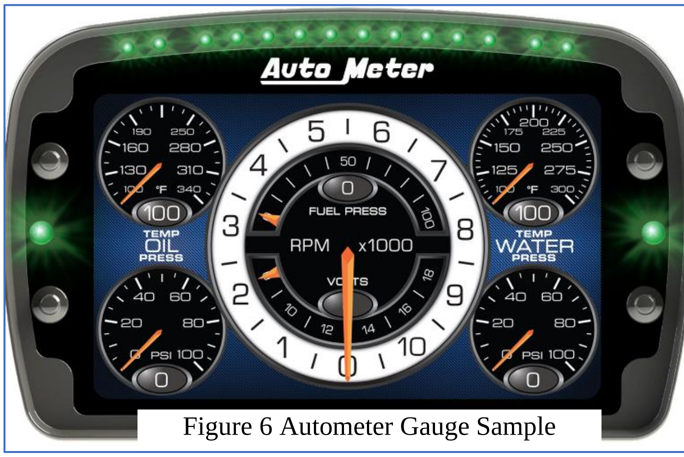


Figure 6 Autometer Gauge Sample

suite through the addition of user installed gages. The system has internal memory to record information, has visual warning indicators, multiple inputs to take pulsed/ digital or analog, and other racing-oriented features. Though designed with a track/on road focus, the unit is robust boasting IP65 sealed, -7 degrees C to 80 degrees C, 0-100% Relative Humidity, and continuous vibration up to 20g and shock of up to 50g. When discussing [5] vibration g-force values are used due to the test method for validation. The vibration amplitude is measured in gravitational units because the test results are collected by an accelerometer and the unit is 9.8m/s^2 displacement as 1g [6]. This unit is capable or replacing the entire gauge cluster in a modern automobile used for racing with the addition needs for data capture (lap times, engine diagnostics, etc.) and is priced as such at $2500. The diagnostic data feedback that is provided in real time and that is recorded would be useful in a heavily modified off-road vehicle as one tracks the changes in vehicle performance related to the modifications.

3.1.1.2 Cameras

There are several camera systems that have been developed that go beyond a standard backup camera. These can be separated into the category of interwoven display and the multiple camera approach. Land Rover's ClearSight ground view system represents the high end of vehicle obstacle navigation aids. Among those that act as a spotter via multiple cameras are TrailVision Off-road Jeep Camera System by Retrofit Off-road (Nolensville, TN USA), Red Peak Inc. Heavy Duty Camera System (Henderson Nevada USA), and Summit View Camera by Brand Motion (Southfield, Michigan USA). These systems all work to make the task of traversing obstacles easier. They standout in many scenarios from tight spaces, difficult lines through obstacles, to only sky and blind drop off moments, a second (or 6^{th}) set of eyes is beneficial.

The most prevalent aftermarket spotting cameras for trail use involve remote mounting of several cameras to provide coverage around the vehicle. These systems use a variety of cables from proprietary versions of s-video cables to rca and multi-pin connectors. The web of cameras will cover different scopes based upon the number in the kit with many manufacturers offering multiple tiers. The cameras will then feed into an LCD display with controls for toggling between the various camera feeds in split, quad, or full screen. The Red Peak kit includes the option for a DVR with a removable 32GB SD card. These systems vary in the cameras selected, though many are wide angled with IR LEDs to enhance night images. The "RUBICAM" by Red Peak makes a play on the Jeep Rubicon namesake and was the first of the commercial systems. The Summitview system has the undercarriage cameras with 185 degree horizontal and 135-degree vertical views in comparison to narrower angles of the other systems. These units are designed to be separate from the factory vehicle displays and are more universal in application. Summitview dose provide a unit that can interface with the factory head unit for Jeep JKs with factory 6.1" display. Samples of kit contents are shown below in The Summitview and Red Peak systems. Those shown at right represent $550 and $1200 respectively. These systems use analog video feeds with RCA composite video and the newer S-video type connections. The display modules are able to interpret and display the analog signal as a video screen

Figure 8 SummitView System

Figure 7 Red Peak System

output. The resolution on these cameras is not as high as those of modern transmission systems but is enough for the intended application. The connections are simple and robust.

As shown below in Figure Clearsight demonstration, the interwoven nature of the Land Rover ClearSight technology sets it apart from the separate camera feed set-ups discussed above [7]. The unit makes use of cameras mounted in the door mirrors, and front grill to provide a trapezoidal area of coverage around the front of the vehicle providing a view of both tires and over 8.5m in front of the driver's seat. The ability to operate at up to 18mph is impressive considering the need to consolidate multiple video feeds into one image that maintains depth perception so as to accurately depict vehicle and tire positioning. See Figure Evoque Range for a sense of coverage. This technology debuted with the 2020 model year Range Rover Evoque.

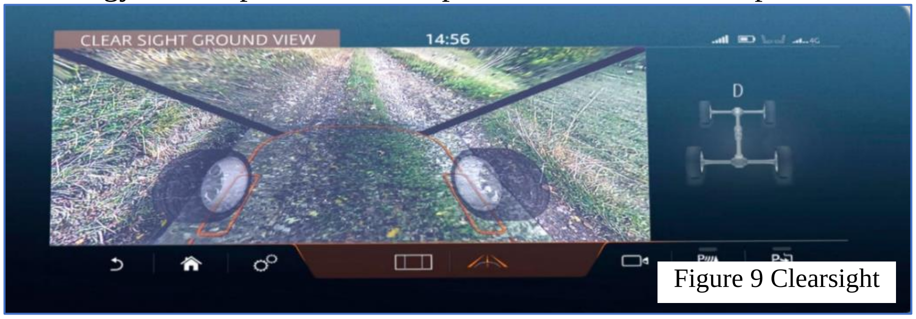


Figure 9 Clearsight

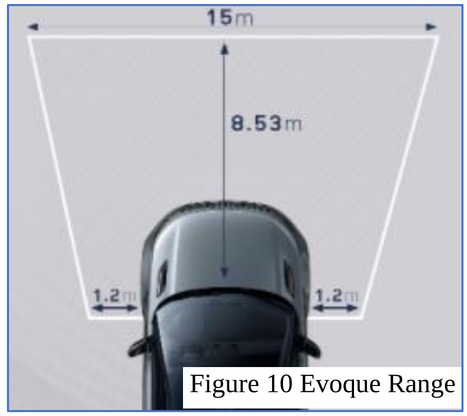


Figure 10 Evoque Range

3.1.1.3 Aftermarket Integration

Modern vehicle electronics systems have become increasingly complex. This has made the challenge of adding aftermarket accessories and functionality difficult. Whether it be commercial up-fitting for specialty vehicle applications or personal customization of private vehicles, the need to alter vehicles from standard OEM configurations has been clearly demonstrated.

Part of our design process is to integrate our design into an existing system. The Jeep engineers have already completed their design and the vehicle has been built. As a result, no changes can be made on their end to accommodate our system. It is our responsibility to incorporate our system into the vehicle without adversely affecting the vehicle. Adversely affecting the vehicle is defined as taking away the vehicle's ability to meet its objective as a self-sufficient off-road vehicle as described previously. Our design will work within the confines of the vehicle with all modifications to the vehicle being engineered following best practices. The goal is to "do the math" so that the parts are not simply made to work but are thought through and the solution can be defended based on engineering standard.

To circumvent the challenge of attempting to integrate with factory systems a second user designed system for the management of aftermarket demands is desired. The proposed project scope covers the 12V power distribution/ protection hub for connecting aftermarket electronics and the control center for these added features. The end goal is a stand-alone unit that can be mounted within an engine bay or elsewhere on the vehicle that acts as a central hub for connecting aftermarket electronics and separate driver accessible control panel for data logging, display, and control functions. Keeping these additions organized, routed efficiently, and operating reliably is made a challenge due to the form factor required for the automotive environment.

In researching this need one finds many solutions available that tackle an area of this problem.

In researching 12V power distribution for aftermarket automotive demands, one can see many offerings ranging from conventional fuse, relay, bus bar configurations to more advanced solid-state units. 4x4 SPOD (USA benchmark), ARB LINX (Australia), ApolloTech/VOsvSwitch (China), represent the modern solid-state based solutions with modularity, compact form factor, and phone application integration being their highlights. On the other end of the spectrum are older more conventional systems such as Painless Wiring (USA), Blue Sea Systems (USA) and Advanced Accessory Concepts (USA) to name a few. On the user interface side of things depending on the desired functionality there are many offerings. Many prefer actual buttons and physical switches instead of a touchscreen (See Figure Old School) due to the tactile feedback, by feel/memory operation feature, and the robust reliability provided by them. Some prefer the slimmer profile and high technology feel of a touch screen (see ARB_Linx) and those systems are available at a greater cost with the option to pair with an application on a smart phone.

Figure 11 Old School

Figure 12 ARB LINX

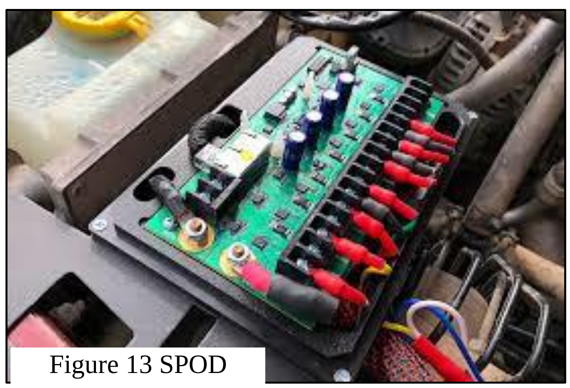


Figure 13 SPOD

The general premise for the central hub is a power lead from the battery and a ground to the vehicle ground (chassis) that then has circuit protection, switching control and a method for connecting items while still providing a sealed system. The upper unit pictured in the Old School image is the in engine mounted piece whereas the lower is to be within the cabin above the rearview mirror. A look inside one of the central units is shown below with the SPOD system. The circuit protection circuit and the switching via solid state relays can be seen along with the bus bar for connecting accessories.

Note the accessory connection bus running the length of the housing. The system is sealed to prevent water and dust intrusion. As a result, heat is managed through appropriate heat dissipation via heat sinks within the unit and proper component selection and trace sizing on the PCB. It is shown here in a Jeep JK mounted on the driver side forward portion of the engine bay. Dip switches are used to help simplify programing of switching functions and cutoff voltages. The units can be daisy chained together to turn into a scalable method of accessory management.

3.1.2 Existing DIY Projects

This area showcases examples of do-it-yourself approaches to the camera and aftermarket electrical aspects of this project. There are many degrees of effort, skill, and difficulty in the various personal approaches to problems. By not being commercial offerings, these types of projects often are completed without having to undergo review to see if standards and codes are met. One will find items across the spectrum from hacked together so poorly you would not trust it in an RC car to those nicer than what the OEM's produce. These show interesting ways for working within the confines of an existing system (in reference to the vehicle as designed by manufacturer).

3.1.2.1 Total Vision Products Off-Road System

This project was a collaboration between individuals and Rod Thomas the owner of camera system manufacturer Total Vision Systems. These units were made as part of personal projects using the vehicles of his friends including a Toyota FJ cruiser, Toyota Tundra, and a Toyota Tacoma. The systems were concepts done to explore the viability of a commercial kit. The FJ cruiser dash is shown below and was debuted at the 2009 Overland Exposition West [8]. This is a major event in the off-road adventure travel industry and is a showcase for much of the aftermarket automotive industries gear and gadgets. In the demonstration for the system the driver completed one of the events vehicle obstacle courses with his windshield, side windows, mirrors all blocked. The course was

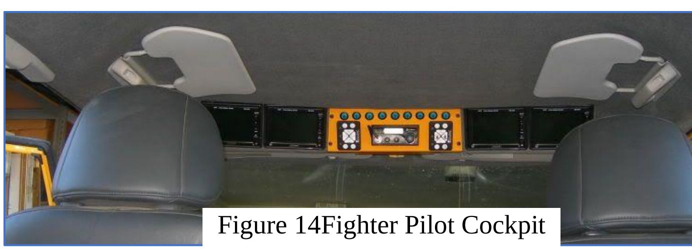


Figure 14Fighter Pilot Cockpit

Figure 15 Taco Cam

completed solely through use of the installed camera system. These set-ups did not digitize and interweave the display. As a result, to achieve proper coverage they ended up with 7-9+ cameras in the system based on the vehicle. The challenges that arose through the design such as camera mounting selection and control mounting selection in addition to the hardware itself can be used to gauge the level of modification needed for a clean installation that provides the views desired [9]. A “fighter pilot cockpit” of sorts is visible across the roof of this FJ cruiser [10]. This system incorporated additional aftermarket electrical control functions. The Tacoma Screen can be seen at right in Taco Cam Figure.

3.1.2.2 Arduino Powered Jeep Wrangler

This one demonstrates microcontroller use to perform control functions in the vehicle. Here Eddie Zarick has created a “Jeeputer” to add functionality that he can control to an older model Jeep Wrangler TJ. His is but one example of this being done, but it allows one to visualize the concept. He has added remote start, temperature sensors, light sensors for automated backlight control, accessory switching, and a real time clock for time and date to name a few. The options are limited to imagination, time, and budget. The control panel is mounted in an overhead configuration able to be interacted with from the driver’s seat Figure Overhead Arduino with a separate control hub shown here in Figure Rats Nest.

Figure 16Overhead Arduino

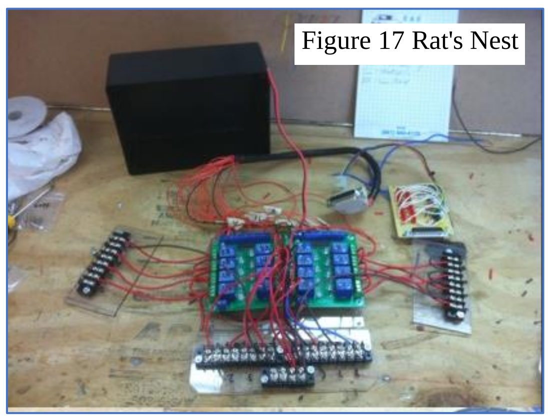


Figure 17 Rat's Nest

3.1.3 Our Product Distinction

Going over the many existing approaches to the various aspects of vehicle alteration many considerations to be taken into account were raised. Chief among them is the mounting/ interfacing challenges of working behind someone else in regard to a design that is already complete. The difficulty in electronics design from scratch was also apparent. Without the budget and time to realize the more sophisticated options we had to determine a realistic view of what the project would be. A prototype to provide proof of concept for a system designed to integrate various aspects of these existing solutions into one system designed to work as a single unit from the start. Over the iterations of the design process this should enable a more optimized, compact and dedicated hardware solution.

3.2 Circuit Protection

Circuit protection is needed to maintain safe operating conditions for system electronics. An integral part of circuit design is the implementation of safeguards to keep equipment within its ratings so as to prevent damage and maintain function. In selecting circuit protection there are several factors to consider. For the discussion to follow is divided into voltage, current, power, and environment. Where our system falls in the spectrum is addressed in each section.

3.2.1 Current

Current is the rate of flow of electric charge through a surface. There are two types of current flow, one directional net flow of charge carriers known as direct current and bidirectional switching currents known as alternating currents. Direct current (DC) and alternating current (AC) have different concerns when it comes to their effects on a circuit's components.

Our system is a direct current system. This requirement is set by the desire to use existing vehicle power supply and readily available electronic components. With it being a direct current system, many concerns with phase relationships and power factor that apply to alternating current systems do not apply here. In our situation, current is equal to voltage divided by impedance $I = V / Z$ as stated in Ohm's law. The amount of current flowing through a circuit will change based upon the resistance/ impedance of the components as the voltages should all be in parallel so that everything sees a constant 12V nominal value. The current draw for each device/ circuit should be known in order to design appropriately.

The prevention of an overcurrent is more important in our application than a no current or under current case (synonymous with low voltage and discussed later on). Overcurrent is defined as more current than the circuit is designed to handle. A short circuit condition is a prime example. During a short circuit there is a lower (zero in ideal case) resistance path between the positive terminal of our DC voltage source and the circuit ground. This will allow the battery to discharge at a high rate and a current many time larger than what would normally flow occurs. This can destroy the battery and cause a fire as the high heat associated with the greater current will exceed the equipment ratings and melt/burn the wires/ connectors etc. In line fuses and circuit breakers are used to prevent overload currents. Sometimes there are initial current surges due to inductive loads (for example, requiring more current for a brief period to start a motor).

This must be taken into account when selecting fuses, whether to increase the rating of the fuse or to have slow trip fuses for example. Our loads are resistive loads and as a result the current draw should be constant. If components are sensitive to current surges, then an inrush current limiter may be applied. This is typically done for switched supplies when going between AC and DC, or any set-ups that have large parallel capacitances at the input or those with low impedance under transient conditions. DC-DC converters and electric motors also fall into the category of potentially needing inrush current protection. [11] For further discussion a spike is viewed as an event with short duration in the 10^-9 to 10^-6 seconds range and a surge is an event with duration over 10^-3 seconds. [12] Sensitivity of components should guide the selection of protection as well as industry standards. These are to be discussed in their own section.

3.2.2 Voltage

Voltage is the difference in electrical potential between two points. We are working with a low voltage battery supplied system. All elements should be designed to operate between 12 and 14.8 volts, all items will be in parallel generally speaking so that the voltage is the same. In these situations, voltage is equal to impedance multiplied by current $V = I * Z$ as stated in Ohm's law. Over voltage, under voltage, and reversed voltage polarity are the primary concerns for our application. Within specifications logic circuits are functioning properly and other items are predictable in operations. Fluctuations in voltage can cause devices to operate unpredictably or not to operate and thus a steady appropriate supply is important. The sensitivity and tolerance to voltage variation depends upon components. Some sensors and microcontrollers considered for this project's subsystems may fall into this category. Over voltage could occur due to problems with the vehicle charging system and should be protected against in the original manufacturer circuit construction. However, as a form of redundancy protection for this fault could be applied so as to prevent damage. In more sensitive electronic circuits Zener diodes often fill this role.

Under voltage problems could also be due to problems on the charging system side of the equation. Our job would be to design our additional electrical demands in a way that they cannot act as a load greater than what the power supply can deliver. This would mean that the system has safeguards in place so that the system load is removed from the vehicle battery before dropping the voltage on the vehicle battery below that which is needed to start the vehicle. That value depends upon more than just the voltage. The charge state and battery health in conjunction with engine health and starter health contribute to vehicle starting ability.

Ambient temperature, number of charge/discharge cycles, level of discharge, battery type, age and more work to describe the state of a battery. In order to not contribute to the deterioration of the cranking ability a low voltage cutoff will be employed to isolate our system from the vehicle. This can be done via multiple routes, ignition controlled so that our circuit is only powered when the engine is running and thus the alternator is charging the battery, a monitoring circuit that disconnects our circuit when it senses that the battery voltage has begun to drop to below 12.2 volts, or a manual disconnect switch that relies on user action. An examination of parasitic draw should be made of the device in the powered off state so as to know potential effects to the vehicle battery when off so that the timing for low voltage cutoff to kick in for vehicle off-no-starting for long periods effect is known.

Reversed voltage polarity here refers to a reversed supply voltage. This would occur with the system connected to the vehicle battery and the battery cables are swapped so that the positive lead is on the negative post and the negative lead is on the positive post during service or during a mix-up when jump starting a vehicle. If unable to design so that these connections cannot be reversed, then visual warnings and indicators should be installed and protection against this should be done. [13] Diode based and Field Effect Transistor (FET) based options are available to achieve this goal. Reverse breakdown of components due to a reverse polarity event could send devices into nonlinear regions of operation and result in various faults.

3.3.3 Power

Power is a measure for the rate at which work is done. Its unit is the watt which is equivalent to joules per second. As described above we are looking at DC current, low voltage applications. In these situations, it is equal to voltage multiplied by current. P= I * V as stated in the power equation. Power comes into play as a relation of the two elements already discussed and is really best viewed as the outcome of changes in the other two. A comparison of 12 V and 24 V DC systems is compiled in the table below as both are used in automotive applications. For example, if the power requirement is kept the same at 12 Watts and the voltage is varied the resulting current is shown. Current is then kept constant and the resulting power is shown below in Table 2.

This demonstrates how the parameters affect one another. It matters because power in physics, the ability to do work, is measured by either physically moving something or generating heat. In electrical circles, the generation of heat is the primary concern when look at single phase power system. [14] Current generates heat and this heat must go somewhere as covered above. The temperature flow between components and system as a whole with the operating environment determine the temperature components will reach. Our loads are resistive loads and thus the power dissipated in each component is of concern due to the desire to keep the heat within the electrical and physical limits of the devices in use, from proper wire gauge to the connectors and devices themselves. The

Table 3 Power Characteristics. Table: P=IV

Condition	Case 1	Case 2
Constant Power at 12 Watts	12= I (12) I = 12/12 = 1 Amp	12 = I (24) I = 12/24 = 0.5 Amp
Constant Current 2 Amp	P= 2 (12) P = 24 Watts	P=2 (24) P= 48 Watts

Brown outs are a potential concern when working with digital logic circuits due to the fact that a drop in volage as a result of the reduction or restriction on power availability can greatly affect their operation. When a binary one or a binary zero are separated by only a small voltage margin, fluctuations can result in incorrect readings. This can cause a chain of seemingly correct faulty code that if not caught could cause poor function or damage to the system. Microcontrollers and similar items that do not have protection from this built in need to have external circuitry to combat this potential problem.

This often can be achieved with dedicated integrated circuits. If building in the discrete form the circuit is relatively simple on the hardware side or can be implemented via software. A sample hardware-based solution using a comparator and a Zener diode was examined due to the need to create a PCB and the potential for a power distribution PCB.

This design was rejected due to microcontrollers selected having on chip circuitry to eliminate this risk.

3.2.4 Voltage Regulation

Our discussion is focused on DC-to-DC conversion as no inverters are needed to go between AC and DC. There are two types of voltage regulators, linear and switching. Linear voltage regulators step the voltage down by acting as a resistor and drop the voltage to the desired value by dropping the voltage across themselves. The formula would be (V_input – V_desired_out) * Current Draw = Power Dissipated. In a 12 V to 5 V at 3 amps example, (12-5)*3 = 21 Watts. A large amount of heat to dissipate and an inefficient process unsuitable for higher currents (> 50mA range depending on allowable power dissipation constraints). Switching regulators utilize pulse width modulation to rapidly turn the supply on and off and regulate the average output voltage. Because of their design switching regulators are generally more efficient in terms of power and are the preferred option due to cost when power levels are above a few watts. Filtering to eliminate noise at the input and output of a switching regulator is necessary.

3.2.5 Environment

A final catch all category of environment is to be considered when deciding upon circuit protection. The operating and storage environment must be anticipated so that adequate protection from hazards is designed into the system. A primary failure mode to protect against is the improper routing of electricity. This can be paths no longer being isolated and connecting with one another or ground causing undesired to dangerous behavior. Interruptions in the routing of electricity that result in open circuits can also cause problems. These conditions can be traced back to wire abrasion due to wiring harness routing, harness movement, and improper construction.

Damaged connections due to vibrations, heating and cooling cycles, or improper connections can also play a role. The physical characteristics of an environment from humidity to vibrations, temperature, corrosive elements, moisture and sun exposure all must be accounted for. The level of protection against these and other environmental factors is dictated by likelihood of encountering, sensitivity of system, priority, form factor constraints and cost. Standards have been developed so that best practices for electronic component isolation are known.

Standards governing separation from potential environmental harm are discussed later in this report as they pertain to our system. Materials selection is a large portion of environmental isolation as the general principles of construction and isolation are similar amongst designs. For example, using stainless hardware vs galvanized hardware when mounting if the water concerns are salt water. Another would be the expanded nylon mesh used to encase harness and prevent abrasion, looking at nymax vs PVC vs other plastics and their ability to handle heat, sun exposure, and other chemical properties such as flame retardant.

Heat is an enemy for electronic components. High temperatures make it difficult for heat transfer to occur between components and environment when the difference in potential between the two is not present heat will not “flow” out of the device. Designing so that devices can remain within their safe operating range in spite of the changes in environment is important. This can be done through device tolerance by selecting components whose specifications place it in excess of what is required for the predicted environment. Environmental management through insulation, mounting considerations, and similar approaches. Heat can also be managed through the incorporation of cooling fans, ventilation, passive, and active heat sinks. A passive heat sink is a conductor of heat used to pull excess heat away from more sensitive components and could be something as simple as a metal mounting surface for a device. Another form of passive heat management is vented housings to allow airflow and heat to rise and escape as opposed to being confined in a compartment and saturating the part. Airflow venting can be designed to incorporate other airflows as well. These do not require additional energy to perform a cooling function. An active heat sink would be something like a heat pipe. Here fluid is used to move heat from one region to another. Another example would be a dedicated cooling fan running to circulate air and remove heated air so that it does not build up within an enclosure.

Designing for an engine bay life cycle requires the foreplaning for heating and cooling cycles that span a wide range of temperatures. These temperatures can span a wide range based upon location on the vehicle as shown in the figure showing data taken by Pelican Products during their testing of a Chevy Silverado at idle. [15] One of the more difficult scenarios is to account for stand still operations at idle or after prolonged operation. These are heat soak events. The first case of operating stationary at idle removes the primary

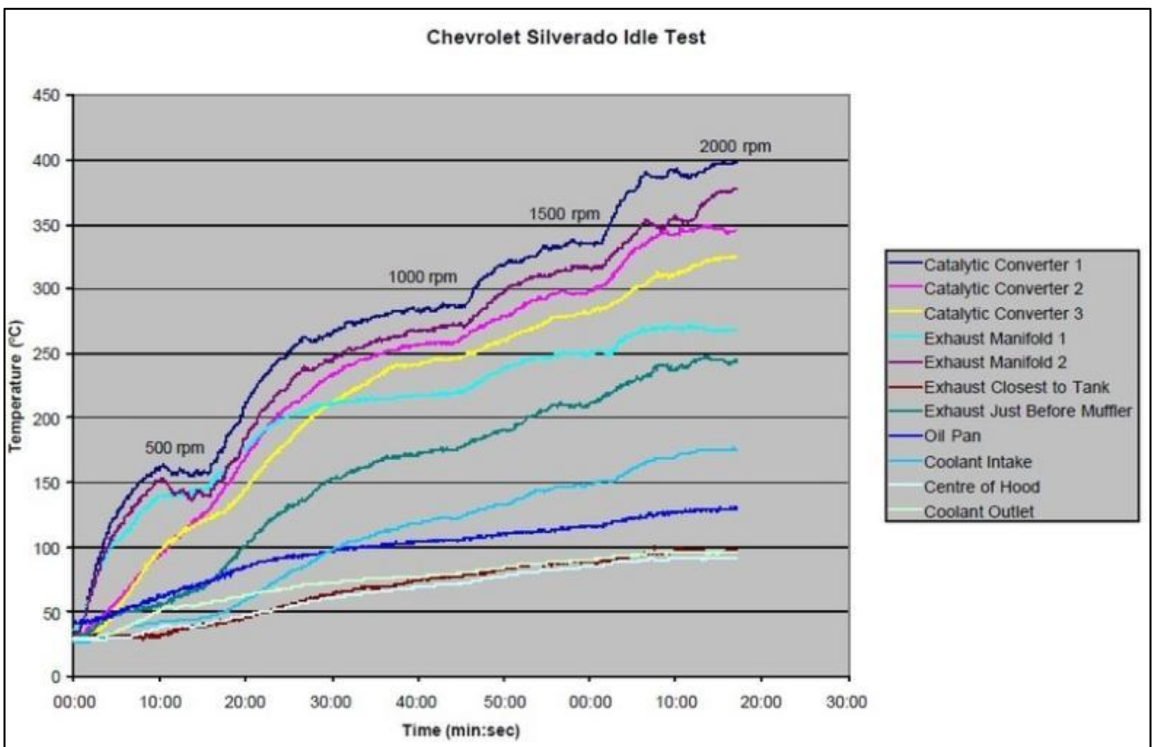


Figure 18 Engine Bay Temperature

cooling force for ambient air and components within the engine bay, moving air. Air typically is forced into the compartment, across the radiator thus circulating hot air, allowing heat exchange at the radiator for engine coolant and as a whole this is used to manage temperatures. There are cooling fans designed to help pull air across the radiator and into the compartment when at idle, when working properly they keep the heat exchange occurring within specifications. A study was conducted on compartment temperatures and a graph showing their results is referenced in the idle chart. Case two is different in that the cooling system is no longer in full operation. The water pump that circulates coolant is connected to the pulley system that is engaged only when the engine is running, as a result when shut down even if the cooling fans are still running, the coolant is no longer circulating. This leads to a rise in overall block temperatures and the entire compartment temperatures rise as a result.

3.3 Heads Up Display

A heads-up display is an integral part of this project as the heads up display will be used as an emergency notification system for the driver and the driver will see the H.U.D notifications on the windshield before anything else when there is an issue. Some features included in the heads-up Display will include emergency proximity notification, temperature notifications, and voltage notifications. Some challenges faced with creating the heads-up display will be using the right kind of display and lens system for this application. As mentioned, a display will be used along with a lens system to project the information gathered by the device onto a reflective strip on the windshield for the driver to observe the data displayed. Another challenge to be faced is making sure the projection of the heads-up display will be fully visible in bright settings.

3.3.1 Introduction and Background

A head up display (HUD) is commonly used to display information in a more convenient manner for most applications. HUDs have been used since the 70's in airplanes to display valuable information to pilots. The appeal of HUDs is that the information is usually displayed in such a way that it is integrated with reality. So in an aircraft the HUD shows information on the front window of the aircraft so that pilots can still be observant of surroundings and have valuable information in front of them. HUD technology has been advancing very rapidly in the recent years and can now be found in common items, such as cars or motorcycle helmets. First the concept and operations of this technology will be explored, then key parameters and limitations will be listed to help further understand the current state of the technology. The HUD will be compared to other technologies that have a similar function. Finally, the main applications of HUD's will be discussed.

When trying to figure out exactly how a HUD works you will find that there are a few main features of a HUD that makes it unique from other imaging /display technologies. A HUD system can be split up into 2 main parts that work together. The First part is the projection system, it is responsible for creating the images that will be seen by the user. The second part is the combiner which is usually an interface that is used to combine the user's field of view with the images created by the projection system. Figure 1 is an example of a basic HUD system that shows how the projection system and combiner are used together to create an imaging/display system. To elaborate on the projection system, it can actually be a quite complex system depending on the setup used. Generally, there is a light or. Image source that can be supported by optical elements used to guide the image, such as a series of lenses as seen in figure 1.

The lens set up can be as simple as a 2-lens collimating set up to a very complex lens system. There are also some common systems available to install on any car that do not utilize any lenses. They are simply just displays that are directly projected onto a combiner that is placed on the windshield. As mentioned, combiners are semitransparent surfaces used to overlay an image onto the viewers field of view. So, the viewer can still see through the combiner while also having the information in their field of view. There are varying types of combiners that can be used but this part of the HUD is generally very simple. A simple combiner that utilizes Fresnel reflections are usually just flat pieces of transparent material used to redirect the image created by the projection system. Holographic optical elements (HOE) are another common combiner used in HUD systems. This type of combiner is a thin holographic optical element that acts like a mirror and is able to more clearly reflect the image provided by the projection system. There are many benefits to using a HOE, these types of combiners can be made for curved surfaces, they can diffract at a different angle than the incoming reflected angle, and they can be used to maximize the field of view of the system. Overall HOE combiners are just much clearer than the traditional method of utilizing fresnel reflections [16].

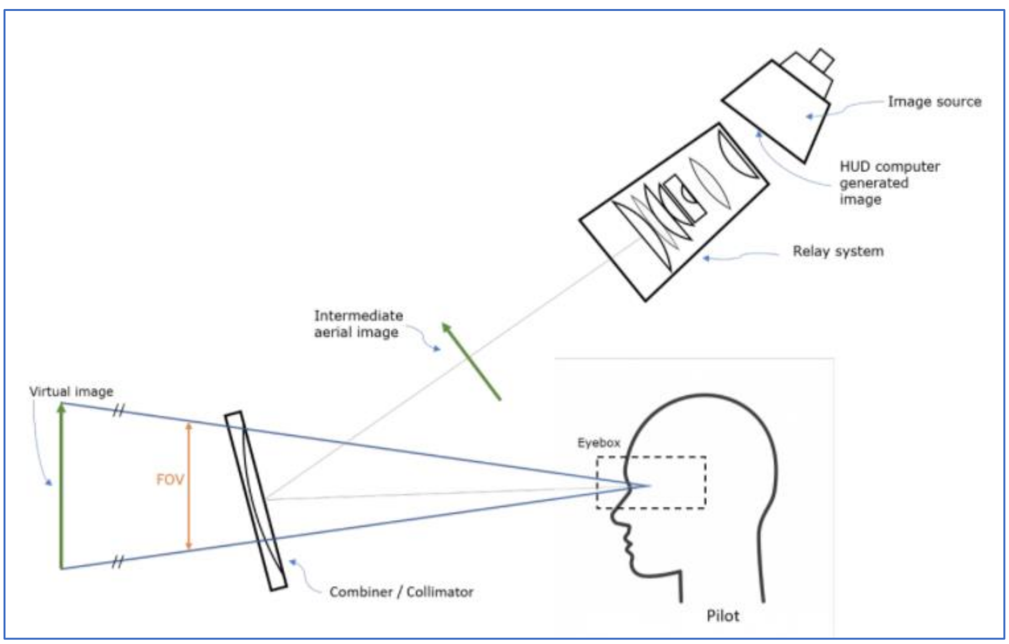


Figure 19 Labeled Heads Up Display

Now that the basic concepts and operating principle of HUDs have been discussed, we can now better understand the key parameters of a HUD system and the limitation that comes along with this imaging/display technology. As mentioned before, HOE combiners are very beneficial because they can provide a larger field of view to the system. Field of view is a key parameter in making a HUD system work. The field of view determines how the viewer will see the image that is created by the image projector. The field of view can determine how large and clearly the image is seen by the viewer. There are other technologies such as waveguides that can be utilized to increase the FOV of a HUD system. There are some other parameters that go into HUD systems such as size of the unit and clearness of the image but field of view is the main parameter that will separate a good HUD from a bad one. Figure below shows how these parameters such as FOV and image clearness is important in a HUD. The left shows a HOE combiner, this image is much more clear than the example shown on the right. This shows how important a good combiner can be in a system. This leads to limitations of HUDs. A good combiner needs to be custom made for a system in order for it to be as clear as possible and have an optimal FOV. Good HUD systems are very expensive to implement, which is why we only really see high quality HUD systems in aircrafts. As mentioned cheap alternatives to HUD systems are being made for regular consumers to implement into their vehicles but they are not as well made. Some HUD systems also have problems with visibility in very bright settings, since HUD systems rely on a light/imaging source the visibility of the images in bright settings are completely up to the brightness of the light/imaging source. For example if the light source is very dim on a bright sunny day it may be hard to see the images when the sun light is shining directly onto the surface where the HUD is. This parameter is is controlled by as luminance and contrast of the system. Some other key parameters in a HUD system are collimation, parallax and the eye box. These parameters are all involved in how the viewers eyes will see the images created by the HUD. Parallax is errors occur because human eyes are separated by a set distance and the HUD needs to align the image for each eye. These issued are usually fixed by the collimation of the system, collimation is a key factor in the clearness of images in HUD systems. Overall the technology is not developed enough to be easily implemented into things such as cars and motorcycles easily. There are some vehicles with this technology equipped already however price and quality need to be considered when looking for this technology in consumer products. [17]

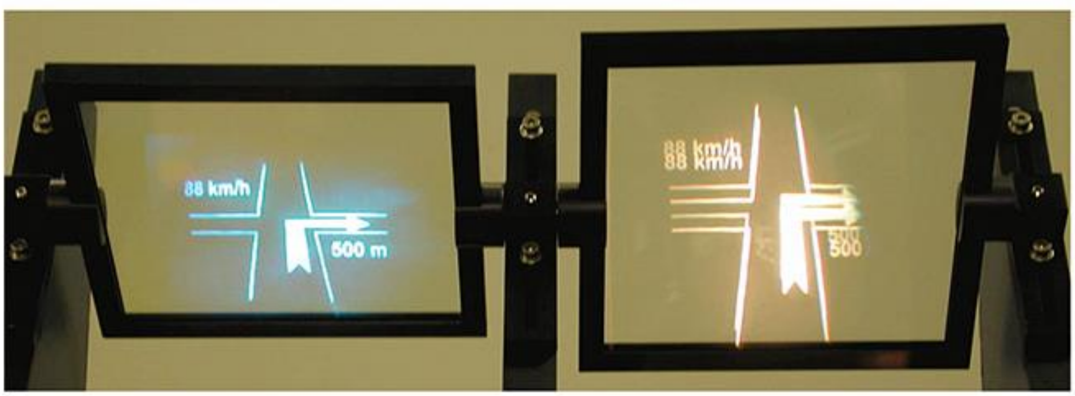


Figure 20 Comparison between a HOE combiner (left) and a Fresnel Reflection based combiner(Right)

Heads up display technology is a fairly new and unique technology so finding other technologies that can compete with a HUD can be challenging. Some similar technologies include holographic projection systems along with augmented reality systems. These technologies are similar in the fact they aim to project in image into the reality of the viewer. Augmented reality is a very similar technology to HUD technology and the argument can be made that they go hand in hand. As augmented reality aims to project images into the viewers FOV. The main difference with augmented reality is the medium in which this occurs. Augmented reality usually relies on things such as screens whether it be a phone screen or headsets that utilize screens to combine reality and the images. However, it is really hard to say that you can use these technologies as a replacement for HUD systems as they are fundamentally different in the mediums the images are projected onto.

The main applications for HUD technology to this day can be mostly seen in aircrafts. Figure below shows the view of a HUD in action on board an airplane [16]. These HUD's can display information in real time so the HUD is affected by the surroundings of the pilot, for example while the plane is in motion the HUD will display the horizon for the pilot at all times. As mentioned, there are smaller cheaper HUD systems that can be implemented into most vehicles, however these systems are much more basic than aircraft HUDs. These smaller systems usually only display simple data for drivers and are not very interactive with the environment around the vehicle. The use of HUDs can make any type of vehicle more safe by utilizing features like this. Limitations aside, if HUD technology can be more easily implemented into cars there are endless possibilities for safety features. An example that comes to mind will be to utilize a HUD to outline objects in dark areas so that the driver can proceed with a better understanding of the surroundings coming up. Glasses have also been created with very small HUDs built into them but there are many drawbacks to this product, so they are not very popular yet. Other applications include interactive windows that utilize HUD technology to display information on regular windows.

In conclusion HUD technology is still very new and still developing every year. Now that we know more about the principles, key parameters, limitations, and main applications of heads up displays its easy to see how much potential this technology has. It may be worth exploring more applications and improvements to this technology and maybe one day there will exist very high-quality HUD systems for everyday consumers.

Figure 21 View of a HUD from inside an airplane from the perspective of a pilot

4.0 Constraints and Standards

The following section covers factors that limit this project in the form of constrains as well as the factors that influence this project through voluntary and compulsory standards.

4.1 Constraints

Like any project we had to take into consideration different constraints to follow when designing our project. Constraints are a crucial part of a project like this as the constraints dictate a majority of what can and cannot be done in a project. As seen from ABET they provide a wide variety of constraints that can apply to any project. Some of these constraints include ethical impact and health risks of a project. Although we can consider the ABET constraints, we found some more general constraints more specific to our project. Some of the main constraints we considered when going through the design process include Safety constraints, Economic constraints, and time constraints. With a small focus on manufacturability, durability, and ethical constraints as well.

4.1.1 Economic Constraints

As mentioned before the budget is a big part of any project as resources are limited especially in our case as four undergraduate students. Economic and time constraints are arguably the biggest constraints in any project and a lot of work must be done to work around these constraints.

Given the scope of this project we decided to have a budget of around $800. The $800 figure came about from research on past projects and willing contribution levels from the team. This seems like a good compromise between getting quality parts that fit within this set budget. This project is not sponsored by anyone so acquiring the funds for this project is completely up to all the members of the team. As mentioned before, working around a global pandemic had a major impact on the economic constraints of this project. We noticed Shipping prices were slightly higher than normal once the lockdown was over. This along with the fact that some group members faced losing their main source of income due to the pandemic lockdowns. To help keep under budget a large amount of research will have to take place in order to find the best products at the cheapest prices for our application. This along with budget allocation will help in ensuring we don't cheap out on important elements in the project. This along with trying to find deals and coupons online are also a big help in keeping under the budget constraint.

The amount of money available greatly restricts the potential scope of this project. Much of the desired functionality was out of the scope of our budget. On the sensor side, many of the properly rated IP65 and up units were much too expensive to purchase as individuals, let alone in quantities needed for experimentation, development and implementation. This analysis is done in discussing camera selection as well. With these being the primary means of collecting information to help the driver make decisions it altered the direction of the project as more research was completed. The project changed from an off-road driving enhancement ready for a harsh environment to a proof of concept for additional development.

4.1.2 Time Constraints

Time is another very important constraint that needs to be worked around. As no project ever has unlimited time to make progress our group ensured that we had a schedule to follow and that we stayed ahead of the time schedule. Since we cannot predict any inevitable setbacks we decided to try and stay ahead of schedule just in case anything happens. Our big end goal is to have our project finished by around April 2021. This seems like a prudent course of action to provide a buffer for the unforeseen issues that will arise.

With time being such a big constraint every decision we made had some impact by our time constraint. Every meeting we set goals for the week to ensure our time was being utilized as efficiently as possible. The time constraint was the most stressful thing to work around as there can be many uncertainties that can arise with a project as complex as this one. We have many different components and systems that need to work together perfectly in unison. This will take a lot of time to perfect so we must ensure to respect this time constraint we have set. As mentioned before the Pandemic also played a big role in our time constraint as shipping times are longer than usual and products are not being stocked as quickly.

We did many things well to manage our time for this constraint. First, we had meetings at least two times a week. One being a short meeting for updates and the other being a big report meeting where we discussed our ideas and research together. These frequent meetings were a big help in getting our work done ahead of schedule. Furthermore, early testing was also very helpful in ensuring our project construction goes smoothly. We were able to order our parts early and not worry too much about long shipping times. Overall, the group just communicated and worked well together to defeat this time constraint.

Student course load, family, and work requirements also played a role in the available time to allocate to Senior Design. The difficulty in meeting was magnified by the time taken to do so in the current environment of no longer working together at the same "office" so to speak as none of us are currently attending UCF physically. This provided practice for the working environment we will face upon graduation and is a real design challenge to be met now and in the future.

4.1.3 Environmental Constraints

Environmental constrains come in the form of how the project is designed, how testing is completed, and in the form of damage mitigation. The operating environment guides practical considerations for component selection. From anticipated operating temperatures to humidity levels the process of design is further complicated by the need to meet a wide range of environments. In a true system able to meet the intended scope of operation this would include being in Death Valley California during a sunny summer day as well as at altitude in the Rocky Mountains during winter. This approaches the space between industrial and military standard level of between -40 to -55 C and 85 to 125 C for those on the exterior with windchill and inside the engine bay. This in addition to vibration, impact, moisture, and similar environmentally introduced hazards all influence design. Florida climate also influences testing and construction by limiting where work can take place due to the frequent rains present. This requires work on the vehicle be performed in an enclosed space as well as the conditions in the field for testing.

Taking data driven, well thought out steps to mitigate environmental impact is the responsible thing to do. There are legal standards to be adhered to concerning interactions with the environment. Specific to our project comes the disposal of waste generated properly and the responsible sourcing of components when economically feasible. The need for locating legal places that will not have an unnecessarily high impact upon the terrain to test the off-road features of this project is a concern. Legal 4x4 trails are difficult to come by and technical non mud or sugar sand terrain is also difficult to come by local to UCF. Travel will be involved to properly test the system.

4.1.4 Ethical and Legal Constraints

From an ethics standpoint a project of this type has the potential to overlap with existing products and processes. Care must be taken to respect intellectual property laws. Inspiration and guidance can be gleaned from existing solutions, yet this work must remain our own. In order to make a commercially viable product that will have an opportunity to thrive in the marketplace it must not face legal challenges in addition to general market competition.

In an age of lawyers there are many steps that must be taken to avoid legal hassles. These can be separated into legal issues that are technical and pertain to a design itself in reference to specifications, constructions, and use. There are also legal concerns in terms of the business side covering everything from labor laws and permitting to financial records and taxation. The scope of this section focuses on technical design specific constraints.

In order to live together in an organized society laws are needed. Over time laws have arisen to cover most facets of life and vehicle modification is included. Which laws apply and how depends on the vehicle, scope of use, and the classification of manufacturer. In the United Sates the National Highway Traffic Safety Administration (NHTSA) is the primary regulatory body and it is a subset of the Department of Transportation. All manufacturers of motor vehicles and motor vehicle equipment items must answer to them. If a product is covered in the Federal Motor Vehicle Safety Standards (FMVSS) one must meet them.

Aftermarket products can be directly or indirectly regulated. The distinction between the two would be tires that have specific standards to adhere to in order to be legal. Indirect regulation would be for items not directly covered with a standard, yet they may be unlawful if they move a vehicle or component out of compliance [18]. If taking this product to market, there are several standards of the FMVSS that have the potential to apply to our product. To introduce a product to market in the United States it must be in compliance with all non-voluntary standards. What steps are required depends upon the product, region, and classification of manufacturer [19]. For example, as of May 1st 2018 all new manufactured vehicles are required by the federally enacted Cameron Gulbransen Kids Transportation Safety Act to have a backward facing camera as described. [20] Associated with this requirement are standards to be met. Our project involves vehicle upfitting and with the vehicle being made prior to that date a backup camera was not required. Since this would be an aftermarket integration without a required standard the guidelines for the new manufactured system could be adhered to as a voluntary standard. Some sample standards are shown in the FMVSS table below. Standards are covered in depth in the next section titled standards.

Table 4 Applicable Federal Motor Vehicle Safety Standards

Applicable FMVSS Standards		
Standard	Title	Content
#101	Controls and Displays	Layout, Safety
#111	Rearview Mirrors	Required, unobstructed
#203	Impact Protection for the Driver	Minimize Chance of Injury
#302	Flammability of Interior Materials	Prevent Interior Fire
Part 556	Manufacturer Identification	File with DOT
Part 567	Certification	Certification Label req

4.1.5 Social Constraints

Social constraints for the scope of this project are people dictated due to cultural/ political, religious and similar personal belief issues. The attitudes and values of the target audience must be kept in mind. This group is as a whole, willing to pay more for more durable products. The axiom of “buy once, cry once” rings true as quality equipment is preferred over items designed to be disposable. This means the potential for the unit to be repaired instead of simply purchasing a new one should the current unit cease to function. IP ratings, as well as a rugged look are selling features to be addressed. The driving force behind the tactile, physical switches as opposed to a touch screen lie here. As far as modern touch screens have come, they are still difficult to operate without looking at the screen. However, once familiarity with a set-up is gained one can operate buttons and switches by feel and muscle memory. In situations that require multitasking of driver vision the ability to operate without looking is a benefit as well as more direct feedback on task selection through the moving and engaging of a physical device. The ability to Customization and personalization are hallmarks of aftermarket modification. In production, having an easy way to switch colors of visible parts for example could help meet this need. In a time of deep political divide in the United States as the main market in North America for a product such as this we believe it best to remain as politically neutral as possible in product design. The avoidance of controversial and divisive logos, symbols, and similar items. Religion does not appear to be a factor in the marketing or designing of this product. The Luddites and the Amish are not the target market and their preferences are not being factored in.

4.1.6 Privacy, Health, and Safety Constraints

When considering the safety constraints of a project there were two factors we considered. The safety of our group members in the design and construction process along with the safety constraints for the product itself.

Starting with the safety of our group, this year is an especially difficult time for group collaborations as there is a global pandemic threatening our population. The spread of Covid-19 was especially intense in our area so to keep our group in good health and avoid unnecessary risk we chose to hold all of our meetings online and do research independently. Then collaborate on our findings each week. This constraint of not being able to meet up in person really changes the dynamic of a group project since we are not able to meet face to face and explore ideas together as a group. This also means some testing of each component would be done individually rather than with a group, so we are faced with extra problem-solving issues as we are not able to problem solve as a group for some components. We believe this was a necessary constraint in the early development of our project as having healthy team members is more important. This constraint led to having to work a little bit harder, but it is well worth the effort in keeping our group safe.

As for the safety of our product, since our product aims at making vehicle operation safer in different environments, we want to make sure the product itself does not pose its own unique safety issues. There are many small electrical components and wires that are utilized in this project. The last thing we want is to start an electrical fire or even harm the user through exposed elements. Since we are utilizing power from the car's battery it would be ideal to have a safety system in place to avoid any overdraws of power to the system which can cause elements to burn up.

We set some constraints that will ensure the safety of our product in its intended use. Ideally, we would like to match actual car manufacturer standards when it comes to electronics and wires in a vehicle. We plan to go over every connection and ensure they are all very secure and covered from any elements, as some of the electronics may be exposed to some mild weather. Overall, we would like to spend extra time and money ensuring the safety of the product especially when testing the product itself before the final version is released.

4.1.7 Manufacturing and Sustainability Constraints

This section highlights the challenges imposed upon fabrication of needed components due to the limitations of available manufacturing resources. Items must be designed in a manner so that they can be built. In modern development this is defined as design for manufacturing and design for assembly (DFM and DFA). This limits future problems to ensure that components are able to be installed without issue and it is made the best way possible based upon available tools. As students without the long-term plan to commit resources to acquiring equipment to manufacture we are limited to those tools we currently own and the UCF facilities. UCF facilities are currently closed or limited in access. The machine shop on campus is generally booked solid and could only be used for a final design due to scheduling and turnaround time. With that in mind we are on our own or having to hire out for prototype and similar testing.

The primary components requiring fabrication will be circuitry enclosures, the heads-up display housing and housings for cameras/sensors. Though there are some commercial off the shelf enclosures, many are not layouts that would be optimized for our situation. The form factor requirement for vehicle integration has space at a premium alongside having a specific layout required to fit amongst existing hardware. For example, many techniques for injection molding of specific housings and the use of materials rated to withstand the abuse of the operating environment are not practical to employ at the prototype stage this project will remain at as a proof of concept. Doing a one-off small production run has made it impractical to set up tooling for specific components to be fabricated.

Use of easy to work materials with hand tools will be the starting point for prototypes with wood, ABS and similar plastics being high on the list followed by aluminum. Use of 3D Cad tools and 3 D printers will be evaluated based upon feasibility and appropriateness for our final application. The team resources for skilled labor are limited to individual team member experience as much outsourcing of work would be outside of budget and project parameters. At the end of the day, we are electrical, computer, and optics/ photonics students and not mechanical or materials engineers. A true venture would have access to more skilled fabricators and designers for these areas of the build. This highlights the need for an interdisciplinary team when working around a system as involved as this project has the potential to be.

Sustainability goes hand in hand with environmental consciousness. Creating a product using processes that are efficient and avoid waste should be the goal of every company. Aside from non-voluntary environmental standards there are also voluntary standards around behavior that is deemed to not impact the environment as negatively as may otherwise be the case. These best practices ensure longevity and the ability to continue the process into the future. Choices we make as individuals and our project vision will impact the degree of sustainable principles that are employed. There are some additional constraints we considered through the span of this project in relation to sustainability. The primary goal was building a lasting reusable product that was designed to be efficient in manufacture and operation.

4.2 Standards

Adherence to established methods of standardization is synonymous with best Engineering practice in modern automotive applications. The global supply chain and need to interface many sub systems into larger and larger assemblies in order to reach the complex final product of a complete vehicle lend this industry to need established dimensions, procedures, and similar documents to enable interfacing between components and the world designed to accommodate them. An overview of those that could be used to further define a design solution to this problem in the form of voluntary standards follows. The following section also covers non-voluntary standards that would need to be met in order to bring this product to the marketplace.

4.2.1 Wiring

There are multiple standards regarding automotive wiring depending upon vehicle scope and intended use. The compilation listed here covers standards that would be purchased and available if working for a larger company that could afford the subscription. These guides show best practices as agreed upon by industry professionals. The Society of Automotive Engineers is a major partner organization for the development of standards. Of note for wiring systems less than 50V standard J1292_201604 covers wiring. Operating range, efficiency, uniformity, serviceability, and performance metrics. The German DIN 72552 codes should be used in denoting components so that the documents are understandable by others. The physical protection and routing of ground vehicle electrical distribution systems is outlined in SAE J2192_201606. Due to the significant portion of our project being display and interface for collected data within the vehicle cabin the in-cabin interfacing for electrical equipment standard ARINC628P5-4 [21].

The driver awareness system promotes safer driving through a better-informed driver. The safety assist aspect of our system leads to ISO 26262. This standard deals with electronic and electrical safety equipment in automobiles. The standard provides guidelines for the design on through the entire product lifecycle for these systems. This standard provides insight into planning for and mitigating malfunctions in critical safety related equipment.

4.2.2 Ingress Protection Ratings (IP) IEC 60529

This classification is the measurement of rating a device has against solid objects like dust and dirt. Along with the protection it has against liquids and by how much and how long. The organization that does the ratings is the International Electrotechnical Commission. The rating system works as a numbering system. The first number being its protecting against solids like dust and dirt. The second number is the number for protection against liquids. All the numbers for each category have different standards. The solid standard is from 0-6. The liquid side of things has a rating from 0-9k.

For the first digit the solids. 0 is the lowest rating this means there is no protection at all for dirty or dust. At the level one rating for solid this means the degree of protection is for solid objects greater than 55mm. This is equivalent to the size of a human hand. The force that can be applied is no more than 50 newtons by an object of 55mm.At level 2 the protection is 12.5mm from solid objects this is about the size of a human finger. The force of an object this size cannot exceed 10 newtons of force. At level 3 the protection is 2.5 mm, so this includes objects larger or equal to that size. At this level a force of 3 newtons cannot be exceeded or there might be a failure to the protection. At level 4 protection object sizes that it's protected against is 1.0 mm this is equivalent to like a thin strap or something along the lines. The force that cannot be exceeded is about 3 newtons. At level 5 the protection that is provided is against dust or really fine particulates that could cause sufficient harm to components or impede the operation of the device. At the level 6 the devices is dust tight so there should be no ingress of dust that can harm the operation of the device. At levels 5 and 6 there is no force requirement that could be located in the research.

Now for the water rating which is the second number in IP ratings. At the level of zero there is no protection at all from water so the device will be adversely affected. At the level one the protection that is offered is. The device is protected against vertical falling drops of water for no more than 1 minute. The rate of the droplets cannot exceed 1mm/min. At the level 2 of protection the water can come from an angle of 15 degrees for up to 10 minutes. The rate of water at which the device can handle is 3mm/minute. at level 3 of protecting the angle at which water can approach is at 60 degrees for a time of 5 minutes. The rate of water cannot exceed .7 liters per minute at a pressure in between 80-100 kPa. The level 4 protection offers protection from splashes of water in any direction for a total of 5 min. The rate of water cannot exceed 10 liters per minute at a pressure of 80-100kpa. Level 5 protection offers protection against water droplets the size of 6.3mm for up to 3 minutes. The rate of the water is around 12.5 liters per minute. At a pressure of 30 kPa from a total distance of 3 meters. Level 6 protection is similar to the level 5, but it offers more protection. The level 6 can handle water droplets at a size of 12.5mm for up to 3 minutes. But at a much higher volume of water 100 liters per minute from 3 meters. Level 7 protection is the start of submersion. At level 7 the device is protected for 30 minutes at a depth of 1 meter. At the level 8 protection is also submersion. But the exact time is not really stated. But at a total depth of 3 meters or less. The last rating is 9k this is the highest and most durable of all the ratings. At this rating it can withstand all the other ratings along with being protected against high power water jets that operate at high temperatures. [22]

Some this to also note is the IP ratings can have more than just 2 numbers. They can also include letters. So, like the letter D is for wires or F will be for oil resistant. H is for high voltage apparatus. M is for when the device is in motion when being tested. S is for the device that was standing still when the test for the rating was conducted. W is for the rating only stands in certain weather conditions. Another thing about the IP ratings is products can have more than one rating. Let's say for example a product gets a rating of IP55/IP57 this tells us that the device did not pass the IPX6 water test. but passed both the tests for IP55/IP57 rating so it passed both 5 and 7 standards but not the 6 for water. Another form of the rating is that they can be for example like IP6X this means the device was tested for the solid object portion. But the device was never tested for water conditions. Another thing about the IP ratings is that they are never tested in real world environments. They are all under controlled environments and test conditions.

This also means that many of the products being tested are not tested in different climates or at different temperatures. So, some of the devices never get the real-world testing to see how they hold up. Some of the rating may not hold in the real world if there is let's say temperature changes. It causes some of the material to shrink then exposing it to the elements. The cost to test the devices under real world circumstances would be much more costly then in a lab. Also there is no way that the test can be 100% controlled and even across the board. So, some products may get a higher rating, but the test was not exactly the same as the product before it. Another thing to also note is that products with higher IP ratings seem to cost a lot more. Meaning the higher the protection rating the more costly the product will be to buy. [23]

4.2.2.1 IP Protection and Off-roading and Automotive Applications

Devices that really need good Ip ratings are ones like our everyday vehicles. Our everyday vehicles see a lot of wear and tear, so they need to have good IP ratings for a lot of their electronic devices. Things like the backup cameras need to have good Ip ratings to ensure they can hold up to the different conditions of the road. At some point it's inevitable that cars will see rain or snow. So, when they attach sensors on to cars, they need to make sure they have good ratings to protect them.

But most daily driver cars do not see the kind of wear and tear that other vehicles might experience. Vehicles used in construction see a lot worse conditions than the daily driver car. So many of the components of construction vehicles need to have very high ingress protection ratings. Like for instances some of the computer systems on big dump trucks or front-end loaders. These computer systems need to have a rating of around IP69 in order to ensure that they get no dust or water in them. due to the very harsh environments that they have to endure. Another application of vehicles that need high end ratings for off road vehicles. These vehicles see a lot of use and abuse. The off-road market is a very large market roughly estimated at $13 billion by 2024. [24] This means a lot of aftermarket parts are being sold around the world. One area that is big for aftermarket parts that need high IP ratings is in the lights department. There are aftermarket lights like KC lights (figure below). These types of lights offer very powerful lighting coverage. Grate for seeing on dusty roads that most off-road trucks drive on late at night.

Most of these types of lights are rated in the IP 68 area due to the harsh off-road conditions they will be experiencing. But as far as aftermarket monitors for things like back up cameras that people also have the option to attach to their vehicles are very costly in the aftermarket. Along with the installation of these aftermarket parts is also the wiring of them. That can also create another large expense when it comes to these kinds of things. So, IP rated devices are highly important in the automotive industry from the recreational side to the commercial construction side. [25]

Figure 22 KC Light Housing

4.2.2.2 Our Project IP Ratings

So, for our project a lot of the components need to be highly robust but also within our budget. So, for the ideal project all our components would need to have Ip ratings of IP68 and above. But this is not reasonably feasible on a budget we have. Like for instance just in the sensors selection alone the cost would be extremely high. Some of the ultrasonic sensors that are used in manufacturing or other industrial industries are a very costly thing. Some of the IP 68 rated ultrasonic sensors would cost upwards of $300+. Now that would just be for one of the ultrasonic sensors. So, considering that the project would require 3 of them we would be looking at $900 alone in the ultrasonic sensors. Along with getting a good IP rating in conjunction with a good sensing distance would also have to be considered for the cost. Now for good high-end IR sensors the cost for one with good range and high IP rating is also a costly thing. This would have been good had we not needed to worry about cost as one of the constraints. Another thing we found was good monitors with a high IP rating also made the cost that much more. We had looked at some of the monitors that they use in construction equipment for our application. But we could not justify the cost. So, one thing we learned was good, rated sensors and monitors. It Costs a lot to have the protection needed for a fully integrated off road vehicle.

If cost was not a factor within the project. We would have liked to add many kinds of sensors to the project. Some of the ones we had looked at with good IP ratings was induction sensors. They were for industrial use and would have provided the protection needed for the application we were looking to do. Having the induction sensors with a high IP rating along with a set of ultrasonic sensors from the same company would have provided us with a much better product more in line with our original idea. Along with having monitors that could handle a lot of water dust and dirt. This would provide a much better and more reliable application for the off road. Due to the fact of the conditions in which it has to operate.

Another nice thing would have also been to have cameras that could handle more water than the cameras we will install. The cameras that will be equipped on the vehicle ideally, we would want cameras that are resistant to the outside environment. But due to the cost and the budget constraints this would not be too feasible. So to help with this a device would have to be constructed in order to help shield the cameras. This will offer some significant protection against the outside environment to help keep the cameras operational while in use on the vehicle. But to get the most optimal product significant money would have to be spent. Some of the cameras could range upwards of a few $100. Depending on their model and lens types along with their IP rating. The ideal cameras would have been ones that are used in applications like underwater ROV. The type of cameras they use for them offer very great protection. Because they are enclosed and have great protection from the outside environment. That is why they can handle things like sea water and sediment from the bottom of the ocean. Having the high-end monitors would have also added much more peace of mind. That way it would increase the reliability of them. One way we could compensate is to offer a good casing to house the monitors in. But this would still not compare to the factory off shelf ones that come ready to use.

The one sensor that does not seem to have much issue is the temperature sensor. It seems like many companies offer a good product line of temperature sensors that have a very high degree of protection. This seems to be due to the fact that most of them must already operate in harsh conditions. A Lot of the temperature sensors that are offered can operate in conditions of up to and a little more than 1000F. So, the wires and the tip of the sensors already come coated to meet a high standard that makes them resistant to all kinds of other conditions. Also, the temperature sensor needs to have good protection. Due to where the sensors would be placed. With it being placed in the engine bay it needs to have good protection from dirt, oil, grease, or other things that may be found in the engine compartment. Some operational parts for the temperature sensor that will have to be protected is the amplifier. This portion of the sensor will have to be in closed to support its operational function. This is because the amplifier is just on a PCB board and is not enclosed at all. This will seriously hinder the operation of the amplifier in the engine bay if it is not enclosed.

Now as far as IP ratings for the amplifier. There are none of the ones selected and purchased for the project. This is because most other companies with high end temperature sensors offer the amplifier and other devices needed to operate the sensors included. Along with high end boxes that will encase the product. Like for instance where the wires would connect into the boxes, they would come with like rubber seals around the connection ports of the devices. This would help to keep water, dust, dirt or anything similar out that might interfere with the operation of the sensors. But all these kinds of systems cost a lot of money. So, it would be better for us to design some kind of housing for the devices ourselves and cut a lot of the cost associated with the high-end programmable logic controls.

4.2.3 General Automotive Display and Ergonomic Standards

Automotive displays have standards governing their form, function, and design. [26] SAE J1757-1, J1757-2, J1757-3 cover vehicle displays, optical HUDs, and power respectively. Camera monitor systems are discussed in SAE J3155 a work in progress standard that is in conjunction with Federal Motor Vehicle Safety Standard 111. ISO 15008 covers in vehicle presentation of information and control systems while ISO 16505 coves ergonomic standards for camera system controls and displays with a section covering test methods.
National Aeronautics and Space Administration (NASA) has invested considerable time and money in study of ergonomics and the human body. Though not a space craft space is a premium and preventing driver fatigue due to poorly laid out equipment is important as is making use of available vehicle space without hindering access. The data on anthropometry and biomechanics provide considerations for ergonomic component design and interface [27]. Designing to accommodate from the 5th percentile female to the 95th percentile male in regards to the body size charts is common design practice [28].

4.2.4 Software Testing Standard

IEEE/ISO/IEC 29119 Software Testing Standard is used as a guide for structuring software tests throughout the life cycle of a software package and is generalized to the point it can be used in multiple industries and roles. The process is split into three portions, planning, monitoring and control, along with test completion. The information in this standard provides ways to organize and document what is being done. Starting from how a test is structured, one must design it so that it examines a specific criterion based upon system need. How to prioritize the aspects that require various levels of testing of the system and how to define the criteria to be tested are introduced to then be adapted to each individual project. Documentation is crucial for data capture and repeatability. Guidance for results analysis is also provided.

Test techniques can range from error introduction, value boundary testing, decision tree testing, logic evaluation, and various scenario tests. The runs will be done to simulate the various states of our program as well as the worst-case scenarios. These tests will be performed under the assumption of proper hardware functioning. Hardware function will be tested separately to ensure that power supply and data feeds are delivered to units within specified values. Keeping our projects context and scope of use will help prevent unnecessary testing and over building the code. This process is described in the software testing section.

4.2.5 RoHS Standard

The need to mitigate the exposure and introduction of hazardous substances is known. It is described within the European Union Restriction of Hazardous Substances Directive 2002/95/EC. [29] The standard is in its third iteration and as the name implies it is focused upon the restriction of hazardous substances within electrical components. The standard specifies the maximum levels of certain substances such as cadmium, lead, mercury, and other less known chemical compounds. Their amount is measured in parts per million (ppm) Some exceptions exist, and the standard is not applicable to all products. Products are sorted into categories and the need versus design alternatives is examined. An example of an exception would be higher lead contents allowed in solders for machined through hole multilayer capacitors. There are variations of this standard worldwide including some parts of the United States chief among them being the state of California. [30]

4.2.6 WEEE Standard

In conjunction with the RoHS standard the Waste from Electrical and Electronic Equipment WEEE Directive 2002/96/EC works to prevent environmental damage as well as waste. [29] The presence of toxic substance within electronics has resulted in the need to manage their disposal in order to mitigate damage to the environment. Controlling how and where these items are disposed of is a large portion of this standard. The rest covers recycling of electronic components that have reached the end of their lifespan. Providing methods to efficiently collect and process this material is part of the standard and has gone through many cycles of revision. The rare earth metals and similar expensive resources should be reused if possible due to their finite and relatively small amounts and potential for difficult access here on Earth.

5.0 Component Selection

This section provides an overview of components and their selection. The analysis of design tradeoffs made in balancing the design requirements and the accompanying constraints in order to meet the desired specifications. It starts with a discussion of computational units and then moves into sensors, optics, and power distribution.

5.1 Microcontroller/Compute Units

All of our cameras and sensors need to have their data fed to a microcontroller or compute unit to process the data and deliver it to the customer. Choosing the right unit is critical to deliver real time data to the user of our product, as it needs to incorporate the ability to process multiple camera feeds and display them to the user at will given an obstacle comes within it's sight lines. The unit also needs to be able to do all this without compromising on power consumption that would lead to the drain of a user's car battery. In order to achieve the needs of our project there are a couple of different units we could incorporate to achieve a well performing and unified system. The options investigated are the Portenta H7, Raspberry Pi 4 Model B, Raspberry Pi Compute Module 3+, Raspberry Pi Zero W, Nvidia Jetson TK1, Nvidia Jetson TX2, and the Nvidia Jetson Nano.

5.1.1 Nvidia Jetson TK1

With autonomous driving demands becoming more and more up and coming Nvidia has taken the lead in high performing compute units capable of taking in video feeds and using the onboard dedicated GPU cores to perform machine learning tasks on the input camera feed/. The Jetson TK1 features a 4+1 CPU core design using 5 total Cortex-A15 cores, with 4 clocked at 2.32 GHz and the extra 1 core clocked much lower to perform lower power background tasks. It also features an onboard Kepler GPU (from Nvidia's 2014 GPU generational architecture) with 192 CUDA cores. It also comes with 2 GB of DDR3 RAM onboard with 16 GB of eMMC flash storage. This board would be beneficial to our project because it also features 2 dedicated camera ports, with the additional USB ports we could also implement more cameras (max of 3 running 640x480 @ 30 fps on the USB bus).

The TK1 also features a full size HDMI port, perfect for running to our display. The TK1 also features a SATA3 port which could be used in the future of this project as we could implement a recording feature that records the video feeds for review. While this board is appealing given its price point (approx. $50 at the time of writing), the access to this spec of Jetson is not as widely available due to its ageing design. It also would be more difficult to incorporate since what is available to the consumer market is the development kit, which does not have removable components such as the chip itself and its memory. This compute development environment would also consume much of the time in software development, as to utilize the GPU to its fullest potential it would require the learning of the CUDA parallel programming language, which could be even more complicated due to the fact that the Jetson community is not as large as other competing compute products. For this reason and the other downsides such as the possibility of a max of 5 cameras, we have chosen not to use this compute unit and its corresponding development kit. [31]

5.1.2 Nvidia Jetson TX2

The Nvidia Jetson TX2 is the most recent and newest version of the Jetson platform, featuring a more recent 6 core CPU design with 4 Cortex A57 cores and 2 Nvidia designed Denver2 cores. This version of the Jetson also features a dual ISP (Image Signal Processor) design that would assist in the decoding of our camera signals. The TX2 also features a newer Pascal GPU (from Nvidia's 2017 GPU generational architecture) with 256 CUDA cores. It comes with 8 GB of DDRM ram and 32 GB of eMMC 5.1 flash storage. Other than performance one of the benefits of the TX2 over the TK1 is the expanded IO, with a possibility to use up to 6 cameras via partner boards that connect the cameras with the J22 connector on the TX2 and go out to 6 CSI-2 connected cameras and an additional 6 or more through the USB 3.0 BUS. The TX2 also features HDMI out for connecting and displaying our information as well as a SATA 3 port such as the one found in the TK1, which would allow for recording of our video feeds at a later date in our project.

This compute unit also has the benefit of an easily removable main compute unit consisting of the core components, allowing us to design a board for it with only the I/O and accessories we would need. This unit however does come with its drawbacks, with the biggest drawback being the price (approx. $400 at the time of writing), and complexity to utilize the built-in Pascal GPU with the limited community. Another downside to this compute unit is in fact the modularity, since designing a PCB with the correct layout and proper connections would require spending a lot of time designing and re-doing PCB's as the data going to and from the module will be very sensitive and could end up failing towards the time of the projects end. The power draw is could be another potential problem with this compute module, as it features some of the most powerful hardware available it draws much more power than other competing compute modules because of its onboard dedicated GPU horsepower. With these drawbacks in mind we are choosing not to use this development kit and compute unit, but will look into implementing at a later date as its features and capability are beneficial to our project. [32]

5.1.3 Nvidia Jetson Nano

The Nvidia Jetson Nano is Nvidia's smallest compute platform, small and modular designed to compete with other small compute boards such as the Raspberry Pi. The Nano is more similar to the TK1 than the TX2. It has updated specifications compared to the TK1 but less I/O than the TX2 given its more compact size. It features a quad core A57 CPU design with a 128 CUDA core Maxwell GPU (from Nvidia's 2015 GPU generational architecture. It has 4 GB of DDR4 RAM and does not feature any onboard storage, instead it requires a microSD for its storage, which is a downside given the performance of microSD cards is very poor in terms of random reads and writes, which our project will heavily use given different camera feeds and sensors. In terms of performance it would be able to handle many of our cameras, however with its limited I/O, such as just 2 dedicated CSI-2 camera ports and 4 USB 3.0 ports. The USB 3.0 BUS should be enough to handle as many as 4-6 cameras depending on bitrate of the cameras and what resolution and frame rate we run them at. The Jetson Nano also features a modular design where the CPU, GPU, and memory could be removed and placed onto a custom designed board.

The Jetson does come at a more affordable price than the TX2, but is still more expensive than the TK1 (approx. $150 at the time of writing). The Jetson Nano does come with the same drawbacks as Nvidia's other products, such as the complexity of the CUDA environment and the complexity of designing a PCB that will work to slot the Nano module into. The Jetson Nano also does not have the storage expansion the other Nvidia Jetson products do, with it lacking the SATA 3 connection we would not be able to expand our storage needs to record video footage on the cameras for review, while this is not the focus of our project right now it is good to know for future iterations of our design that we would go to a product with more expansive storage I/O. For these reasons we have chosen not to go with this solution either due to time and experience limitations with these products. [33]

5.1.4 Portenta H7

The Portenta H7 is a board MCU developed by Arduino. This board does not feature a dedicated CPU but instead features 3 core ARM MCU design. 2 Cores are a Cortex M7 design running at 480 MHz and a single Cortex M4 core running at a slower 240 MHz. It also features a dedicated-on chip GPU thanks to the STM32H747 SOC's built in Chrom-ART Accelerator. This compute unit would be much more appealing than the other MCU offerings because of the capability to run an external display which is required for our designed project. We would however need multiple of these compute units to run our project however, as the I/O and performance is very limited of MCU's. To use these in our design we would need one for every camera feed that would feed into a main compute unit which would then display the camera feeds and statistics to our display. Benefits of using MCU's come in the form of simplicity when it comes to programming and developing solutions for them, as the Arduino community is large and many answers to any problems we may have are out there on the internet.

Something we could implement using this MCU also is the fact we can use these MCU cores in parallel to run some robot vision/machine learning tasks, which we could use to detect foreign obstacles that the proximity sensors would not be able to see. The vast accessories that can be found for Arduino products like this board can also be implemented in future iterations of our project, such as the Arduino Portenta Vision Shield, which comes with built in cameras and microphones as well as additional ISP's to perform further video analysis at a faster rate in conjunction with the Portenta's capabilities. However this solution does come with drawbacks, with a large drawback being the price (approx. $105 for the H7 and $50 for the Vision Shield at the time of writing) since we would need one and possibly one of each for each camera we implement into our system. This system would also need some form of host compute device to interconnect them all, such as a Raspberry Pi or other SOC solutions. With these complexities in mind we have chosen not to use this MCU Arduino based module. [34]

5.1.5 Raspberry Pi Compute Module 3+/4

The Raspberry Pi Compute Module is the smallest form factor of the Raspberry Pi family, with the same specifications as the Raspberry Pi 3 Model B+ and Pi 4 Model B respectively, with the Pi 3 module all mounted to a flexible DDR2 SODIMM PCB and Pi 4 with a PCIe gen 3x1 connection that would allow us to integrate it into our system with our own PCB with only the necessary headers and features on the board. This compute module features a quad core CPU design with 4 Cortex A53 cores clocked at 1.2 GHz (Broadcom BCM2837). It is also equipped with 1 GB of DDR2 RAM and up to 32 GB of onboard eMMC flash memory. The BCM2837 SOC also features the expansive GPIOs and interfaces found in the standard Raspberry Pi's but since we would be designing the boards for it we would be able to use the full potential of the BCM2837's I/O connections. The Raspberry Pi family is very beneficial to our project for its flexibility and ease of use with such a large community for help when needed. Most Raspberry Pi's also have a dedicated HDMI interface which would be necessary to connect our display to for our internal system. This compute module would be beneficial in a final revision of our project where we would shrink down the overall footprint of the PCB as much as possible for each of these modules.

We would need multiple of the modules in order to use these for our project, which is very possible with clustering the Raspberry Pi's together. We would do this by interconnecting each Pi that will be connected to a camera, which would then all communicate as one Pi in theory to our main Raspberry Pi. This also would not be an expensive solution like the for mentioned Portenta H7 as the Compute Module 3+ in its most expensive variant is still more affordable than anything looked at so far (approx. $40 at the time of writing). Just like our other modular options it does come with a complexity drawback however, as these modular SOC's are complex and small in nature to design a PCB for, and the runs to such critical parts are more sensitive when designing such a PCB. In a finalized product form where we could have machines automating the mounting of components and soldering this would be an ideal solution as it would the overall footprint of our project in a vehicle by a substantial amount. Each Raspberry Pi would be capable of decoding 3-4 video signals (1 through the integrated CSI-2 connections and 2-3 off the USB BUS). While this sounds like a suitable solution for our project we are choosing not to use this compute module, as with the rest of the modular units discussed we would not have the time to design a more complex PCB for our components and parts without compromising our data and meeting our deadline. [35] [36]

5.1.6 Raspberry Pi Zero W

The Raspberry Pi Zero is Raspberry's most affordable and trimmed down solution for an SOC, with a single core ARM11 CPU design clocked in at only 1 GHz and only 512 MB or RAM. It does not have any onboard storage and requires a MicroSD card to run its software off of, which is not beneficial as the random reads and writes do not perform well on MicroSD cards. It does have 1 CSI camera connection on board, which is all we would need given we would run only 1 camera off the board. Like the compute module we would need to use many of these units in a cluster communicating to the host device Pi. In another version of our project to be finalized we could even implement the onboard wireless of this module so that it transmits the data from the camera to the host without the needs for wired runs through the vehicle. This would also make it more suitable for any type of vehicle, as we could design it to have the Pi Zero and camera incorporated into one unit where you would then mount and set the angle easily.

This version of the Raspberry Pi is also the most power efficient given its lower end hardware it does not require much power and would not drain our vehicles battery. The Pi Zero also features a mini-HDMI connection which would allow us to run our display without any issues, and a mini-HDMI connection would be durable enough for our project as our design does not call for disconnects and reconnects of the display where a mini-HDMI port would inevitably fail and fall apart. This version of the Pi just like the rest comes with the extensive community for support and help during our project's endeavors. To create a cluster of Pi Zero's we would need more extensive knowledge of the wireless interface and protocol to get these Pi's to communicate with each other since they do not feature a network RJ45 port for networking and communication. For this reason and this reason only we are choosing not to use this for our project in the meantime, once a finalized version is made we will look into wireless clusters to see if it is possible to do. [37]

5.1.7 Raspberry Pi 4 Model B

The Raspberry Pi 4 Model B is the standard variation of Raspberry Pi, with the unit being the simplest form without being too large. It features the most recent specs of all our mentioned compute units, with a quad core CPU design featuring 4 Cortex A72 cores clocked at 1.5 GHz and comes with up to 8 GB of DDR4 RAM. These specifications will make our internal display and interface feel snappy and responsive to the user. These specifications do have a drawback of higher power demands when in full use but when not being tasked to the full extent of the CPU the power usage can be halved. This would be the case for our camera units, as their only task will be to decode the video signal and send it back to the main compute unit. The main compute unit could potentially draw more power in order to display many of the cameras at the same time while also monitoring sensor data. The Pi 4 also features 2 mini HDMI ports and a dedicated DSI display connection, which could allow us for a future model connect more displays to give the user more information to use. The Pi 4 features a single CSI-2 connection but has a USB 3.0 BUS allowing us to connect up to 4-6 camera's depending on the bitrate we choose for them. With this compute module we will end up needing 3-4 of them to get all the camera angles we want to feed into the main Pi 4.

Each unit would be put in main focus areas of the vehicle, such as the front, back, inside, and one for the sides of the vehicle. The Raspberry Pi 4 is not modular, so to downsize it would require extensive PCB design to create a new motherboard for our required components, this would be possible if more time could be spent on the PCB design but for now it will work for our prototype variant. This version of the Pi features the same wireless connectivity as the Pi Zero, but also has a built in RJ45 network interface to create a cluster for the Pi's. The fact that this variant has both communication methods built in is very beneficial, as if time is permitted, we can focus efforts on using the built-in wireless interface to possible then use the Pi Zero's form factor in the future. Another benefit to this version of the Pi is the possibility to run power over ethernet cameras with an additional module, this means that we could set up our system in a similar fashion to modern day security camera setups, where the ethernet cable is the only thing going from the Pi to the camera as it handles both data and power. We will not be doing that sort of a solution in our prototype since it requires higher end cameras and switches to do this, but it could be a potential way to improve camera quality in the future.

We will incorporate these Pi's by connecting up to 2 cameras to each Pi in the given zone it is in, the task of these Pi's will be to decode the video signal coming from the cameras and also take in the sensor data. Each of these units will be in the "device" cluster, where the host Raspberry Pi inside will see this cluster. The cluster will monitor the input proximity sensors to send a signal to the main unit which will then trigger the host to display the corresponding camera. We will create this cluster by running these Pi's through a main network switch and configuring their software to work together as one Pi. For the device Raspberry Pi's, we will have four cable runs going from each one, for power, for networking, for the proximity sensor I/O, and for the camera connections. The host Raspberry Pi will have three connections as well, for power, HDMI, and networking. The Raspberry Pi 4 Model B also comes as one of the cheaper available options (approx. $35 at the time of writing). The only downside of this variant of Pi is the lack of onboard storage, with only being able to use a microSD card, which as discussed earlier has poor performance in random read and write operations. However, with all the other benefits listed we will be using multiple Raspberry Pi 4 Model B's in our prototype product for its flexibility, large community outreach and ability to cluster together. [38]

5.1.8 Ardiuno ATMEGA 328P

The ATMEGA 328P is among the most popular microcontroller designs given its simplicity as well as its large community outreach. We would use this in our project in a simple way to send extra data that our main Pi will need from our temperature sensors towards the front of the vehicle. We will incorporate this through the expansion of GPIO in the Arduino and send the corresponding data through serial connections to our Raspberry Pi. The Arduino has the advantage of also being very power efficient, which given our system is desired, so it does not draw more power than needed. We will incorporate this microcontroller to our PCB design to make it clean and use minimal space compared to using the entire Arduino development kit. The downside of using this microcontroller is the fact that it uses 5V digital inputs and outputs, which given our choice in using Raspberry Pi's is not good considering they use 3.3V digital I/O. To incorporate this we will also design and mount a 3.3/5V level shifter that will translate these in both directions. This is required in order to use both the Raspberry Pi's and the ATMEGA 328P in serial communications modes. Once the ATMEGA sends over the data via serial connection the Raspberry Pi can then store that as a variable and display it to the user in our software interface. [39]

5.1.9 Summary of Compute Unit Choices

Below we have a table of the described components. For our project we will be incorporating 4 of the Raspberry Pi 4 Model B's accompanied by the ATMEGA 328P to feed data into our main internal Pi. We chose these components for easy of programming and lower cost point given our budget. These choices are marked with a '*' to highlight our picked components.

Table 5 Computational Component Selection

Summary of Compute Components: chosen components designated with an asterisk '*'						
	Power Draw	**I/O**	**Connection to Camera**	**Community Support**	**Programing Complexity**	**Cost**
Jetson TK1	Up to 10-15W	7 GPIO Pins (through expansions)	MIPI CSI2 (through expansions)	Smaller	Very Difficult	$200
Jetson TX2	Up to 7.5-15W	40 GPIO Pins/ 2xUSB	MIPI CSI2	Smaller	Very Difficult	$400
Jetson Nano	5-10W	40 GPIO Pins/4xUSB	2x MIPI CSI2	Smaller	Very Difficult	$99
Portenta MCU	5W	22 GPIO Pins	8 PIN Camera Connection	Smaller	High Difficulty	$104
Pi Compute Module	Up to 15W	40 GPIO Pins/4xUSB through PCB expansion	Routable MIPI CSI2	Large	Fairly Simple	$35-75
Pi 4 Model B*	Up to 15W	40 GPIO Pins/4xUSB	MIPI CSI2	Large	Fairly Simple	$35
ATMEGA 328P*	Up to 90mW	14 IO Pins	N/A	Very Large	Simple	$2-$8

5.2 Internal Interface

Our design calls for the use of a display found within the cabin of the vehicle (not the HUD later described). This display will show us our camera feeds and statistics from our incorporated sensors. This will also be the main way a user interfaces with our program and features, showing the output of whatever our user requests from our software. This display will need to be large enough for our user to view each camera in the full layout provided by our software, while also being sharp enough to view each camera in it's portion clearly. Other than the display we will also need a way for our user to interact with things output on the display, for this we are looking into various options such as buttons, knobs, or possibly a touch screen if time permits. Optimally the display would be somewhere between 7 and 10 inches. We have a couple of options when it comes to the internal display and how we implement it, whether it be based just from a screen with a touch display, buttons, or interfacing through an app on your phone to connect to the main Raspberry Pi. Another thing to note, the Raspberry Pi 4 has a dedicated display connection known as MIPI DSI as well as HDMI connections.

5.2.1 MIPI DSI Connection (Display)

The MIPI DSI (mobile industry processor interface display serial interface) connection found on the Raspberry Pi Models is a 15 pin connection that is dedicated for displays. This type of connection and ribbon cable connector is found in many current electronics today for its cost effective and advantageous benefits. One of those benefits is the low power consumption of displays that use this type of connection. This will be advantageous for us specifically when trying to design a system that does not drain a battery faster than the alternator can regenerate the lost power. Many of these displays are so low powered that the DSI connection itself can even power the display, which would lead to easier cable management of our final system. Another advantage of the DSI connection is the lower EMI (electromagnetic interference). While this benefit may not apply to our project it is easy to see how this would be beneficial to smaller devices where many cables and mainboards are stacked on top and very close to each other. This is achieved simply by the fact that most devices connected through DSI are not drawing enough power to even generate any form of EMI.

5.2.2 MicroHDMI/HDMI Connection

HDMI is more than likely a connection you have heard of before given that almost every television today has multiple of these to take inputs of any given device. HDMI is much more common than the previous mentioned DSI connection and can be found on many displays in the market today. This would be beneficial to our team as we try to find options for connecting the main display of the cabin to our Raspberry Pi. The Raspberry Pi itself features 2 MicroHDMI ports, which take the existing HDMI connection and shrinks it down to a much smaller size. This is done by simply making the traces and pin outs of the HDMI connection smaller. Connection wise that is one of the disadvantages of using HDMI, as it features many more pins and a controller on the display to function properly.

While for commercial use and products this is a benefit, in our prototype product this would not be ideal as we do not need those extra connections. The MicroHDMI port is also well known for being unreliable when put under heavy use, which in the case of our project being in an automobile that could be found offroad would not be an ideal solution.

5.2.3 Connecting via Phone Application

Our project could be implemented to cooperate with any phone or tablet with a Bluetooth connection, since our Raspberry Pi 4 features these wireless connections. To do this we would have to design an app that would run our software as planned on the main raspberry pi. This would allow our users to use any phone or tablet to download the app and then run it on any size display they want and figure their own mounting solution for it. This would benefit us as a team as we would not have to design a display mounting solution, at the cost of facing the user with this challenge. We could even benefit in connecting our system to a WiFi network when parked, where we could develop a full stack system that would allow a user to view recorded footage they captured on their time out from any browser.

This would be beneficial to the user, since if we were to incorporate a recording feature it would take up large amounts of storage, where as with this method we could allow a user to automatically back up the stored video footage. We could implement as many functions we could think of with this type of connection to our system, however our team does not consist of full stack and app developers. To incorporate this sort of feature set we would need much more experience in development of softwares mentioned. We would also need higher access to things like Apple's™ app development tools to make our application available to all users. Given the complexity and time it would take to implement a phone application into our system we are choosing not to go this route.

5.2.4 Sunfounder 10.1" Pi 4 Screen

The Sunfounder display is the first choice we will be looking at for our display options. The first benefit of this display is the fact that it is has the capability to mount our raspberry pi to the back of it, which would lead to a clean look which will be important for our user when they install it into their vehicle. We would also benefit from the integrated angle mounts and housing found on this display, as with our design we will need to save time when it comes to developing housing for all our components. The resolution of this display is 1280x800, which is not very impressive especially given its size. The resolution of the display should be higher given it also features a internal HDMI controller, which we could easily plug our Pi into from one of the microHDMI ports. This display features and IPS panel, which for our user's and the possible viewing angles will be beneficial to them.

The downside to having that ease of use and capability is that this display draws too much power for the Pi alone to handle. For our system to be as clean as possible we do not want to incorporate the need for another power supply feeding this display. This display also does not feature any sort of touch input, limiting us to use an interface based on buttons and knobs, looking dated in the process of doing so. The cost of this display is also high given its feature set and abilities, given you can find much larger displays or higher resolution displays for cheaper than even this one. This display also may be too large for some vehicles our users may use, where the room on the dash is limited. For these reasons we are choosing not to use this display, as given its cost and need for more power are large enough reasons to avoid it. [40]

5.2.5 Uctronics 7" Touch Display for Pi 4

The Uctronics display has a very wide feature set for its price of as much as half of the previously mentioned Sunfounder. It features a screen resolution of 1280x600 which while not as good as the Sunfounder provides the same amount of clarity given its smaller display size. The Uctronics display also features and HDMI controller for our Pi to directly plug into it via its microHDMI port. This display is power driven from a micro USB port on the side, this could be a good potential option as we could power it from the raspberry pi. Surprisingly this display also consumes a lower amount of power, running at only 4 W of total power draw. This display also comes with touch capabilities, which would allow us to program a graphical user interface and increase the ease of use of our product. The downside of this display is the fact it has no housing for it, meaning the thin display is exposed to the elements, which with our system is not ideal. It would also mean we would have to design a housing for our display, which would consume more time compared to other already integrated solutions. This display does feature an IPS panel, which is very good for viewing angles for our user to clearly see the camera feeds they have selected on the display from any point of view. [41]

5.2.6 Sunfounder Raspberry Pi 7

Sunfounder makes a variety of displays like the one discussed earlier at 10.1 inches. This display however is a 7 inch display with a resolution of 1280x600. This display comes with the most features of all the displays discussed in this section. This display not only has a housing for itself and the Raspberry Pi but it also has a built in power supply that can feed the Raspberry Pi power to its USB Type C connection if we were to incorporate that. This would be beneficial in a final version of our product that would allow us to create a very clean front display interface. This display also features touch capability which would allow for future programming of the display to use instead of our chosen route of buttons below the display. While this is not necessarily beneficial right now for our prototype it does allow for future iterations of our product to incorporate touch GUI's. This display also features an IPS panel which would be ideal for our use case given the viewing angles of IPS are necessary for our user to view the displayed video feeds and cameras. If we were to use a TN or cheaper alternative panel it would result in washed out and at some angles even inverted color space which would not assist our user in trying to determine what is on the camera feed. [42]

5.2.7 Summary of Chosen Display

Overall, many of these displays would have suited for our needs in this prototype of our project. They all feature an IPS panel which is very important for the user of our system to be able to view the content at any viewing angle of their choice. Some of the displays also feature some sort of housing for our Raspberry Pi to mount to, which would be beneficial to keep a clean setup. The idea of using a phone application to connect to our system would be the most high end and advanced setup, allowing users to use whatever Android or iOS device of any size to make the main display, but this comes with many more challenges which given our timeframe would hurt more than be beneficial. The hardware displays are most certainly the best route for this iteration prototype of our project comparatively. We also took a look into some touch capable displays that would allow us to look towards the future with a touch version of our prototype that would allow us to program a touch based GUI for our system, making operation much easier than through button navigation. Large displays would be nice to incorporate but for our prototyping phase we will choose a smaller 7 inch display that is easier to design for and incorporate into our Jeep that we already have. All that being said we will be using the Sunfounder 7 display for our project, as it features the best overall features given its relatively affordable asking price of only $60. We will take advantage of the integrated housing and possibly the power supply built in for the Raspberry Pi, allowing us to have a very clean system in the cabin of our vehicle.

Figure 23 Sunfounder 7 inch Display with Raspberry Pi installed

Table 6 Display Summary

Summary Of Chosen Displays				
	Phone Application	Sunfonder 10.1	Uctronics	Sunfounder 7
Connection Interface	Bluetooth via phone	HDMI	HDMI	HDMI
Resolution	Varies	1280x800	1280x600	1280x600
Display Size	Varies	10.1 inches	7 inches	7 inches
Touch Capability	Yes	Yes	Yes	Yes
Panel Type	Varies	IPS	IPS	IPS
Complexity	Very Difficult to design an app in given time	Not much, plugs in Directly	Not much, plugs in Directly	Not much, plugs in Directly
Housing	N/A	Yes, and holds Raspberry Pi	None	Yes and holds Raspberry Pi
Cost	$0	$75	$45	$60

5.3 Camera Hardware

When looking into what camera options are available for our applications it was quite the surprise to see just how much support there is for small form factor cameras. After concluding that raspberry pi's would be the main drivers for the camera system the next task was to find a suitable camera for our application.

The cameras required four our application would need to be durable to be able to survive harsh vibrations and collisions with small debris. So, a camera with a hard case to protect it would be ideal in this case. Small form factor is also an important factor to consider as there is not a large amount of space under and around an off-road vehicle to just safely mount large expensive cameras. Cost is another main factor that should be considered along with the choice of camera, as mentioned the camera needs to be made of quality materials to be able to survive off road applications while also being cheap enough in cost to help achieve the budget goal. Considering the scope of this project, cameras with IR night vision features is a good feature to have. When off roading the light conditions will never be perfect especially in the trouble areas under and around the vehicle. When coming to a decision for the right camera there are many other factors to consider but these are the main features required for our specifications.

Table 7 Camera Selection

Camera Selection			
Specs	RPi camera	Amazon.com Dorhea for Raspberry Pi	Amazon.com Arducam 1/4 Inch
Resolution	1080p video	1080p video, 2591x1944 Pictures	1080p video, 2591x1944 Pictures
IR	Yes 850nm	Yes	Yes
Lens	Fisheye, Adjustable Focus 3.15mm Focal Length 2.35 Aperture F	Adjustable Focus 3.6mm Focal Length 1.8 Aperture F	Adjustable Focus 1mm Focal length
Dimensions	25mm x 24mm	32mm x 26mm	10mm x 10mm
FOV	160	72	64
Build Quality	Good Build Quality from Reputable source	Questionable source with decent reviews	Very Small, good reviews
Power	3.3V	3.3V	3.3V
Price	$30	$17	$26

Some secondary considerations to consider include things like the resolution of the camera output. The resolution should be clear enough for the driver to be able to distinguish what exactly is going on outside the vehicle but there are also benefits to using lower resolutions. At lower resolutions faster frame rates are possible and this could help in fast pace situations along with taking less bandwidth to transfer lower resolution images to the display. Another factor to take into consideration is the field of view of the camera. In the case for this project a large field of view is necessary to be able to see as much as possible around and under the vehicle. Lack of vision around the vehicle could lead to catastrophic failure, all it takes is a small puncture to the oil pan of a vehicle to completely disable it.

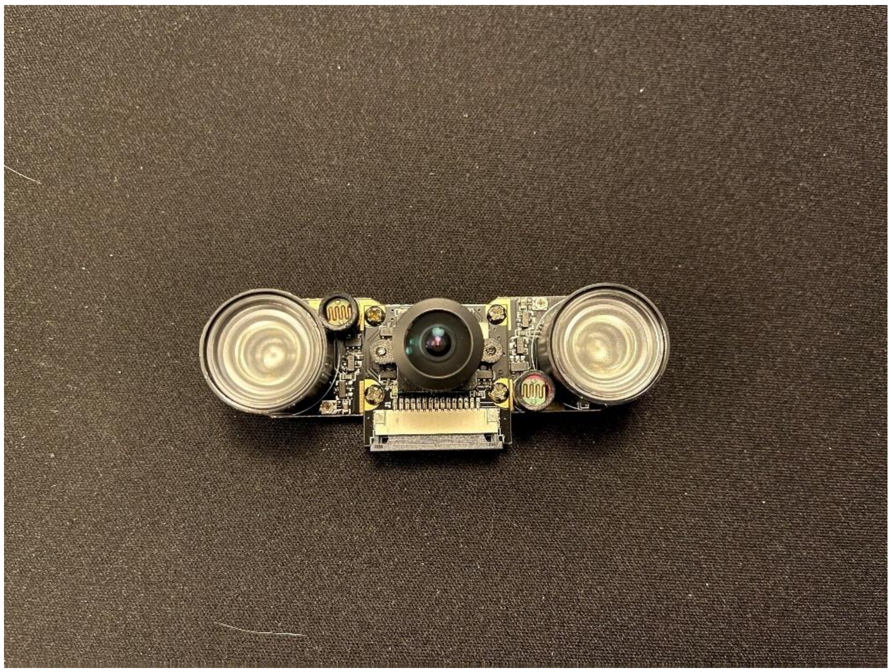


Figure 24 RPi Camera with attached infrared LEDs

The process of choosing the right camera for application was no easy task. There are hundreds of options we had to choose from and narrowed our search down to 3 different cameras that brought a unique feature to the table. A big factor of this project is visibility, so we ended up choosing the RPi camera from https://www.pishop.us/. This camera provides the best visibility and quality. The 160 degrees view that comes from having a fisheye lens will go really well with the scope of this project. This along with the RPi camera having the highest aperture number (F) of 2.35 means it allows in more light than the other cameras since the aperture is the biggest. Thus, resulting in more clear images in low light situations and better visibility for the user of the product. While it is not the cheapest camera, we investigated we decided the extra price was worth the greater visibility and features of this camera.

5.4 Imaging System

The following begins the primary coverage of the camera display portion of the design section. Displays will be utilized to convey the camera feed to the driver.

5.4.1 LCD Displays

The first type of display considered for our application was a liquid crystal display as they are very cheap and widely available. LCD displays have been around for a very long time now and are a very reliable form of display. LCDs have many layers to them and they work on the principle of having a positive and negative electrode layer that cause the liquid crystal molecules to align themselves depending on the electric field applied to them. These molecules can allow various levels of light to pass through them to allow you to see various colors. The pixels on an LCD generally have three colors Red, Green, and Blue. This allows the display to create a variety of colors by mixing these colors in a pixel. However for our applications the LCD may have too many drawbacks to be considered for our heads up display. LCD displays actually do not emit light; they rely on ambient light, this means the projection of the LCD display will hardly be visible onto the windshield of a vehicle without a bright external light source.

5.4.2 LED Displays

Considering the brightness issue of the LCD displays the LED display may be another good option as LED displays are simply a panel of light emitting diodes arranged into an array. Similar to LCD displays LED displays also use Red, Green, and Blue or RGB to emit different colors for each pixel. Since LED's are being used to light up the display, no external light source would be needed like the LCD display. LED displays are commonly used for outdoor use in things such as billboards due to their clear visibility in bright settings.

Some issues found with trying to use an LED display for our application would be the size of the display and compatibility with the hardware being used. LED displays are much larger and bulky compared to some of the other display options. It was also very difficult to find a suitable LED display for our Raspberry pi drivers

5.4.3 OLED Displays

OLED or Organic Light emitting Diode displays are another great contender for the application of this project. The general principle of OLED displays are very similar to LCD displays except OLED displays emit light. Some other advantages include, better contrast, higher brightness levels, wider viewing angle, and lower power consumption. Not to mention OLEDs are more simple and thinner in design. Not to mention there is a very wide variety of OLED displays available for raspberry pi's.

All these advantages come at a cost however, the OLED displays are generally more expensive to create compared to LCD's. Another factor to consider is that OLED lifetimes are not as long as LCD lifetimes. More recently OLED technology has improved lifetime enough to where this should not be a deal breaker when considering an OLED display. Another issue is OLED screens can become hard to see when under direct sunlight.

However, they are still very bright emissive displays so this issue can easily be avoided because a casing can be made to cover the screen itself along with using a reflective coating on the windshield for even more clear visibility.

As mentioned, the OLED display works in a similar principle to LCD displays. The OLED display consists of organic thin films placed between two conductors. This organic film made of a carbon-based material emits light when current is applied to it. The OLED screen has many layers but the three basic layers to the functionality of the OLED involve a cathode and anode for the transfer of current and the organic emissive film in between the cathode and anode layers. This organic film is very robust and can operate at higher temperatures than other types of displays. There are even cases of OLED displays that are flexible and can be formed to curve and fit certain shapes.

Overall, the benefits of OLED displays heavily outweigh the disadvantages, which is why we chose to use an OLED display for the Heads up Display portion of our device. The figure below shows the basic structure of an OLED display to show how the stacked structure of the display can be compared to LCD displays.

Overall, the benefits of OLED displays heavily outweigh the disadvantages, which is why we chose to use an OLED display for the Heads up Display portion of our device. As far as product choice we narrowed our display down to two different parts. The first display is from Crystalfontz.com with part number CFAL9664B-F-B2. We did further testing with this product since it meets many of our requirements for a display. First this display is very bright and has a contrast ratio of 2,000:1. It is important to have a bright display with a high contrast so that the image is visible when projected onto the windshield of the vehicle in bright settings. This display has a resolution of 96x64 and a very wide viewing angle of 160 degrees which is plenty for our heads up display notification system. We may not utilize such a high viewing angle, but it is a nice feature to have. Other displays with smaller viewing angles may not be as visible and the colors may appear to be washed up at extreme angles. This display is also very compact, lightweight, and very durable being able to operate up to 70° C (158° F). The unit weighs 1.4 grams and is 24.8mm wide, 22.42 mm long and 1.33mm thick. Budget also played a big role in choosing this display, coming in at $8.23 per unit this is one of the cheapest OLED displays we could find while still being a quality product. Finally this product also offers a development kit for easier integration into a system, that comes with a custom board for the display and a large amount of forum support for getting the display to work correctly.

Another OLED display considered for the HUD is the ER-OLEDM015-1C-SPI sold by https://www.buydisplay.com. This display also offers many of the same benefits as the Crystalfontz display previously mentioned. However, this display offers a 128x128 resolution. This display is a bit more expensive coming in at $16 per unit however this display offers more connectivity options which may be much more helpful considering our use of microcontrollers and raspberry pis. The increase in resolution can also benefit the image quality and make the images easier to see for the driver. Along with the sacrifice in price this unit is also slightly larger with dimensions of 36mm x 44mm.

For our display we ended up choosing the ER-OLEDM015-1C-SPI from https://www.buydisplay.com. This display we a bit more expensive than the other option but still a cheap quality unit at 16$. The specs were fairly similar between choosing two specific displays, but the extra resolution will be a big benefit for the heads up display unit. That along with being the better-quality part will ensure a successful product.

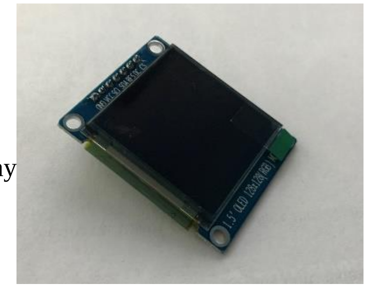


Figure 25 ER-OLED Display

The table below shows the OLED comparison chart.

Table 8 OLED

OLED		
OLED Specs.	Crystalfontz.com CFAL9664B-F-B2	https://www.buydisplay.com ER-OLEDM015-1C-SPI
Dimensions	24.8mm x 22.42mm x 1.33mm	36mm x 44mm
Cost	$8.23	$16
Resolution	96x64	128x128
Contrast	2,000:1	2,000:1
Interface	8-bit Parallel, SPI	3/4-Wire Serial SPI
Operating Temperature	-20°C - 70°C	-30°C - 70°C
Power Supply	2.7V	3.3V
Dot (Pixel) Size	0.05mm x 0.19mm	0.045mm x 0.194mm
Quality	Cheaper quality not as durable	Great reviews for durability

5.4.4 AMOLED Displays

AMOLED displays or active-matrix organic light-emitting diode displays are very similar to OLED displays. As far as specifications the AMOLED display would be the ideal choice. As it improves on the drawbacks of the OLED display. Unfortunately for our application the price of AMOLED displays does not fit the budget for this project. The technology is also not developed enough to be able to realistically implement into this project as well. Some other factors to consider are screen burning issues in AMOLED displays. These AMOLED displays should definitely be considered for future iterations of the project if the technology has been developed enough to bring cost and screen burning issues down. Another factor to consider is the lack of support for AMOLED for the raspberry pi.

5.4.5 Display Selection

The chart below covers the overall thought process for selection of the display to convey the camera feed view to the driver of the vehicle.

Camera Display Selection Tool		
Types of Displays	Pros	Cons
LED	Bright, Cheap,easy to use,low power consumption	too big, not alot of options
OLED (display we chose)	Bright, high contrast, sharp images, lots of support , durable,flexible, low power consumption	moderate price
LCD	Very cheap,small,easy to implement,lots of support,low power consumption	Not emissive
AMOLED	Bright, high contrast, sharp images, lots of support , durable,flexible, best image quality,low power consumption	Very expensive

Table 9 Camera Display Selection Tool

5.5 Sensors

The Sensors that will be used for E.D.A.D.S Will help enhance the driver's capabilities to detect objects or specific functions of the vehicle. Then give feedback to the diver via warning light within the vehicle s Hud system. There will be three types of sensors. Resistances Temperature Detection (RTD), IR and Ultrasonic sensors. The RTD sensor will be used to measure the ambient engine bay temperature. The IR sensor will be used to detect the tire temperature. The ultrasonics sensors will be used to detect objects behind the vehicle within a 1.5-foot range. for the engine bay temperature sensors, the data for that will be displayed on the HUD system. There will also be a predetermined value in which a warning indicator will also be tripped. displaying either an icon on the Hud system or just show the numbers enlarged. The ultrasonic sensors will work similarly but when an object is detected within a foot of the vehicle a warning indicator will be displayed on the HUD system. The IR sensor will work similar to the RTD sensor and the value will be displayed on the HUD system with the numbers.

5.5.1 Temperature Sensors

The first section to follow covers the various methods and features to be examined in temperature sensor selection. The discussion then moves to cover specific models and the final choice is highlighted.

5.5.1.1 Thermocouples

This sensor is a widely used form of sensor. The operation of this sensor is done by putting together different types of metal and joining them. Having two different metals will allow for the conductivity to be different. This will allow for a voltage difference between the two. This effect is also known as the Seebeck effect. There are many kinds of thermocouples. Along with different classifications for instance. E classification is made using Nickel Chromium/Constantan; it has an operation range of -40C to 900C with a sensitivity at 68 uV/C. Where on the other end they have a B classification that is Platinum Rhodium with an operating temperature between 0C to 1820C.The most used classification of the thermocouples is the K classification. The K classification consists of Nike Chromium/ Nickel Aluminum which has an operation range of -180 to 1300 C. Some of the down sides with Thermocouples is the fact they have a small output voltage. This means the sensors will need a more precise amplification in order to get an accurate reading. Along with if you have long wire runs this can cause a big deal as far as noise. This noise can in turn mess up the reading when the signal is sent over a long wire. This change can cause big inconsistencies with the output reading.

Issues can also arise at the cold junction. The cold junction is the point at which the two pieces of metal meet. This meeting happens at the two pieces of copper wire. This junction creates a loss in electrostatic. In order to correct this a thermistor is usually used or a very good resistance temperature detector. This thermistor measures the electrostatic at the cold junction then applies it to the voltage if the thermocouples. This will create less of an inaccuracy. Mean manufacturers already have the cold junction compensation built into them. Most thermocouples are contact sensors. This works good in mean applications that need a contactless sensing application. They also have a high sensing range so this will make it use full in many applications. They are robust to so it helps. But they can be temperamental to vibrations also by they way they are designed. Also due to the fact they have the cold junction that needs to have the voltage difference factored in. This creates for an added point that could potentially interfere with the operation of the sensor calibration. Each type has to be calibrated different depending on the type of junction and the type of material. So, this could create issues for the user if they do not realize this. So it will intern affect their output. [43]

5.5.1.2 Resistance Temperature Detection (RTD)

RTD sensors work based on the principle that when temperature changes so will the resistivity of the metal will change. This change in resistivity is what RTD sensors are based on. There are many different configurations of RTD, but they all involve a resistor. There are wire diagrams with 1-4 wire set ups that are hooked to a resistor (image below). The reason for the more wires is the more wires the more accurate the sensor will be. This is due to the fact of the design of the RTD. The RTD sensor head itself is made up of Platinum. The use of Platinum is because it is a highly stable element. Now the wires that connect the Platinum head to the rest of the sensor body and the other resistor are made up of insulated copper. This insulated copper has a resistance of its own. This resistance is also susceptible to electron flow in heat this in turn could offset the measurement of the sensors.

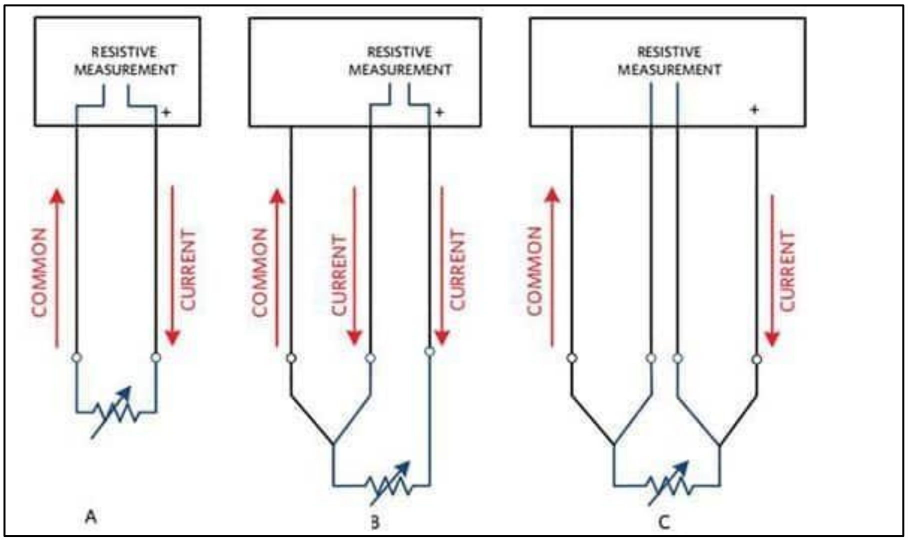


Figure 26 Resistance Temperature Detection Set-ups

The most common wire configuration is the 3 wire RTD. This is because it uses a Wheatstone bridge. This allows for two of the wires to cancel each other out so that way the third wire can be used to carry a small current giving a more accurate reading. The 4-wire version is by far the most accurate version. With the 4-wire version it allows for the it to compensate for the resistance of the copper wires. With this version there is no need to pay attention to the length of the copper wires. The output of RTD is the best because it has the most liner voltage output. Some of the down sides of RTD sensors are they do not change too well with time. This happens because of the thickness the materials used allows for a slower change in the overall temperature element. RTD sensors are used in most industrial applications. They work well in places that have a lot of radiated heat coming from components. Or also in places with extremely high vibration they can remain accurate. They are also good in places that are hard to mount sensors due to the fact they are generally small and compact sensors. Other industries are used in HVAC. They are durable and good for being used in humid environments along with dry environments. They usually measure the temperature in rooms that are air conditioned. RTD sensors can also be designed with transmitters. They are more used for places where being sanitary is necessary. Like in medical equipment or in labs. [44]

5.5.1.3 Thermistors

A thermistor works on the same principle as the RTD sensors. By temperature changing the resistivity of a material when it is exposed to hot or cold. But instead of using Platinum at the sensing element they typically use a plastic polymer or a ceramic material. The polymer plastics they use are made up of many different materials. There are ones that are transparent that use silver fractal dendrites (AgFDs). The film of these sensors are usually composed of many different elements. When the composition of the films is changed, they can yield different results. Like for instance some ceramic mixtures with epoxy can increase the resistance of the element 9x. The nice thing about the use of polymers is that it lowers the cost of making and buying thermistors. But there are several drawbacks to the thermistors. They do not have a very large temperature range when compared to the RTD sensors. Most thermistors have a range for detection in about the 0C to 100C range. They do not work well in cold environments due to the fact they are made from polymers. Thermistors also need a lot of correction for their voltage to temperature output. A thermistor has a very nonlinear voltage to temperature output. This output requires a lot of correction.one of the ways this is corrected is by use of a resistor. This resistor has fixed value. This fixed value resistor along with the resistive material voltage is then converted to a digital value via an ADC. This helps to correct a lot of the nonlinearity issue. Thermistors also come in many different forms as far as resistance value. The value of the different resistances allows for the thermistor to have many different applications. The range difference resistance also corresponds to the temperature ranges the thermistor is good at Due to the low cost of thermistors they are ideal options for many kinds of applications. They can be found in a wide variety of industries. They are in the HVAC industry, the food and beverage industry, and medical applications. They are also found in a lot of household items like microwaves, circuit protectors, and digital thermostats. [44]

5.5.1.4 Semiconductor Temperature sensors or IC sensors

Semiconductor temperature sensors also known as integrated circuit sensors are widely used. IC sensors get their name because they are integrated circuits using semiconducting material like wafers. They are made from silicon wafers. Constructing them from silicon wafers allows for 1000’s of them to be fabricated at once. This allows for a much cheaper cost. Some of the nice features about the IC sensors is they allow for a fairly linear output graph. This makes it much easier for the input device to read without having to make many corrections other than noise reduction. This is if the user has a good understanding of semiconducting material. Sometimes the semiconductor is not all the way attached to the outside surface. This can allow for oscillations to happen with the voltage creating a not so accurate read. Also, the IC sensors do have a good temperature range within about the range of -40C to 150C. I think if they exceed too much, they will get hot and just start to melt the semiconductor. Some of the most popular versions of these sensors are the AD 590 and the LM 35. The two are the ones most people go to when looking for this kind of sensor. There are many different variations of IC sensors from all kinds of vendors. The different variations mostly just provide different ranges of temperature IC sensors also come in a digital read out form most are analog, but the option is available. There are five different kinds of IC sensors in the way they are constructed. [45]

Voltage Output Temperature- This type provides a voltage output with a low output impedance. This also allows for them to be nearly a liner output. **[**29]

Current Output Temperature sensors- This type of sensor acts with a large impedance. There is about 1 micro amp passed per 1 degree in kelvin change. They typically require a voltage to be supplied in between 4 and 30V. This depends on the manufacture of the sensor.[29]

Digital Output Temperature Sensors- This form allows for an easy connection with an ADC. It more to less streamlines the conversion. It's one of the first kinds of sensors to incorporate a sensor along with an ADC onto one chip. This type is more for the use of heat management of microprocessor chips. Some manufacturers of this version also make them for this like machine use monitoring or food transportation.[29]

Resistance Output Silicon Temperature Sensors- This version is like the RTD sensors. But instead of using a large resistor it uses the properties of semiconducting material. This allows for a much easier manufacturing process to use already existing manufacturing silicone techniques. Most silicon resistance temperature sensors use this equation R=Rr(1+a(T-Tr)+b(T-Tr)^2-c(T-Ti)^d) a,b,c are constants Ti is the inflection point. One issue with the resistance temperature sensor is the self-heating can cause error. [46]

5.5.1.5 Diode Temperature Sensor

This is one of the simplest forms of temperature measurement using a semiconducting material using just a basic diode. This is one of the most cost-effective ways to measure temperature out of all the other semiconducting ways. But with it being one of the cheapest ways to measure temperature. It comes with a major downside: it is highly inaccurate. This inaccuracy can be large some +/- 30C if not more. There are ways to correct this one way with is by the type of diode that can be used. One of the common ones to improve the accuracy is by using a 1N4004 diode. By putting them back to back it can improve the accuracy. By helping to eliminate some of the power that is lost during the highs of the current. So, to better improve it beyond that using an equation T=(V1-V2)/(8.7248e^-5*ln(I1/I2)). A good ratio to have between the currents of the diodes is to have a 1:10 ratio. This will help to improve the overall Kelvin temperature measurement. This method still could be better improved on by using sensor grade parts. But no matter what this application will be nearly as good as using a an out of the box temperature sensor that is design for that specific application of measuring temperature.[29]

5.5.1.6 IR Temperature Sensors

IR sensors are used to measure the absent heat of an object. There are two kinds of IR sensors passive and active. Most all objects admit some form of infrared radiation. The active IR sensor emitters an IR beam. While passive just receives infrared light. The active

IR sensor works by using a light emitting diode (LED). This Led will admit an infrared light. This infrared light will then reflect off a surface and bounce back. The bounce back of the light will be picked up by a Photodiode. When IR light hits the Photodiode it will then change the resistance along with the output voltage of the diode. This change in resistance and output voltage is proportional to the light received by the photodiode. A passive IR sensor just receives infrared light from the surrounding area without transmission of its own source for infrared light. Circuit diagram shown in Figure below.

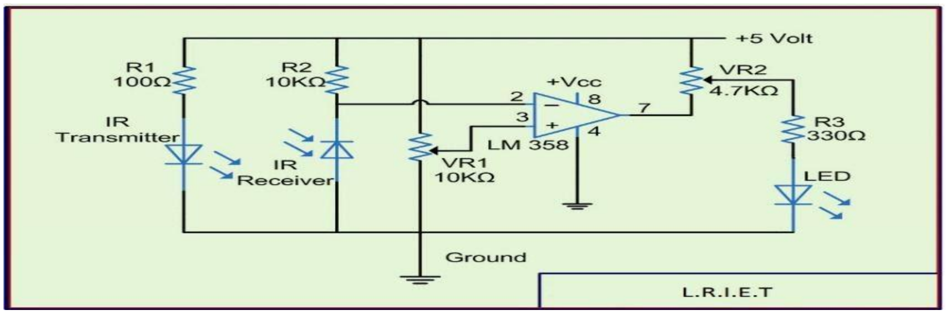


Figure 27 Base Circuit IR Sensor

The amount of light that the photodiode picks up depends on the distance the light traveled. The further the light had to travel the more light was scattered. The more light that scattered means the object is located at a much further distance. This will then relate to less of a change in the resistance of the photodiode meaning the voltage will stay low and the object is far. This can be affected by some other things like the color of the beam that is being used. Mostly it is a light that is not visible or a green or red Led. Also, it depends on the object that is being measured color if the color of the beam is the same as the object light will be reflected. If the object is saying black light will be absorbed more and less will be reflected. This could intern influence the results. Most IR sensors can work in the dark because most objects admit infrared radiation that can be seen by the human eye. An IR sensor will not be able to measure temperature through glass. If you try to get an IR reading through glass it will not work, you will only be measuring the temperature of the glass. Also, IR temperature sensors are the best for non-contact temperature sensor applications. [47]

5.5.1.7 Selection of temperature sensor

We had considered taking temperature readings of all different places along the vehicle. Like for instance the engine bay, Transmission, tires, interior of the cabin or exterior to name a few. The place of measurement along with the location of the measurer would determine our selection of temperature sensor. We narrowed down that we would only like to measure components in the engine bay along with the tires. Also provide a read out to the driver, along with warning if the components got too hot. Once we decide what we wanted to measure the selection for the sensors we knew would have to be a contactless sensor. To provide the ambient surface temp of the tire will be under motion. Along with providing the general temperature under the hood in the engine bay. The option we chose for the tires was an Infrared sensor because it allowed for contactless sensing.

The IR sensors will be located within the tire well of the vehicle. The choice for the location was based upon the location of the tires we wished to measure. Also, to better shield the sensor from being knocked off the vehicle by trees or any other object that may brush along the sides of the vehicle. The reason for use for the IR sensors is it allows for a contact free sensing of the vehicle components of the tires. This will eliminate a sensor being only in one location of the tire like attached to any components directly. Also depending on the distance from the tires to the sensing element it will provide a larger field of measurement on the surface of the tires. As the sensor tip is further from the surface.

We will also use one RTD sensor to measure the engine bay temperature. This kind of sensor seemed like the best option to measure engine bay temperature. We chose this option because they have the highest rating for temperature vs cost. They can also operate the best in extreme heat with a lot of vibrations. We plan measures near the engine block of the vehicle. This will provide a good reading to know if there is any danger of overheating. The sensor will provide a warning if the engine block gets too hot. The reason we chose the RTD sensor over the thermocouple sensor. Was since the thermocouple sensors would not have held up well with vibrations of the vehicle. Due to the design of the thermocouple. The two probes would have vibrated with the vehicle causing an inaccurate reading. Another reason for not using the thermocouple over the RTD. All around for the cost of the RTD and the reliability is way better than the thermocouple. The RTD sensor depending on the resistor value gives a much more accurate read the higher the resistor value. Both the RTD and thermocouple would have been fine to operate in the engine bay temperatures of around 180-200 C.

5.5.1.8 ZTP115 Thermopile IR sensor non-contact

This was another option of IR temperature sensor we had looked at. This sensor works on the same principle as the MLX 90614. But this sensor has an operating range in between -40C to 105C. This is comparable to the MLX 90614.It also has a much cheaper cost than the MLX 90614 coming in at around $5.94 not including shipping and handling. But this reduction in cost does not give us the same reliability or benefits as the MLX90614.The sensing range is not as great. Based on the application they use the sensors for it has a much wider beam then the MLX sensor. But as far as the distance it does not have as much distance when doing the detection. Maybe around 2Cm. There was not much given on the detection range for the specs. Also, this has more of an analog output making it a little more involved as far as putting it together on our application.

These sensors meet a few of our needs. Like for instance it meets the budget by a long shot. Another one of the needs it meets is the supply voltage at 5V. This would be good seeing how the raspberry pi is supplied at that voltage. One thing we did not like was the fact it used an analog output. This really wasn't a big issue, but we figured if we could have a much easier read out why not opt for it. Another thing we felt we could do better with was the field of view. With only a field of view of 60 degrees we felt there had to be one with a much better field of view. So, we did not end up going with this sensor. [48]

5.5.1.9 OS136A-1-V2

The OS136A is a high-end sensor. This sensor is used in a lot of industrial applications. The sensor is well rated for temperature coming in at -18C to 202C. This is more than enough range for the application which we are going to be using it for. One downside to this sensor is the voltage that is required to power it. This sensor would need 24V DC just to power the sensors alone. This high voltage is also needed due to the sensors high range of detection. This sensor has good temperature sensing of up to 122 CM or 48 inch. Another nice thing about this sensor is the construction of it. It has a nice stainless-steel coving that provides really nice protection from water and other outside environmental things. This would be perfect for the application in which we are looking to use it for. Because we need sensors that would be well built and protected from outside environmental factors. Due to the fact the sensors would be exposed to things like this.

One of the down sides is that fact the sensor needs a high supply voltage we can really use it. Seeing how we wanted to supply all the sensors by the raspberry pi. The 24 V could not be achieved since the raspberry pi's only output 3-5V dc. Also, we could not run the sensor off the car battery due to the fact that it only outputs 12V DC. Another issue with this sensor is the cost of the sensor alone. This would not be good for the budget at all. Because we still need to purchase others. So, this sensor would be perfect if not for the cost and the supply voltage. This would have been the sensor chosen if not for them 2 factors money and the supply voltage. [49]

5.5.1.10 MLX 90614 Non-Contact Sensor

The sensor we decided to go with is the Melexis MLX 90614 Non-Contact sensor. This sensor is a passive IR sensor. This sensor has an operating voltage of in between 3V-5V making it ideal for the type of board hook up we are looking to incorporate into our project. This sensor has an easy hook up with only 4 pins. The sensor will use the PCB I2C for a more simplistic use and interface. Another reason we went with this sensor is for the cost at only $15.95 not including shipping and handling. Some of the other options that were looked at were one almost identical to the MLX90614 long distance version. This one gives a close range and good accuracy at close ranges with not as wide of an area of detection. So, by using the version posted in the photo above gives us a much better detection area. Being able to cover a good amount of surface of the width of the tires more fully. Due to the fact we will be incorporating it on a jeep with large and wide mudding tires. The distance between the wheel well and the top of the tire is enough to provide area for the sensor to detect. A mounting bracket will likely have to be made to support the sensors and its wires. So, it will; not cause interference with the tire in rotation. Also, it allows the wires to stay tucked away and in a neat arrangement. For the mounting of the sensor, it will have to incorporate a custom-made mounting system. This will need to be done to make sure the sensor is within close proximity to the tire. This is because of the range of the sensor to ensure accurate reading. The sensor +/-.5 C at room temperature. This is good to make sure we have a stable accuracy of the tires. The sensor can also operate at a range of -70C to 125C. It can also measure object temperature it the range of -70C to 380C. This will be more than enough for the application we are looking for. [50]

Figure 28 MLX90614 3V-5V IR Sensor

Summary table of IR sensor comparison			
IR sensor	MLX 90614	ZTP115	OS136A-1-V2
Manufacturer	Melexis	AMPHENOL ADVANCED SENSORS	OMEGA
Cost	$15.95	$5.94	$230.00
Temperature ranges	-70C to 380C	-40 C to 105 C	-18C to 202C
Output type	I2C	Analog	Analog
Field of view	90 degrees	60 degrees	
Range	5CM	3CM	122CM
Pin count	4	4	4
Voltage	5V-3V DC	5V DC	24 V DC
Selected for project	Yes	No	No

Table 10 IR Sensor Selection

5.5.1.11 Thermocouple Type-K Glass braid Insulated

This is one of the other kinds of resistance temperature sensors. This one uses two wires of different materials to measure temperature. This thermocouple temperature sensors seemed like a good option as a sensor for the project. It came well within the budget at only being $9.95. This would be a good upside for the sensor. The sensors also had a very good operating range for temperature between -73C and 482C. This also was a very good thing considering the places in which we need to take the temperature from would be hot. The sensors also had a good wire protection on it. The wire for the sensor was wrapped in a fiberglass braid. This would help prevent any abrasions on the wire or just in general wear and tear of the wire. But a lot of sensors also offered this feature. Due to the places in which the sensors have to operate. Another thing to like about the sensor is it uses the serial port. This also makes for easy connect ability helping to simplify things.

Some of the down sides of this sensor was the fact it was a thermocouple. There was some worry because it used 2 wires to take the voltage difference to get the temperature. That when left in the vehicle while running the vibrations may interfere with the accuracy of the sensor. Another issue was the fact that this sensor is also unprotected at the head of it . The two wires are just exposed to the elements means that dirt and anything other may also interfere with the reading more. This would not be ideal for the place where we want to locate the sensor. One last thing that became apparent with this sensor also was that if it was exposed to more than 500C there is a heat shrink wrap around the covering that could potentially melt. This is not good because the sensor may come into direct contact with components that could potentially get that hot. Then this would cause that heat shrink piece to melt. This sensor also needs an amplifier just like some of the other ones that we looked at. This sensor also has from the amplifier that's needed with it a +/- 2C variation in the accuracy. But overall, this sensor has some good things about it but is just not as good as some of the other options. [51]

5.5.1.12 Temperature sensor -Platinum RTD sensor PT 1000

The temperature sensor we chose was the PT 1000. There are many good options as far as RTD sensors. Another option that was being looked at was the PT 100.The PT 100 is about the same sensors as the PT1000. But there is variation between them. Some of the variations are the resistance sizes. The PT 1000 boasts a 1000ohm resistor at 0 degree C over the 100ohm at 0 degree C in the PT 100. This difference is a lot when considering the accuracy of the two sensors. The PT 100 could have a range of +/- 1 degree C vs the Pt 1000 that can have an accuracy of around +/- .1-degree C. Now the accuracy when compared to the cost is not too bad to have the more accurate one. The PT 100 comes in at a cost of $11.95 vs the PT 1000 at $14.95.

This ends up not being a bad tradeoff for accuracy vs cost. Another thing is they are both PT meaning they are coated in platinum. But the Pt 1000 is equipped with a 316L stainless steel shield. This 316L stainless steel means that it is highly corrosion resistant. The metal contains nickel and molybdenum making it also resistant to chemical contaminants and acidic solutions like bromides. This will help keep the durability of the sensors and provide it to last longer. This will help since the location in the engine bay will have very harsh conditions. Both the PT100 and the PT 1000 have a max operating temp of 550 C and a range of -200C to 550C.

This will ensure safe operation of the sensor. Seeing how most jeep temperatures under the hood get up to around 180 -200 C. Both models have a resistance variation of around 3.85 ohm/C nominal. This means for every degree the resistance goes up around 3.85 ohm. This means as the temperature gets hotter the resistances will start to increase. Making it harder for the current to pass with all the atoms bouncing around. Both sensors have roughly the same dimensions. They both have a 4mm diameter and roughly a 30mm long tip size for the sensing end. The PT 1000 is a three-cable model. This allows for a much more accurate reading. By allowing the two wires connected to the drive the resistor and record the voltage. These two wires will be used to subtract their two voltages and then record the difference. This will allow for detection of voltage drop within the wires.

This then allows for the third wire to be connected to one end of the PT1000. With the comparison between the PT 100 and the PT1000 it made way more logical to go with the PT 1000. Its cost may have been a little more but with the option of the better accuracy along with the corrosion resistant. This would all make for a better choice considering where the sensor is going to be placed. Also, both the PT 100 and PT 1000 make integration with our Raspberry PI easy. That's just a bonus for the team. This both sensors will also need to be used with an amplifier. [52]

Table 11 Temperature Sensor Selection

Comparisons of Temperature Sensors			
	PT 1000 3-wire RTD	PT 100 RTD	Type K
Manufacturer	Adafruit Industries LLC	Adafruit Industries LLC	Digilent, INC
Cost	$14.95	$11.50	$9.95
Temperature ranges	-200C to 550C	-200C to 550C	-73C to 482C
Output type	Serial	Serial	Serial
length	1 meter	1 meter	1 meter
Pin count	3 wire	3 wire	2 wire
Resistance at 0C	1000 ohm	100 ohm	N/A
Accuracy	+/- .1 degree C	+/- 1 degree C	+/-2C (based on amplifier)
Resistance variation per C or voltage	3.85 ohm	3.85 ohm	41.27 uV C
Voltage	5V	5V	5V
Amplifier needed	Yes	Yes	Yes
Selected for project	Yes	No	No

5.5.1.12.1 Adafruit MAX31865 RTD PT1000 Amplifier

In the figure below is the Max 31865 amplifier. The amplifier will be used to amplify the voltage of the temperature sensors. This will be needed due to the fact that the temperature sensor uses such low voltages when there is a change in voltage. We figured it much better to have one that was compatible with the sensor then having to try to make our own. In order to make our own it would require a lot of PCB work that would take away from other things we could be working on in the project. For the price at $14.95 we felt this would be well worth the money so that way we could work on other parts of the project and not have to worry so much about building an amplifier for the temperature sensor.

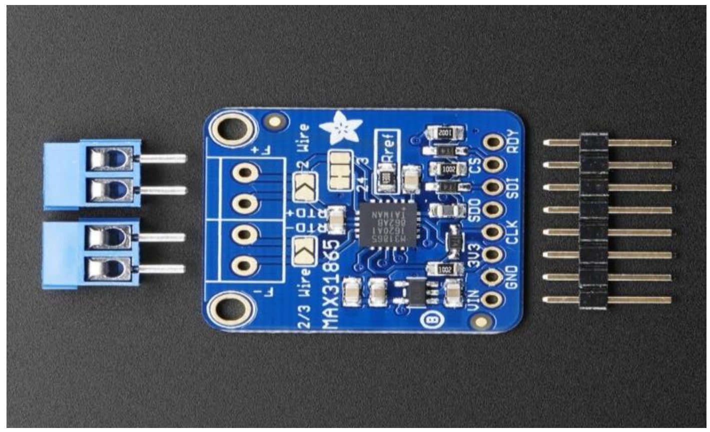


Figure 29 Temperature Sensor Amplifier

In order to set up the amplifier some soldering would have to be done to the board. First the pins would need to be added to the board. The pin layouts are Vin this will be used to supply the power to the board. This pin can take anywhere from 3-5 V DC the board has a voltage regulator built in. Next is the Vo this is the 3.3V output front he voltage regulator. on this pin if needed you can get up to 100mA.Then there is the ground pin this is well the ground. Next are the different logic pins. The first one is the SPI Clock pin this is the input. Next is the SDO pin this is the serial data out so that data can be sent from the MAX 31865 to the processor of either a raspberry pi or a microcontroller. Then the SDI serial data in pin this is the opposite of the SDO. The SDI pin receives data from the microcontroller/ raspberry pi. The chip select pin is next this allows for the data transaction from the SPI pin to the chip.

Then there is a data ready pin that will be used if we want to speed up the data transfer between the chip and the pi. after all the pins get soldered on. Up next the input port for the sensor will have to be soldered on to the board. The ports will be used to connect the sensors power pins to. Then a few other locations must be soldered shut in order to make sure the connections are right based on the design of the temperature sensors. Because there is a 3 wire, we had to solder shut the ⅔ wires spot on the chip. along with cut out one of the connections on the chip. Then the solder closed two more locations on the chip. depending on the type of sensor we had would also change what would have to be done to the chip. The only sensor type that did not require work was the 4 wire sensors. They did not have this version in stock at the time we purchased the 3 wire. [53]

5.5.2 Proximity Sensors

The next section to follow covers the various methods and features to be examined in proximity sensor selection. The discussion then moves to cover specific models and the final choice is highlighted.

5.5.2.1 Ultrasonic Sensor

Ultrasonic sensors use sound waves to measure the flight time from when the signal is sent out to when the signal is then bounced back and received. As given by the equation below.

$$\text{Distance} = \tfrac{1}{2}\, T \times C$$

(T = Time and C = the speed of sound)

This equation would need to be adjusted based on the medium in which sound waves are being passed through. Sound waves are 4.3 times faster in water vs in air so the equation would have to be adjusted accordingly. The frequency at which the sensors operate varies based on manufacture and application. Most frequency ultrasonic sensors use is higher than what can be heard by the human ear above 20,000Hz. [54]

There are two designs of Ultrasonic sensors that are in use. Ones that incorporate both a sending and receiving transducer. Or ones that include both in just one package. The size of the ultrasonic sensor plays a big role in the cost of the sensor. The small and more condensed the sensor is the higher the cost. Based on my looking at a different option on the market the cheaper ones seem to be ones that incorporate both a sending and receiving microphone. Like the ones that come in the Arduino kits.
Some of the downside to ultrasonic sensors is. They do not deal well with noise interference. Such as interference from other ultrasonic sensors or high winds. Heat is also another factor when temperatures rise sound waves will then travel faster. Therefore, making the flight time of the sound waves shorter. Making the object seem much closer than what it is. Vibrations are another issue when dealing with ultrasonic sensors. Due to how they operate by vibrating a transducer. That in turn compresses air and creates waves. The vibrations could then in turn make the transduce vibrate and off setting its reading and receiving. [55]

5.5.2.2 Inductive Sensor using Eddy currents

Inductive proximity sensors are another form of contactless sensing. The incorporation of inductive sensors is in a lot of places. From traffic stop light control to car washes and car sensors and metal detectors. Inductive sensors can only detect metallic objects. The basic operating principle. Is creating a magnetic field around the sensors by passing current in a circuit like a copper coil. This coil will in turn generate an electric field around itself. When an object comes into range of this electromagnetic field. It induces Eddy currents on to an object that is in the vicinity of the electromagnet. The Eddy currents then in turn change the oscillation amplitude of the current. Change in the oscillation and amplitude is cased when. The magnetic field from the Eddy currents and the induced magnetic fields that oppose each other. This then dampens the amplitude and frequency of the current in the magnetic coil. In metals that are Non-Ferrous like aluminum the opposite effect can be seen the frequency and the amplitude both increases. Ways this change in amplitude and frequency can be detected is with a Schmitt trigger. Schmitt triggers will detect the change in threshold voltages. One of the down sides to Inductive sensors is they can only detect metallic objects. But one of the up sides to them is they can detect metallic objects through nonmetallic objects. [56]

5.5.2.3 Magnetic Sensors Hall Effect

Magnetic sensors are used to detect moving ferromagnetic material or other magnets. Some of the easiest forms of magnetic sensing is a Hall element. That picks up the change in voltage in a Hall element that has a current passed through it. When a magnet is placed near the face of the Hall element the current then is separation separated by positive and negative electrons. The force at which the two electron types are separated is proportional to the change in voltage. There are many design types for magnetic sensors. One form is to use two Ferromagnetic pieces of metal. That will then be closed when a magnetic object approach. The force of the magnetic attraction will bring the two Ferromagnetic rods together creating a contact and then supplying a voltage. The applications of magnetic sensors are exceptionally large. Some of the tasks they are used for is to measure things like rotation of gears in like a car. Or to measure overall distance of magnetic objects from the sensing element. Some of the downsides of magnetic sensors is if you have another Ferromagnetic interference. This interference can then case the magnetic field to wander in turn causing a weaker voltage output. [57]

5.5.2.4 Capacitive Sensors

Capacitive sensors work like a parallel plate capacitor with two plates and a dielectric in between. But unlike Inductive sensors that emit an electromagnetic field capacitive sensor emit an electrostatic field. This electrostatic field is measured by the change in current that passes through the plate. As the plate emits an electrostatic force. As an object moves close it changes the distance of the air dielectric. This change in distance influences the current that can be passed through the sensors plate. This change in current creates a change in voltage. In turn this change in voltage is proportional to the change in distance of the object. Capacitive sensors are used in many applications from measuring proximity to the measurement of thickness and liquid levels and many more things. Capacitive sensors can detect any kind of material from metallic to water. Shape and size do not affect the capacitive sensor. Some of the downside of capacitive sensors is they do not have a large detection range compared to other sensors like the ultrasonic and inductive ones. The max range seems to be within about 40mm.Anouther downside with the capacitive sensor is if you have another object nearby. It may cause an inaccurate reading due to the drift of the electrostatic field. The fact these sensors use an electrostatic field is one of the reasons they do not have particularly good long-range sensing capabilities.

5.5.2.5 Radar

Many of today's vehicle automation and safety functions that relay on area sensing relay on radar. A cursory examination showed that though this route would solve many problems for object detection that the before listed sensors have, our budget is unable to afford. One example being Banner Engineering QT50R an IP67 rated radar unit used for object detection in the ranges we have considered and then some. The cost for it was $981 and was in line with many others in being beyond the scope of our budget.

5.5.2.6 Photo Electric Sensors

Photo electric sensors are a sensor that detects changes in light intensity. It is typically either the detection to various degrees of its immitted light source or the non-detection thereof. The source (LED), receiver (phototransistor), signal processor all works to convey information at ranges far superior to capacitive, magnetic, ultrasonic, and inductive sensors. The main configurations are through beam, reflective, laser reflective, and diffused. Diffused is the emission of light and collection of diffused signals that makes it back to the receiver which is at the same point. Reflective is diffused with a specific aimed reflector set-up that requires a component in addition to the transmit/receive unit. Laser reflective Due to the nature of our application only one-sided units could be considered. Those in the 15.75" range acting as a normally closed indicator (Light on, Dark off) in the diffused category from automation direct at $23. However, these types of sensors are not designed to operate in the outdoor environment where sunlight, and weather (rain, fog, etc) disrupt and drown out the signal transmission.

5.5.2.7 IR Proximity Sensor

IR sensors are another form of proximity sensor. It is Similar to the IR temperature sensor in the way it works. For the IR proximity sensors, a LED or laser is used to admit a light. This light is then sent out toward the target or object that is to be measured. The light then bounces back and is picked up by a photodiode. The light that is received changes the resistance within the diode. The light that is received is not the same amount that was sent out. The light is refracted indifferent ways the more time it travels in the air. This loss is proportional to the distance the light travels. The amount of light lost depends on the color of the light and the color of the surrounding light. The more surrounding light that is around the sensors the lighter the photodiode picks up. This can offset how far the target appears to be. One way to help reduce losses or inconsistencies. Is the light transmitted at a high frequency that is not visible to the naked eye. The light is also switched on and off at an extremely high frequency to better eliminate any interference. The frequency of the IR light can also be changed depending on the application. Depending on the color of the target some of the light can be absorbed so that would require a different frequency to be used for an IR sensor. IR proximity sensors can pick up just about any solid object. They have trouble detecting water. Some of the other things that can offset IR sensors. Things like too many particles in the air like dust or dirt. Vibrations can offset the IR sensors. Again, places with just too much light that may flood the photodiode giving it inaccurate readings. Another thing that is an issue for this type of proximity sensor. Is power consumption depending if the light being admitted is a strong laser beam it could have a high power draw on a system

5.5.2.8 Vertical cavity surface emitting laser (VCSEL)

This is another form of an IR sensor used to measure distance. This sensor is usually cut from a silicon wafer that's either P or N type doped. They have many layers of doping applied to them. One of the key features of this type of sensor is it emits light perpendicular to the semiconducting material. There are many different types of VCSEL. Some of the different types of VCSEL are VCSELS with an external cavity. These allow for a larger area to be used and in turn more power can be drawn to use for the lights. In some cases, up to 30W can be drawn. There are VCSELS that are known as longitudinally Integrated Monitor diodes. This type of VCSEL has a diode that is put in under a mirror of the VCSEL. This allows for a photodiode to be put in to measure the light coming out of a nearby VCSEL. They also create VCSEL to have tunneling junctions by configuring different semiconducting material with different doping.

One of the nice things about VCSEL is the fact they handle measurements at close ranges better. Other IR sensors seem to have issues at close range or are not 100% accurate. Some of the places these sensors are incorporated is in laser printers, computer mouse along with face ID for smartphones like Apple iPhone. One of the nice things about VCSEL is the fact you can have them in compact forms. This allows them to be integrated into small areas. Along with having them in compact forms it also allows for much less power consumption. This low power consumption along with its compact form makes it excellent for small electronic devices. This smaller power consumption has a drawback meaning the distances that can be measured is not as far compared with other IR sensors. But some of the pros of this sensor is it allows for a better signal to noise ratio over other LED IR sensors. Along with a higher resolution. They also are good for 2D and 3D sensing that is why they are incorporated with a lot of phone cameras. [58]

5.5.2.9 Light Detection and Ranging (LIDAR)

With recent developments in Lidar technology we looked at what it would take to potentially implement Lidar technology into our own application. Finding Lidar in car navigation systems are becoming more and more common, especially in self driving cars. This is a testament to how accurate and efficient lidar detection can be compared to the other detection technology out there. A typical lidar sensor will emit light pulses throughout the environment then detect those light pulses that bounce off nearby objects. The sensor takes into consideration the time it took for the light to bounce back to the detector and can accurately spatially locate the objects around the sensor. A virtual environment can then be created from this data. This would be very helpful in our application as we could track the environment around the off-road vehicle and easily identify objects that are in possible collision range.

Lidar has many benefits over the other detection methods. The main benefits being Lidar has a very far range and high resolution. Lidar technology has been used under aircrafts in order to accurately map out large environmental features such as elevation changes and vegetation density. As seen in the figure below Lidar imaging would be a great feature to be included in this project. However, it may not fit the budget constraints as lidar technology is still relatively new. Along with the support also still lacking compared to other options.

Lidar is another form of proximity sensor. This sensor is good for measuring all kinds of data. The way Lidar reads the light is thought of as a camera system with pulsed lasers a lot like sonar does with soundwaves. Lidar is good for generating 3D images of areas. Most of the time lidar is used in aerial vehicles. This is one of the largest ways to collect lidar data. Like for instance The National Oceanic and Atmospheric Administration (NOAA) is using aerial lidar to get a better mapping of waterways and coast lines. IN order to use aerial lidar you need four components. The lidar system itself, along with GPS satellites to track the X, Y location of the plane. Then there is the Inertial Measurement Unit (IMU) that will be used to measure the altitude of the plane along with the pitch, yaw and roll of the aircraft. Then last is the computer to record the data. A lot of times the Lidars laser is either green or Infrared. This is because it allows the laser to better bounce back off trees and other foliage. This calculation is to get the distance for the height of objects from the air when the Lidar pulses its light. Is for the most part (the traveling time) * (the speed of light)/2 = distance. But this will not take into account the rocking of the plane. So now we need to calculate the ground elevation. We use the IMU data that records the distances the plane travels up and down. While the GPS records location of height of the plane. Then we subtract the altitude – the distance the light travels to obtain the ground elevation. We then must account for the fact that [59]

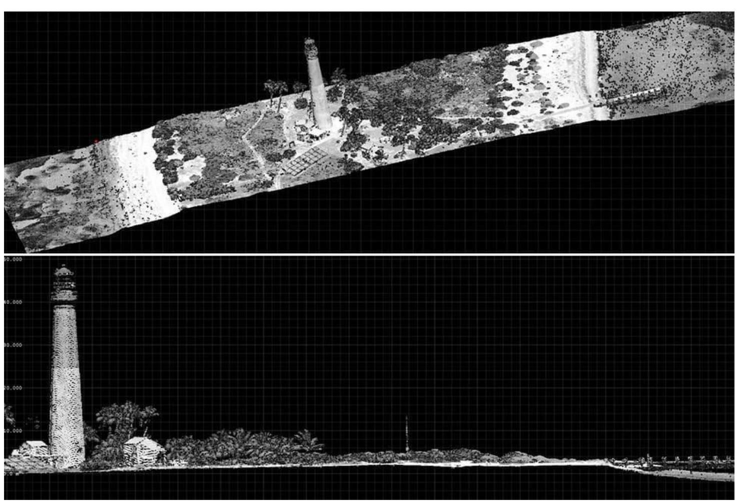


Figure 30 Output of arial LIDIR scan

some of the light that leaves the plane is at an angle. This off angle is called off-NADIR, when the light does not leave at an off angle this is just called NADIR. Another interesting this about LIDAR is it can also measure the height of trees. This calculation is done when the light travels through the top of a tree. Then by taking the amount of energy returned at different times will then give the height of the tree. Another big application of lidar is in vehicle detection and autonomous cars/trucks. In autonomous vehicles they use what is called spinning LIDA. This spinning LIDAR is most of the time found either on the hood of the car or on the roof of the car. This spinning allows for the LIDAR to see a 360-degree view around the car.

5.5.2.10 Proximity sensor selection for vehicle

After looking into the many different options of sensors along with the different characteristics. We decided to move on with just one type of sensor: the ultrasonic. The choice of the two was the best for the design and function we are looking for. The reasons we did not choose others I will explain now.

The reason for not going with the LIDAR. Was one just the cost of the LIDAR system for a good decent system it was easily $100+.Then on top of that the fact the vehicle would also be off road and just used as a daily driver made no sense to a costly piece of equipment. Another downside to the LIDAR system was due to the fact it involved a lot of coding to operate the system. The system is more used to get 3D representations of the landscape. So, there would be no point to do all that coding when we were only interested in the range. One thing that also became apparent was the fact the LIDAR system had a lot of big optical lenses on it almost like binoculars. This would not be good for the application we needed. Due to the fact the lens would be hard to keep clean and create major inaccuracy for finding the distance. We also did not have any of the other equipment to operate the LIDAR. We would also need GPS and an IMU. So, overall lidar is just too costly and complex for our application.

Other sensors that looked promising were the IR sensor along with the VCELS. We did not choose the IR sensors based on some of the issues with it. Also, for the fact it was going to be incorporated for the tier temperature sensors. One reason we chose not to do the IR was also the cost of the systems with a wide beam seemed too much to pay. The IR for the large array also needs to have a lot of current draw to operate. With the vehicle being off road the IR might have too many issues with the light changes like when passing under trees. Also like the LIDAR the IR has issues with it needing to have the leans cleaned to keep any interference from particles. Now for the VCELS it was kind of the same reason as the other two. But a little since having the compact power efficient sensors would have been nice, they did not seem to make any that had large arrays for fields of pick up. Also, the VCELS like the LIDAR seemed to have a much larger advantage for 2D and 3D object detecting. They would send back many readings. It might be complex to code for what reading we needed. Overall, the VCELS had done well as far as cost compared to the IR and LIDAR. Coming in as a reasonable cost as far as their operation specs.

The capacitive sensor was another one that seemed promising. It was good on cost. It could measure any kind of object from metals, plastics, water, and people. This range of sensing capability seemed ideal for our application, but it also came with drawbacks. Some of the drawbacks was because it is a car it would have to operate in conditions like snow and rain. This is not ideal due to the fact the sensor can detect these things. So, if the car was driving down the road in the rain or snow it might constantly keep tripping the sensor. This would be bad because the driver might start to just ignore them warnings and pay no mind to them. This would also cause for the rest of the system to act accordingly and keep tripping the cameras. Another downside to the capacitive sensors is the range of detection is not remarkably high.

Some of the best ones used for industrial applications seemed to have a max detection range within about 0mm-80mm. This short detection range will not help. Also, the capacitive sensors do not really have a large detection area. This detection area is more limited to the front of the sensor. This will not allow for a large spread of detection areas needed for the application. One thing about the capacitive sensor that was also attractive was the cost was very reasonable. But overall, the down sides outweighed the cost and the fact it could pick up just about anything. It would not work well within our application. One of the last ones we investigated was the magnetic sensor. The magnetic sensor is like the induction sensor, but this sensor had one big drawback. The magnetic sensor only had the capability to pick up on magnetic objects. This was a real big limitation with this sensor to only be able to pick up on magnetic objects. This sensor can also pick up on ferrous metal objects if they are moving. This should limit us to only objects with high iron that are moving or magnets. But I do not think too many of them are on the roads. This sensor would have been nice if we were going to measure turns of the drive shaft or things of that nature. Also, the magnetic sensor had the issue with magnetic drift if the sensor had many objects in its field of view it might not detect them.

Few good things about the magnetic sensor though is the cost is reasonable to be considered. Along with the fact that the sensors had a particularly good range of detection with plenty of spread to detect things. Overall, one of the big issues with all the other sensors. Is that in order to get the range along with durability we needed was a lot of money. Some of the sensors would cost upwards of $300+. This would not be good on the budget we were trying to work with. just a few of them would break the budget and leave no money for any other of our components. So, the ultrasonic sensor seemed like the most ideal for the rear detection application. we could get them cheap. They have a good range of coverage for the cost of them. They are able to detect any kind of object but water. Another reason the ultrasonic sensors are the better option is the fact that they not only have a long range they can detect. Then come with many options for the angle of direction that makes it great for to get good coverage so that way there is overlap in the sensor area. This makes it nice so there are less gaps in the detection field. This will allow for the use of less ultrasonic sensors to be able to save on the budget. Along with the fact that it will require the use of less pins on the raspberry pi’s.

This will be good to not have to buy extras just to compensate for the lack of pins. One of the benefits also using the one kind of sensor you won't need to overlap more than one kind of sensor together in order to get an area of coverage. Using one kind of sensor; it might not be able to detect certain kinds of objects leaving a blind spot on the bumper. but one thing about the ultrasonic sensors is if objects are too close it may not pick it up. the field of range might not be that wide at all at that point. So, it's like a cone the further out from the sensor element the wider that cone. So, if ultrasonic sensors are not placed in the right spots along the bumper, they can also leave blind spots. Or if the sensor is not programmed to detect things at a certain distance it could lead to the gaps in the sensing area. Another issue the ultrasonic sensors have is they don't like vibrations or high winds. In order to overcome this, we will be placing them inside the rear bumper. This will provide some coverage from the wind to not offset the sensors. then an apparatus will have to be used to allow for some vibration damping. There are ones available on the market. so, it might be best to modify one of them and use that for vibration reduction. But this is an option that will have to be explored. Like the cost in comparison with how well it will protect the sensor from vibrations. Another reason for the placement of the sensor inside the bumper is to help protect it from other elements like rain and things that could potentially knock it off the vehicle.

One option we have to incorporate to the overall operation is. the ability to shut the ultrasonic sensors off. We needed this option for the Off-road portion. That way when the vehicle is going through like tall grass or other obstacles off road. It would not continuously keep tripping the sensors. This might then make the driver lax to the warnings in the Hud. This could make the driver not look at the warnings. But giving the driver the ability to control the sensors seems like the best option to alleviate any of these scenarios that could happen. But overall, the ultrasonics best fit what we wish to do with the project. it allows for flexibility along with the cost saving benefit we need to budget. So that way if we run into more unexpected things, we have the extra money to spend on them and keep us within our budget.

Another nice thing about having the ultrasonic sensors is they have a lot of option as far as the size. Some offer the option to have both a sending and receiving transducer. Or the option to have just the one transducer function as both while still providing excellent cycling time for reading. The one thing about the ultrasonic sensor was you can pick a lot of options as far as the field of view. Some have very narrow beams; some have very large beams. The variety was a good option for us so that way we could choose a good wide beam to give us the most coverage area as talked about earlier.

5.5.2.10.1 UC4000-L2

The UC4000 is a top-of-the-line ultrasonic sensor. This sensor would be great for the project, but it offers a lot of down sides to it as well. One of the big down sides to it from the start is the cost at $424.21. This would not be good for the budget at all. Another downside is the amount of voltage needed to supply this at 10V minimum and a max of up to 30V. The raspberry pi’s would not be able to support this at all. They put out a voltage at 5V. Another downside is it uses a special pinout cable mostly used with PLC. Some of the good side of it is it has a 6.5-foot detection range. This would give us a lot of coverage, but we would still need more than one of them to get the coverage needed. We would need about 3 of them and at $424.21 this is much more than we wish to spend. Another upside to this sensor is the fact it is a lot more durable than the other two options looked at. This would be a good fit provided we had the 30V supply and the PLC and an unlimited fund. This would be more of the ideal sensor for the project if we had them. So that way we could incorporate it onto the project. But needless to this sensor was not selected for the project. [60]

5.5.2.10.2 MB1614 HRLV

The MB 1614 is a lot like the MB 1003. The two both have a wide-angle beam and the same sensing distance at 195inc. Both also come with the same read rate of 10Hz. They both also use the same operating voltages 2.5V-5.5V this is perfect for how we are looking to use the sensors with the Pi. Of the major physical differences between the two of them is the MB 1614 uses two transducers where the MB1003 only uses one. Another difference is the price of the MB1003 is $37.95 whereas the MB 1614 is $34.95. We will end up not using this sensor even though it is almost identical to the one we will be using the MB 1003. The reason we will not use this sensor is because it has the two transducers. This means vibrations may greatly impact the results of this sensor. The vibrations will offset the device more due to the fact it has a sending and receiving transducer. So, having only the one transducer seems like a much better option then having the 2 that's why the MB1003 will be picked. [61]

5.5.2.10.3 The MB 1003 HRLV Sensor

This is the sensor option we chose to go with. It has one of the best wide-angle beams in the line of HRLV MaxSonar. This is good for our application due to the fact it will provide good coverage along the rear of the vehicle. This will help with the overlapping of the sensor field of views. Below in the figure are the ranges of the sensor at different ranges. There are different ranges provided at different supply voltage levels used. The voltage we will be supplying our sensor with. The current draw with the sensor will be in the 3.1-3.5mA range. The current draw will very briefly spike due to the sending of the ultrasonic sound wave. This could in turn cause the Raspberry pi to go into a shut off mode. In order to correct this issue a capacitor will need to be utilized. This will help to prevent a large current draw. So that way the raspberry pi will not go into a shut off mode. Some other nice features of the sensor are the high read rate at 10Hz. This will allow for better reliability in reading as the car is moving. The sensor also incorporates many ways to read the sensor. PIN 1 on the sensor is for temperature sensing. PIN 2 is used for a Pulse Width Output. PIN 3 is used for the analog output voltage. The relation of the analog output is for the 1023 for the 10-bit resolution. So forever 5 on the ADC corresponds to range in mm. as an example for let’s say 60 bits you multiply that number by 5 so 5*60=300mm.The analog option also works with 5V. PIN 4 is the ranging Start/Stop. This setting uses a pull up high on the pin if this pin is left unconnected it will allow the sensor to freely keep reading. If held low the sensor will stop ranging. The high mode only lasts for 20uS.PIn 5 is the Serial Output this is the PIN we will be using.

Start/Stop. This setting uses a pull up high on the pin if this pin is left unconnected it will allow the sensor to freely keep reading. If held low the sensor will stop ranging. The high mode only lasts for 20uS.PIn 5 is the Serial Output this is the PIN we will be using. This pin will allow for an easy connect ability to our Raspberry pi 4. Using this pin allows for less complications as far as the coding and the set up with the sensor. We will be supplying the sensor with 5V to get the best detection field. Some of the other features with the sensor

Figure 31 MB1003 HRLV

is it has a good operating temperature in between 32F to 149F allowing for a good operating range of the sensor. The sensor is also good with weather as far as rain it can handle a good amount. It will not perform at all if completely submerged in water. The sensor's max range is 195 inches with a larger field of view the further the detection range. One downside is very large objects at 11inch will just continue to be reported as 11 inches. But this will work well the driver will have time to check the cameras within the vehicle to see the object. The dimensions of the sensor are compact so that is also a bonus for our application. Having just one transducer over the other version also will allow for better reliability. Also, the cost was another reason for selecting this sensor at only $37.95 it came within our budget. The company of choice for the sensor was Maxbotix they also provide great customer support. [62]

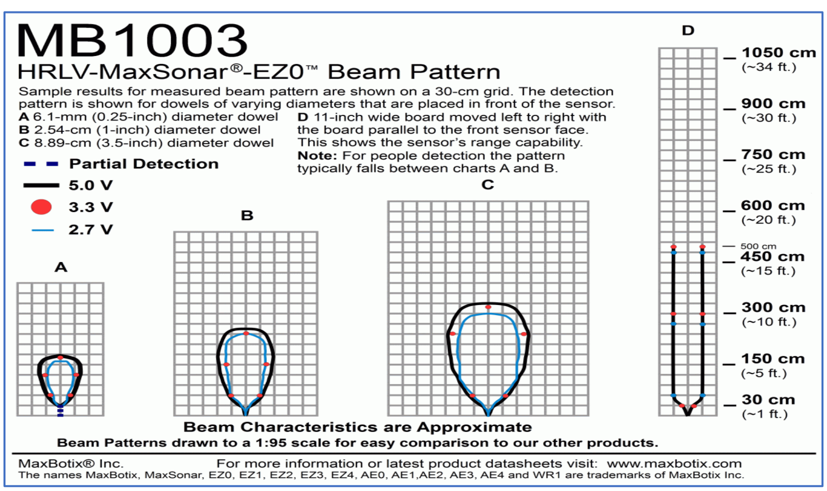


Figure 32 The area of detection of the MB 1003 HRLV sensor

The number of these sensors we decided to go with was 3. The reason for having 3 is because of the amount of area we need to cover on the bumper of the vehicle. The total length of the vehicle is around 72inches. Now the amount of detection at 1 foot with these sensors is two around feet wide. But in order to increase this area we plan to elevate the sensors up on the back of the vehicle with them angled down at about 45-degree angle. To help give wider coverage area reducing the number of sensors that would be required then if we directly mount them on to the bumper. This will also help detect things that might be higher up on the back of the vehicle. This will allow for more safety then if they are just directly mounted on/inside the bumper.

The decision matrix used to select the proximity sensor is summarized in the table below.

Table 12 Proximity Sensor Selection

Proximity Sensor Selection Decision			
	MB1003 HRLV	**MB1614 HRLC**	**UC 4000-L2**
Manufacturer	Max Botix	Max Botix	Pepperl+Fuchs, INC
Cost	$37.95	$34.95	$424.21
Distance ranges	195 inch's	195 inch's	157.48 inch's
Output type	Serial, Analog	Serial, Analog	Serial, Analog
Transducer number	1	2	1
Pin count	7	7	Special Connector
Read rate	10 Hz	10Hz	16Hz
Accuracy	1%	1%	.1%
Field of view at max	6 foot	6 foot	6.5 foot
Voltage	2.5V-5V	2.5V-5V	10V-30V
Inverter needed	No	No	No
Selected for project	Yes	No	No

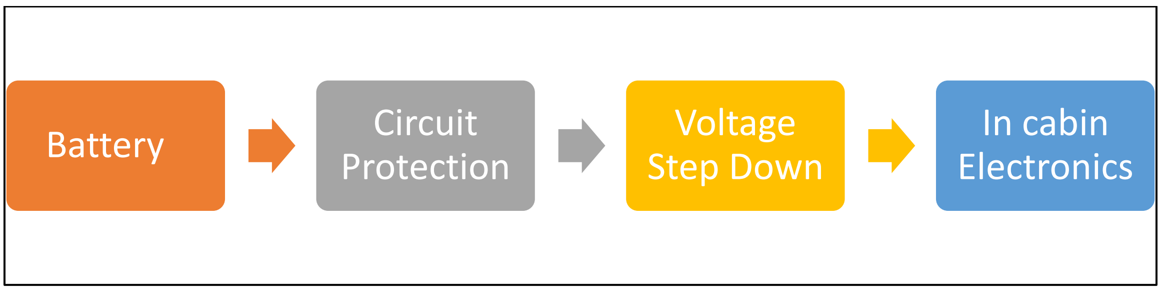
6.0 Hardware Design

To incorporate all of our components we will need to design a system in a fashion in which each piece has a place in our vehicle system. We will also need to lay out how the wiring will go from one component to another. In this section we will discuss the challenges in wiring the system in a fashion to where we can accurately relay data from our sensors and cameras to our internal host or master system. The following chapter covers the component selection and the resulting design for project hardware and software.

6.1 Power Distribution

This section contains the layout for the power distribution and circuit protection portion of the hardware build. The needed items are outlined, and their selection is then discussed in detail. The process separations for component discussion is shown in the below figure.

Figure 33 Power Distribution Component Overview



6.2 Battery

The vehicle battery was chosen to power this project due to the ability to meet design requirements without needing an additional battery and related components. The project is intended to be a more robust hard mounted unit and thus the additional wiring needed to use the stock vehicle battery as opposed to a separate 5V battery for our system was not against design parameters. This kept the design less maintenance intensive without having the need to charge an additional battery. With the system being useful on and off pavement it is not foreseen to be something owners remove after install as some other accessories that are added and subtracted as needed based upon operating environment. The additional electronics demand is calculated to be at most 15 amps at 12 volts DC. This results in 180 watts of power. The stock battery supplies 600 cold cranking amps with a reserve capacity of 120 minutes and a 70 Amp hour (Ah) rating. 12-volt amp hours are used to describe electrical charge capacity. 70 amp hours of capacity theoretically means that that battery can supply one amp of current for 70 hours or any combination thereof. This equates to a ballpark number for our system without other vehicle electrical demands at 70 / 15 = 4 hours and 20 minutes of use before the battery would be killed. In order to prevent this and other potential problems circuit protection is needed. The location within the vehicle engine bay is shown below.

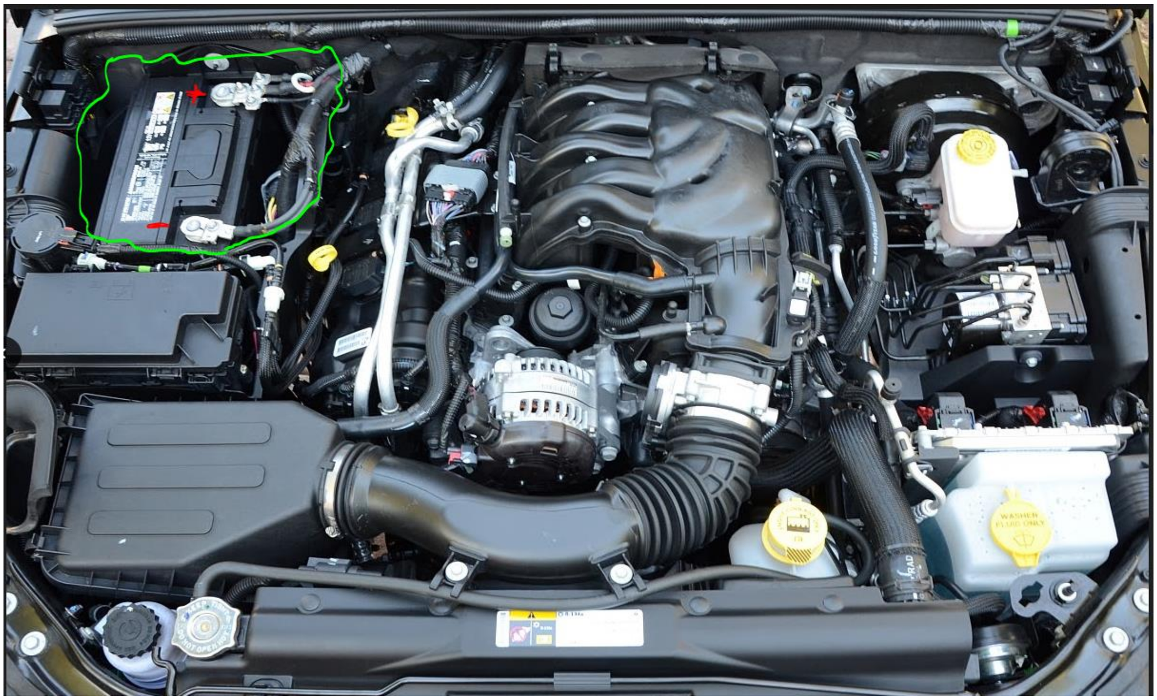


Figure 35 Engine Bay

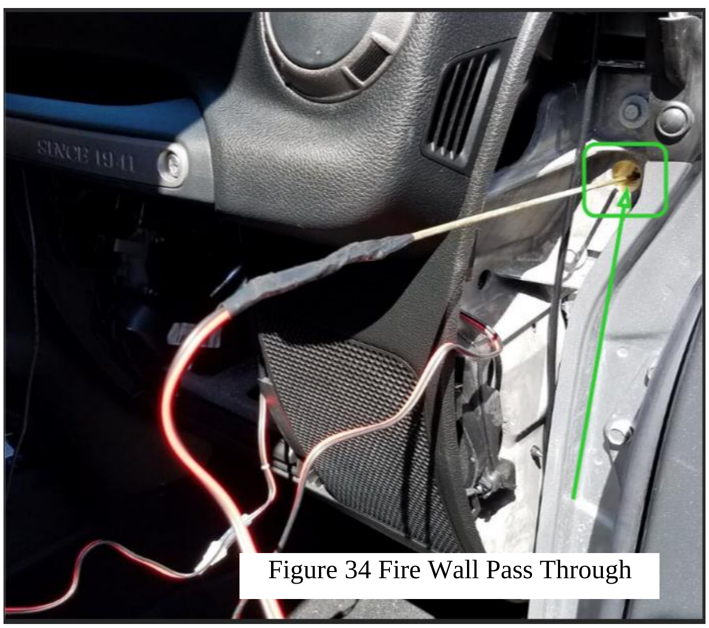


Figure 34 Fire Wall Pass Through

The firewall pass through that will be used to route from the engine bay to the main cabin is shown at left. There is one predrilled on both the driver and passenger sides of the vehicle. Power from the battery will flow along this path to the in-cabin unit. The wire will need to be able to handle 15 amps over an estimated ten-foot run. Based upon wiring ampacity vs wire gage charts the wire gauge for using stranded copper wire is 12 gauge if a less than 3% voltage drop is desired. [63]

6.3 Circuit Protection

Circuit protection is defined as keeping the parameters within their designed operating range. The prevention of over/ under current and voltage is desired. The circuit protection considerations are broken down in the following table titled circuit protection considerations. The prevention of battery short circuitry and dangerous over currents, brown outs for microcontroller operation, reverse biasing of the system due to improper battery installation, and a low voltage cutoff are key elements that do not involve signal modification that is discussed in the next section.

Table 13 Circuit Protection Considerations

Circuit Protection Considerations				
Item	Operating Condition	Realization	Location	Function
Fuse	20 Amp Fuse	Manual Reset Inline Fuse	Main Panel	Acts to prevent dangerous over current conditions
Low Voltage Cutoff	Isolate once battery drops below 12.2 V (50% charge)	Purchased Unit	Main Panel	To prevent draining the main vehicle starting battery
Reverse Bias Protection	If a reversed polarity is detected, isolate electronics from source	One-way connectors	Main Panel	To prevent damage to electronics in event battery is reversed
Brown Out	Prevent microcontroller operation during under voltage conditions	Built into Raspberry Pi Interface	In Cabin Center	Prevent faulty operating due to difficulty distinguishing between voltages

This battery has the ability to supply more current than is needed, in fact a dangerous amount. Adequate protection is essential. The 15-amp rating was calculated at four raspberry pi units drawing at a max of 3 amps each when running full capacity with reserve for the heads-up display. Fuses typically come in 10- or 15-amp values and the need for a specialty one in between is not needed. A manual reset model was selected due to the desire to know when an error occurs so that a resettable unit does not continuously flip on and off if unable to be checked immediately. Resettable was chosen for the ability to reuse and not replace when diagnosing problems in the field.

The low voltage cutoff was included for conditions where the unit is being operated with the engine off and battery not being charged and for parasitic draw if the vehicle is not driven for extended periods of time. The value of 12.2 V was chosen in order to leave the battery at 50 percent charge and thus able to start the vehicle again in most circumstances. Reverse bias protection has been included to protect in the event the vehicle main battery is installed incorrectly with the terminals reversed. These two features were placed onto our own PCB in order to save money and space.

Additional brownout protective circuitry was not needed due to being included within the units chosen. A side by side comparison and component selection is displayed in the table below.

Circuit Protection Component Selection Summary			
Item	Option Explored	Features	Decision
Fuse	In-line ATC	Cheap, easily replaceable, common	Second choice
Fuse	Glass in-line fuse	Cheap, easily replaceable, common	Not desired
Fuse	Resettable	More expensive but does not require replacement if tripped	Selected
Low Voltage Cutoff	Store Bought	Complete, small, rugged form factor, expensive	Back-up
Low Voltage Cutoff	Design PCB with conventional relay	Requires design, small form factor, cheaper parts wise, more labor costs	Second choice
Low Voltage Cutoff	Design PCB with solid state components	Requires design, smallest form factor, cheaper parts wise, more labor costs	Selected
Reverse polarity Protection	Change Terminals to make impossible to connect backwards	Mechanical deterrent	Back-up
Reverse polarity Protection	Dedicated Circuitry, own PCB	Can be integrated into existing PCB design, isolate if reverse polarity detected	Selected

Table 14 Circuit Protection Components

With the approaches chosen, the next task was deciding upon implementation. The table below highlights options considered and a discussion of what was chosen and why follows on the next page titled distribution components. The fuse chosen was within budget, performed within the operating voltage and the interrupt and breakdown current parameters. The Zookoto style fuse was selected due to the clear visual indication, easy reset, and straight forward mounting option. Pictured in the image here at left.

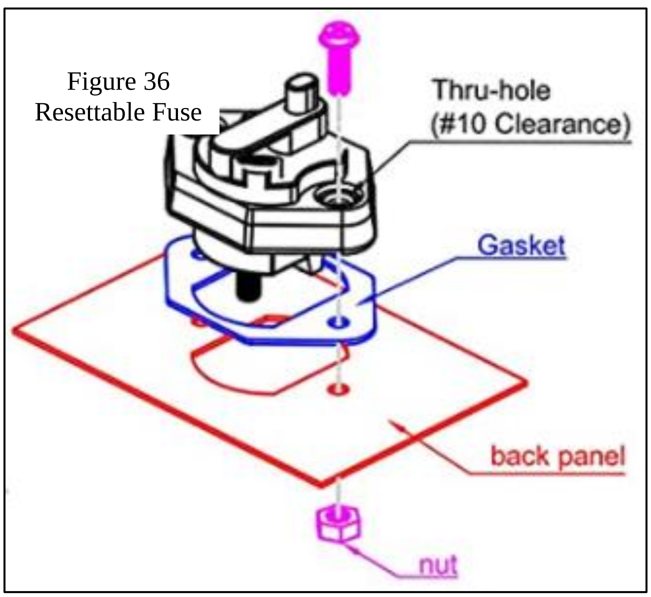


Figure 36 Resettable Fuse

The project requirement of creating a printed circuit board combined with the high price (1/16th to 1/8th of the total budget) have led to the gravitation towards creating a printed circuit board to carry out the low voltage cutoff and reverse polarity protection functions.

The following table compares a selected range of component types and the selection process for project design. The cost was the deciding factor once the minimum specifications were meet. For our fuse the 15 amp standard acting with manual reset were the main attributes with IP rating, ease of mounting, and compact form factor being the remaining characteristics of interest. The low voltage cutoff circuit is designed to isolate at 12.2 volts for our application. This value was decided upon as described above, the need to set or already be set to this voltage for disconnect guided the selection and cost was the factor that made the final decision in conjunction with time to be allocated for development. The time needed for development resulted in the scrapping of personal PCB and purchase of commercial off the shelf solution.

Table 15 Distribution Components

Distribution Components			
Item	**Action**	**Cost ($)**	**Comments**
Fuse			
Jegs manual reset fuses	Push Button 15 Amp ATO	6.99	Standard Acting
Powerwerx ATC style circuit breaker	Push Button 15 Amp	2.89	Standard Acting, SAE J553 Appr -40 to 85 C
Zookoto Through hole complete Unit	Push Button 15 Amp contained and sealed unit with mounting holes	15.99	Standard Acting Specification: SAE J553; SAE J1171 (Ignition Protected); ABYC E-11; UL1500
Low Voltage Cutoff			
Evworks ZEVA LVC12	Commercial off the shelf sealed unit with mounting holes	54.00 + shipping from Australia	Power consumption: 5mA when active, 0mA when tripped *Current rating: 50A continuous, 100A intermittent *On-resistance: 1mohm
Outback Equipment 12V 50 A Low Voltage Disconnect Circuit Protector	Commercial off the shelf sealed unit with mounting holes, Reverse Polarity and integrated fuse	72.99 + shipping from Australia	input voltage: 10–16V Output current: 50A Control type: MOSFET Disconnect voltage: 10.5V Cut-out delay: 1 minute Reconnect voltage: 13.0V Fuse protected: 60A (2 x 30A) Reverse polarity: Built-in Thermal cutout: 65 degrees Environmental protection: IP65 Current draw: 10mA

Our PCB	Student designed to provide low voltage cutoff below 12.2 V and reverse polarity	35 (est)	Designed to work within the ranges expected, is not currently sealed, design discussed

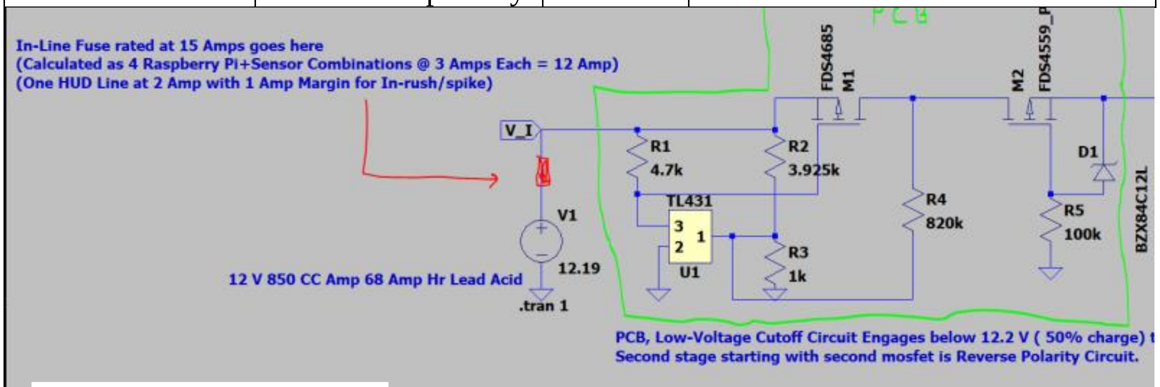


Figure 37 PCB LVC and RP

In the above circuit the cut off voltage is determined by the following equation Cut out = 2.5 * (1 + R2/R3). The image is from LT Spice Simulation. Sample schematics were use as a starting point for combining and modifying into the design shown. [64] The production cost is estimated at $27 dollar per board plus $7 dollar shipping for a one off single board batch.

6.4 Voltage Step-Down

The vehicle operates between 12 and 15 V DC depending on if the vehicle is in operation or not with the alternator charging the battery. The microcontrollers and other electronic components are designed to work off of 5 V DC. A DC to DC step down converter is required to provide power to the main assemblies down stream from the battery and circuit protection block. In researching the design of these converters, it was decided that purchasing a commercial off the shelf unit would be the most efficient in use of time, money, and power delivery. The selected unit is shown in the DC-DC Converter figure. Due to the need to power four raspberry pi units four 12V to 5V DC at 3 amp ports are needed. A four pack of the units pictured was 11.99 from the Drok Amazon store. These units can accept from 6 to 32 V and handle a current of 3 amps with the needed USB connector to interface with the power ports on the Raspberry Pis.

Figure 38 DC-DC

Mounting was a challenge to be considered when shopping various ICs ready made for this task. As shown above there are no holes for mounting and thus other solutions would need to be explored for use of a unit such as this. With the need to build an enclosure already established by other component needs in order to properly protect them this added mounting challenge was not deemed significant enough to warrant product non selection.

An overall schematic can be seen in the figure on the following page to show the relationship of power distribution components.

DC-DC Converters			
Item	**Specifications**	**Cost ($)**	**Comments**
DC Step Down			
Valefod LM2596 DC to DC High Efficiency Voltage	3.0-40V to 1.5-35V Buck Converter No USB, simply through hole contacts 3 Amp	10.99	6 pack Unit cost: 1.84
UCTRONICS Module Regulator Board	DC 6V 9V 12V 24V to DC 5V 5A Buck Converter USB Port	14.99	2 pack Unit cost: 7.50
USB Buck Converter, DROK 4pcs DC-DC Step Down Module	6-32V 12V 24V to 5V QC 3.0 USB Port	11.99	4 pack Unit cost: 3.00

Table 16 DC-DC

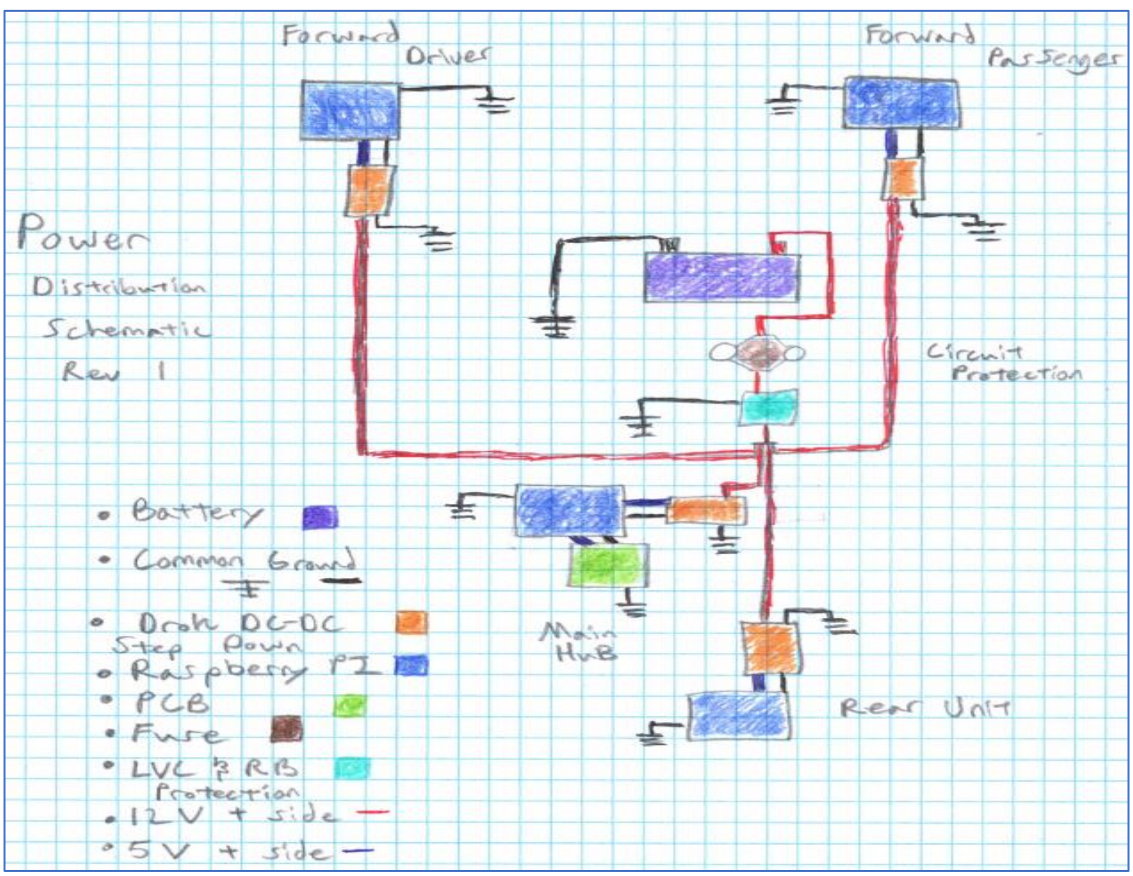


Figure 39 Overall Power Distribution Schematic

6.5 Layout of Components

The main part that the user will interact with will be the components laid out inside the cabin of the vehicle. This is where our main host and master Raspberry Pi will be connected to our display. We will also have buttons below the display to allow users to interact with our software GUI. To have the capability to cluster the Raspberry Pi's we will have an incorporated network switch located towards the front with our main Raspberry Pi as well. On the left and right side of the vehicle we will have corresponding cameras for the left and right view of the vehicle. The cameras themselves will be connected directly to the Slave Pi's through the MIPI CSI2 port which will then go via network back to the master Raspberry PI. Towards the rear of the vehicle we will have another Slave Pi connected to its camera via MIPI CSI2, it will also send data back to the Master Pi located by the front. For this rear Raspberry Pi specifically we will need longer network and power cables to reach the front of the cabin. This should not be too difficult given CAT5 has a very long maximum length of 328 ft, more than enough to reach the front of the vehicle.

Towards the front of the cabin we also will have our custom designed PCB with the ATMEGA 238P onboard to handle the operation of our temperature sensor. The PCB incorporated with the ATMEGA 238P will also incorporate a 3.3/5V logic level shifter in order for the Master Pi to communicate via serial to and from the ATMEGA 238P. The reasoning for this is the fact that the Raspberry Pi's logical GPIO Pins understand inputs given in 3.3V digital, where as the ATMEGAs logic calls for 5V in its GPIO. Once the logic is converted it is sent from the TX of the ATMEGA 238P to the RX of our Master Pi, which then will take that signal and display it to the user via either the Display or the incorporated HUD.

Our Master Pi located at the front of the Cabin is where all of the logic and interaction with our system will be. The Master Pi is responsible for the logic that happens within our system, such as the proximity sensors tripping to show the camera feed of the corresponding sensor, or switching between our given modes. The Master Pi will also be feeding data and information to our HUD system, which connects to the Pi via GPIO pins which we will program to run the display. So technically the Master Pi has to displays that it will be running and updating. The Master Pi will also be wired via its serial GPIO to the ATMEGA 238P on a PCB, where it will get data from the temperature sensor from it via serial connection and display warnings both on the HUD and on the Display if things get too hot in the engine bay. The temperature sensor itself will be wired to the ATMEGA 238P's GPIO via our custom designed PCB. The cables themselves will be susceptible to damage, so we will need to user some thicker and higher end cable in order to stop interference and too much of a voltage drop at the range of the temperature sensor.

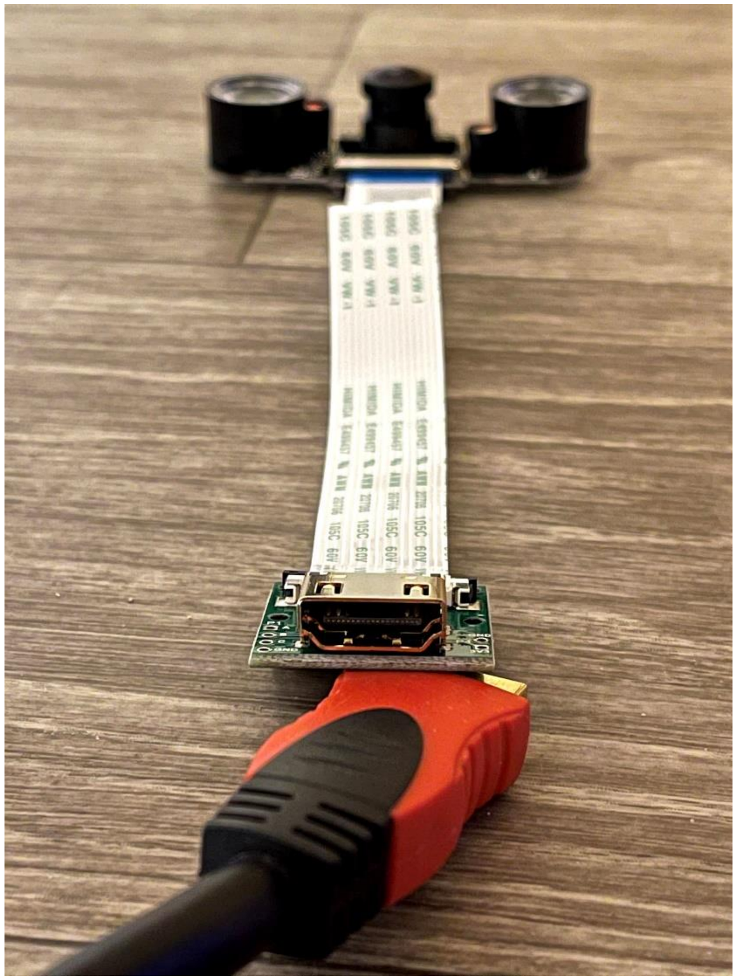
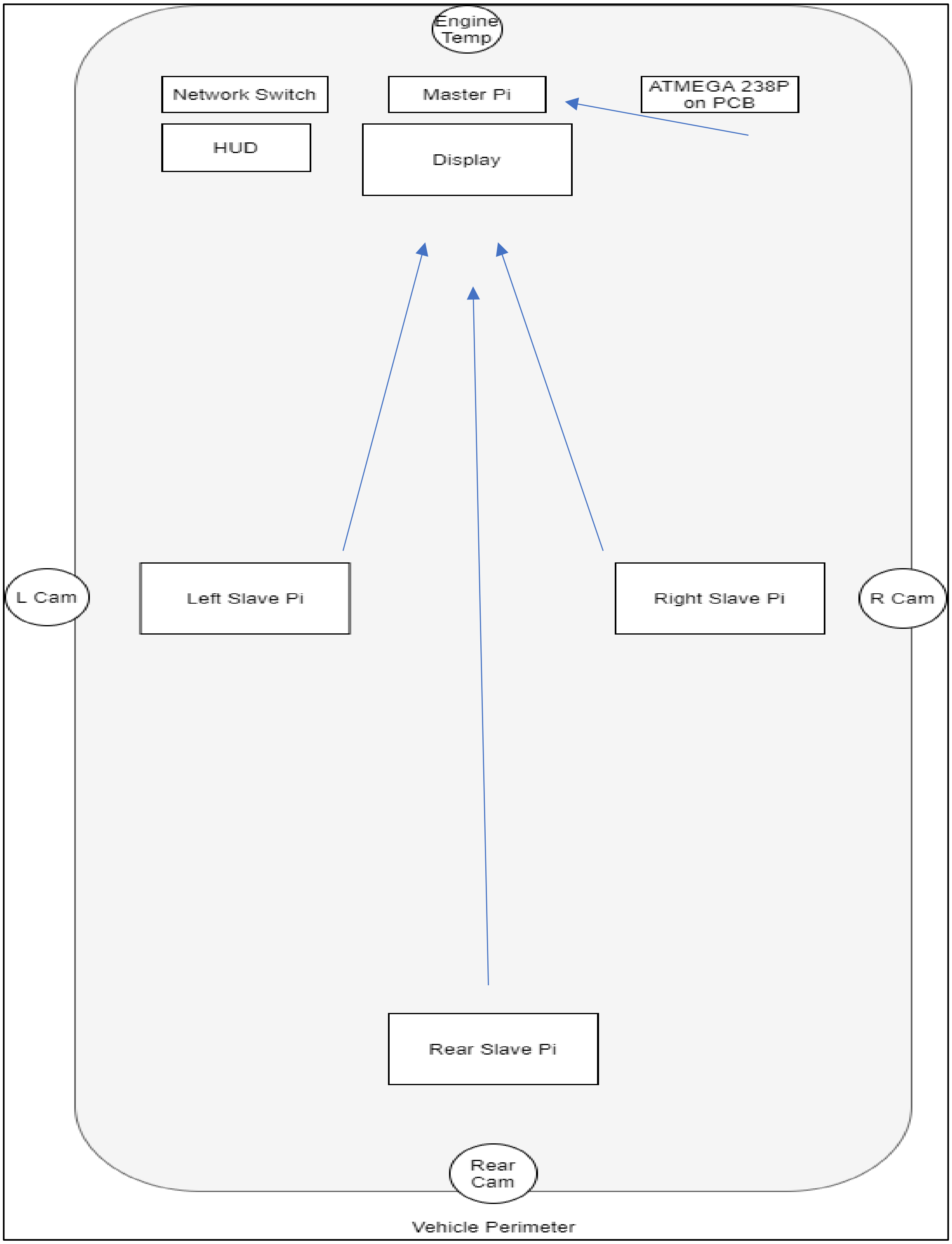


Figure 40CSI Ribbon to HDMI Conversion

The slave Pi's with their cameras will be tacking advantage of an existing solution that changes the pin out of the Camera's CSI ribbon cable to a more beneficial HDMI cable, this will allow us to take advantage of some range and makes the system more durable as a whole. The HDMI cable show is much more durable compared to if we were to run a ribbon cable. There will be 2 pieces of this, one on the end close to the camera and the other on the end closer to the Raspberry Pi we are connecting to.

We will need to keep an eye on signal integrity, as HDMI can go a decent length but was not intended for designs in this manner. While we could implement this solution in our own custom designed PCB this existing solution will allow us to focus on the software and hardware implementations within the vehicle such as the display and HUD found in the cabin. In testing I saw with a cable over 15 feet in length resulted in compromised video signal that resulted in dropped frames in our software. Figure Cluster Block Diagram below.

Figure 41 Block Diagram Cluster



6.6 Incorporating the ATMEGA 238P

We will be using the ATMEGA 238P Microcontroller to pass the temperature sensor data to our master raspberry Pi, we are doing this in order to have more access over the GPIO pins found on the Raspberry Pi, as we could incorporate multiple temperature sensors on the ATMEGA chip and send them to the Raspberry Pi via serial connection. This will free up the GPIO pins on the Raspberry Pi, which is beneficial given the Raspberry Pi's processing power can be used to incorporate more things, like even another display like our HUD.

6.6.1Temperature Sensor Wiring/Communication

The temperature sensor wiring is pretty straight forward. The sensor itself must first be connected to the Max 31865 amplifier. This is relatively straightforward; there are three wires on the sensor. It is then connected on to the 4 ports the first 2 red connectors go on to the F+ side then the last blue one will then be connected to the -F side. Then from the amplifier to the Arduino the Ground pin will be connected to the Ground pin of the Arduino. Then the 5V pin on both the amplifier and the Arduino will then be connected together. Then the clock pin to the 13-pin spot on the Arduino this is the SCK in. This SCK pin is used for the serial clock of the Arduino. The next pin to be connected will be the Slave Data Out (SDO). This pin is used to control the data flow. This will be connected to the 12 pin on the Arduino. The pin 12 is the Master in slave out (MISO) that will be used to control the flow of data out of the amplifier. Next the Slave Data In (SDI) will be connected to pin 11. This SDI is to receive data from the Arduino. The pin 11 is the Master out Slave In (MOSI). This is to get data from the Arduino to the amplifier. The last pin from the amplifier to the Arduino that will get connected is the ready (RDY) This pin is used to let the Arduino know the data is ready from the amplifier. Then there are two possible ways to display the read out. Via the USB cable that will provide a read out on to the COM port when using the USB cable. Or the other way will be to use the Tx/Rx buses to then connect it to either an LCD screen or to connect it via the raspberry pi as we plan to do.

6.6.2 Sending data to the Raspberry Pi

To send data over the serial connection from the ATMEGA chip to the Raspberry Pi we need to design a wire schematic that routes to the correct pins. We also need to consider the fact that the Raspberry Pi and ATMEGA 238P understand digital signals at different voltage levels. The Raspberry Pi sends and receives 3.3V digital signals while the ATMEGA 238P sends and receives 5V digital signals. In initial testing with the ATMEGA 238P mounted to the Arduino development board, we used USB connections to establish serial communication to the Raspberry Pi. This is not how we will have it set up in our prototype, but it establishes the proof of concept of this model and we can continue with our plan in using this. In figure below we can see the initial testing that went into this, where a simple message of "Testing Serial Communication" is sent from the ATMEGA 238P to the Raspberry Pi and displayed in the Python IDE shell.

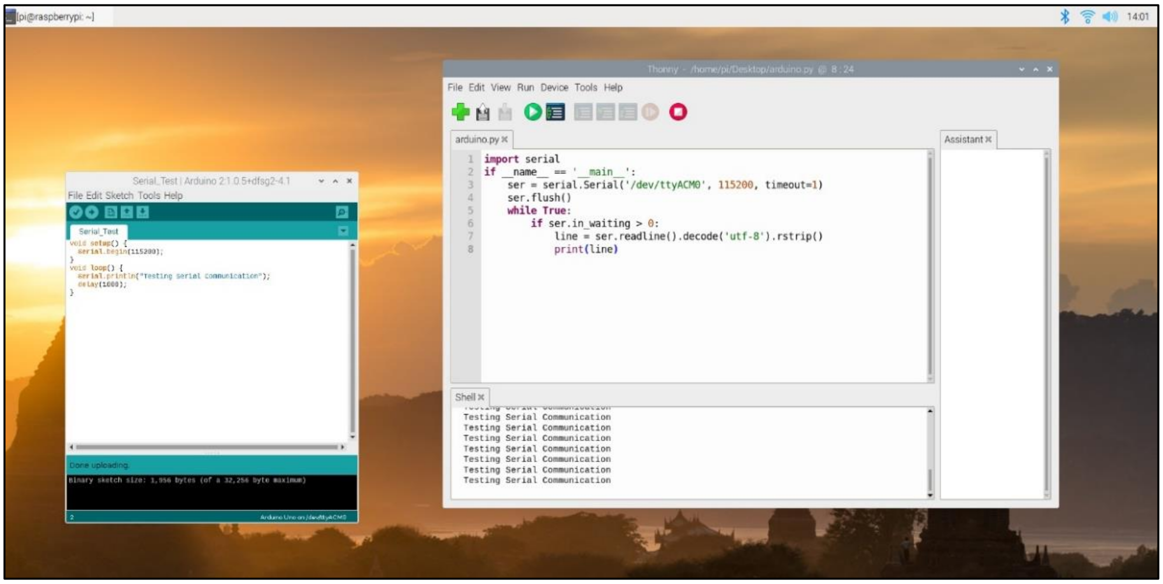
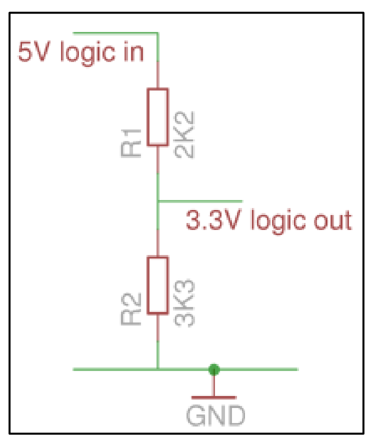


Figure 42 Serial Communication Testing

6.6.3 3.3/5 V Level Shifter

The Raspberry Pi and ATMEGA 238P communicate in different digital voltage levels, this creates a problem when trying to directly wire them for our prototype. To resolve this issue we are going to need to incorporate a voltage level shifter in our PCB design, allowing both the ATMEGA and Raspberry Pi to understand each other, and not fry each other with too much voltage. To do this from the 5V to 3.3V direction (the Raspberry Pi to the ATMEGA) is not difficult at all. Using a simple voltage divider learned in earlier electrical engineering classes we can take a 5V signal down to a 3.3V simply by adding resistance in parallel to our output. To get a proper 3.3V output we will need to use a 2K Ω resistor as well as a

Figure 43Voltage divider for 3.3V logic from 5V logic



Just like when we down step the voltage, we must also up step the voltage to get the Raspberry Pi to step up from 3.3V to 5V for the ATMEGA 238P to understand its digital logic. In order to incorporate this we must incorporate a more complex level shifter than the down step. To do this we need to take advantage of some MOSFETS, but if we also take advantage of MOSFETS we can design a circuit that will actually shift up and down in both directions, which would simplify our PCB more than if we were to use something like diodes to shift up to 5V.

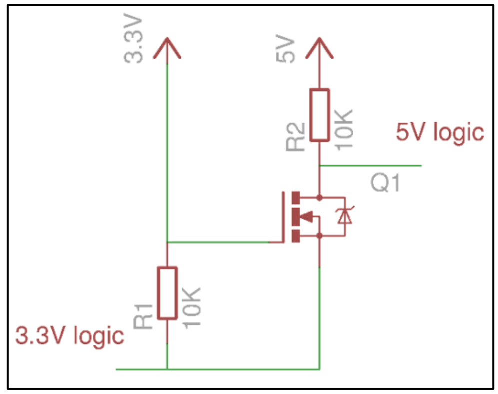


Figure 44 3.3/5V Level Shifter

6.6.4 Bi-Directional logic Level Converter

So instead of having to build a logic level shift as shown above. We decided it would be best to just buy a board that is already a level shifter. We only really need to shift the TX bus going from the Arduino to the raspberry pi due to the fact the Arduino is at 5V and the Raspberry pi pins are at 3 volts. The Rx bus in the Arduino can understand the 3.3-volt input of the Raspberry pi pins. So, no level shifting would need to be done there. But instead of just using the one directional level shifter. We thought why not just go ahead and get a bidirectional level shifter so we can have the proper voltages going to both boards. Having the level shifter on its own chip would help to save us on the PCB design of the Arduino. This would help to cut both the cost and the complexity of the PCB design.

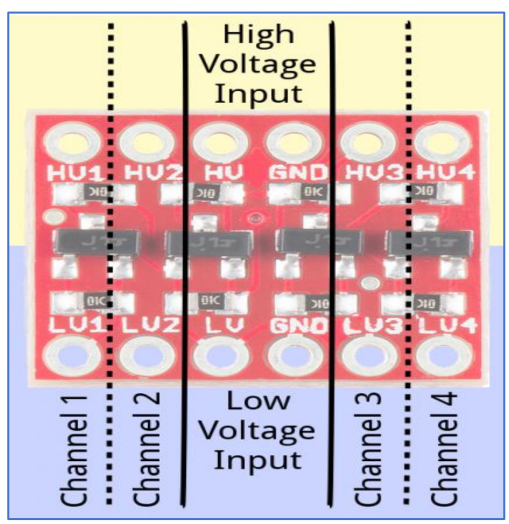


Figure 45 Bidirectional Level Shifter

So, the level shifter we decided to go with was. A Bi direction level shifter from Spark Fun. This level shifter will offer us the voltages we need the 5V-3.3V and the 3.3V-5V.

This is perfect for the application we are looking to do. The level shifter came at a good cost of only $2.95. This is well within the budget for us and might save us from having to resend out a PCB later. The level shifter comes with up to 4 independent channels going each way. This is good because we would only need to use 2 of the 4 channels on each side. So, for the hook up of this Bidirectional level shift it's mostly simple. Each side both has a ground pin on for each board this is for a reverence voltage. Then there is a Level pin on each side so the Arduino will get connected to the side that is HV for high voltage.

The raspberry pi will get connected to the side with LV for Low voltage. Next on the high side the Tx and the RX pins will both be connected one for each on their own separate channels. So, for instance, the Tx to channel on and the Rx to channel 2. Then on the low voltage side one of the 2 GPIO pins will be connected via the channels. So, the Tx of the Arduino that is in channel one of the level shift will have the Rx pin 8 on the raspberry pi. Then for the Rx of the Arduino that is connected via channel 2. Will have the Tx pin 8 connected on the opposite side to the channel 2. This will enable the two of the board to talk. This will allow for raspberry pi and the Arduino to talk. So that way the temperature data from the sensor to the Arduino can be sent over to the pi then sent on to the Hud system. Soo that way when the sensor reaches a specified temperature it will trip the warning indicators on the Hud system.

6.7 Mounting Solutions

Mounting is going to be a very important aspect of our system, as if the user expects to be using their vehicle in any sort of off roading condition we need our components to remain secured to the vehicle. The components must also remain protected from the elements it may be exposed to. With all this in mind we are aware this is our first iteration of a prototype of our product, so all the constraints of external durability are going to be more loose compared to a finalized version of our product that needs to be able to withstand the excess time it is used, and even not used given our product will always be exposed on the vehicle regardless of use or not by the user.

6.7.1 Raspberry Pi’s

Our Raspberry Pi’s need to be mounted in relatively close proximity to our cameras and sensors, this way we can wire these components to the Pi’s without any additional trouble. Our cameras we are using implement the MIPI connection on the Raspberry Pi, which while beneficial from a wiring standpoint (only need the single ribbon cable run vs power and data cables) it comes with the drawback of being more fragile than other solutions. We will need to take this into consideration when mounting our Pi’s and cameras to make sure they are not going to be damaged in any way from the elements faced outside. Luckily for many of these runs there exists a solution that takes these fragile ribbon cables and converts them to a standard HDMI port, which you would then attach both sides to. This component also does this conversion in a passive manner, meaning it will not draw any more power than just using the standard ribbon cable. The design of this conversion is quite simple actually, only taking the existing pin out of the ribbon cable and wiring it to match a pin out on the HDMI port, which on the other end takes that HDMI input and then matches the pin out of the ribbon cable on the camera end.

Figure 46 Aargon Poly+ Raspberry Pi 4 housing

For our exterior Raspberry Pis connected to cameras we will also need to consider their housing to protect the exposed circuitry found on the Raspberry Pi. There are a few methods in which we could do this, whether it be 3D printing a housing and sealing it to gain additional weathering resistance or purchasing and existing product that does this for us. An example of an existing product is found in figure at right from a company by the name of Aargon, this model is specifically the Aargon Poly+. This housing allows us to have access to all the connections we could need while keeping the Pi safe from outside debris issues. It does not feature any sort of ingress protection from water and humidity which would benefit our outdoor Raspberry Pi's but for our Pi that will be in the interior of the vehicle this type of housing will work perfectly, as it does not need as high of a tolerance against the elements. We could repurpose this housing to modify it and fit our requirements given our Pi's that will need further protection. To give these enclosures some better resistance to wear and tear we could incorporate some sealant like silicon to prevent too much humidity from entering the enclosure, this however would also prevent us from being able to easily access our critical use ports such as the GPIO pin out and MIPI connections for the camera. Overall for our prototype this enclosure will suit us in our needs to start, if we were to develop further and make a final version of our product we would custom design a housing for the Pi that would allow us to access all IO while also being more weather resistant.

Wiring wise we will also need to implement the type c connection, as this is how the Raspberry Pi's receive their power input. Coming from our DC to DC converter we will need to terminate the cable to a type C male head. This should be something that we can easily implement, as we will just need to match the power delivery pin out of the type C connector like found in figure below. We will run our positive and negative using 14 gauge wire for the full 15 amp load and 18 gauge (AWG) for our 3 amp loads. In order to provide the right current without imposing too much resistance. In our case we will need to wire to pins A4, A9, B9, B4, for our input Voltage and A1,

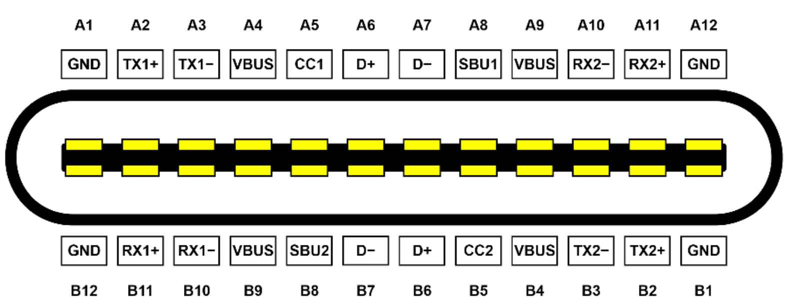


Figure 47 USB Type C Pinout

A12, B12, and B1 for our ground connections. We need to do this multiple time due to the fact that the Type C connections standard is reversible, meaning it can be flipped in either orientation without causing any difference or issues with supplying data (not in our prototype) and power.

6.7.2 Central Hub in-cabin

The primary connection hub for command and control is located within the main cabin of the vehicle. It is here the various electronic components will be arrayed and attached to the vehicle. Managing vibration, electrical isolation, heat dissipation, and water intrusion are all functions of the central hub enclosure. In order to prototype the set-up an acrylic or ABS plastic like material will be used due to ease of manufacturing. The set-up will resemble a large circuit board arrayed as shown below with items being through hole mounted to the base.

6.7.3 Cameras

The mounting solution for the cameras may be a more difficult task than anticipated due to the harsh conditions off off-roading and weather conditions in general. The cameras will need custom made mounts that protect them from the elements along with securely protecting them from debris on the road and trails. So, an enclosure will need to be made for each camera that will also still allow the camera to see clearly. Furthermore, there needs to be accommodations to run wires to the cameras from their mounting positions outside of the vehicle. The forward facing cameras for tire placement are planned to be mounted on the forward portion under the fender. This will keep it sheltered and away from most dirt and debris that would fill the rear of the forward fender well. See figure with bracket circled in green.

Figure 48 Jeep Camera Fender 1

The image at left show the wheel well with fender in place. The green box is the tentative location for front camera mounting prior to testing. It was selected so as to show the area around the tire and the tire itself in relation to the vehicle and surrounding terrain.

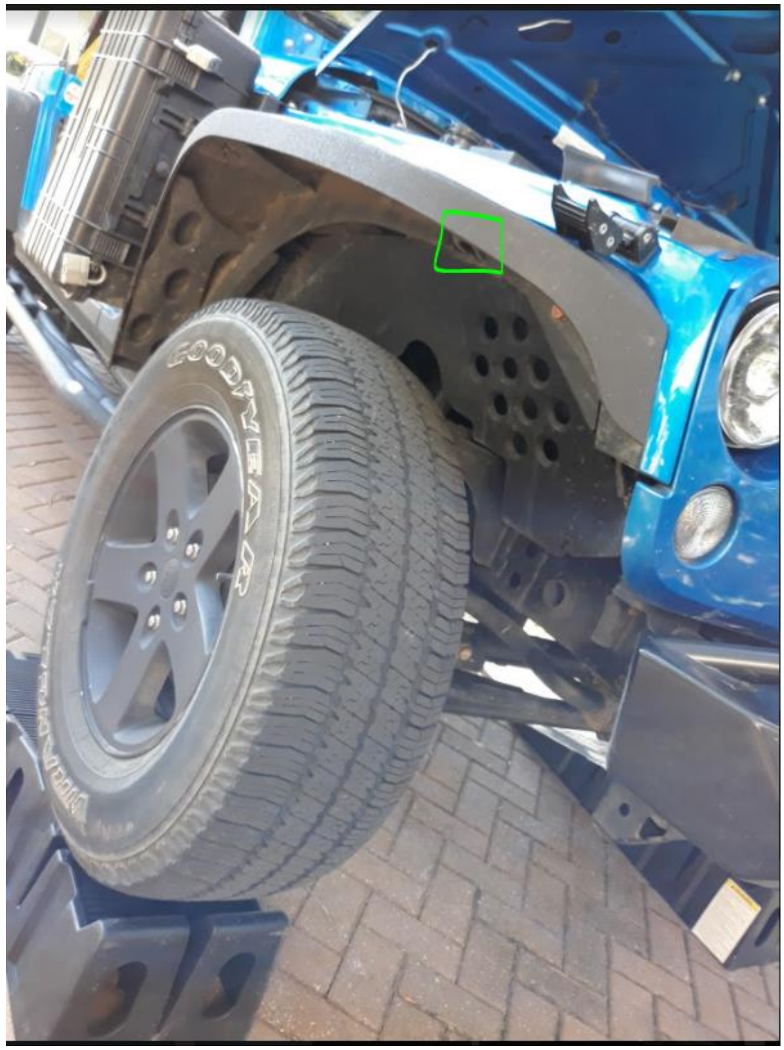


Figure 49 Jeep Camera Fender 2

The images to follow cover the proposed mounting locations for the undercarriage cameras. These mounts are to be determined based upon the level of protection, survivability, field of view, and area of interest. Wire runs and mounting challenges are secondary considerations.

The image at left shows a zoomed out view of the the underside of the project vehicle with the region for underbelly camera mounting highlighted.

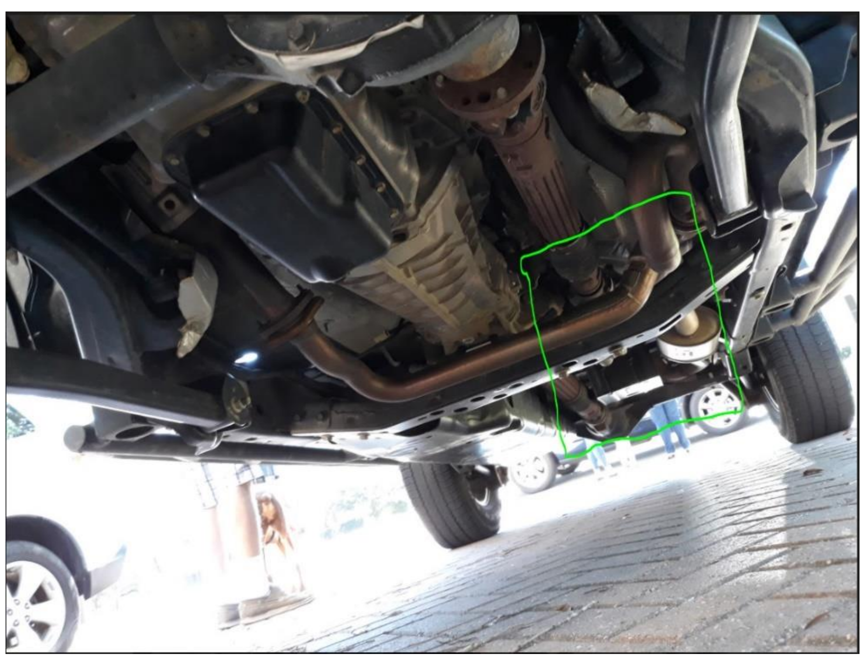


Figure 50 Under Belly Camera 1

The transfer case is shown on the top image at right. The mounting point under consideration is the row of studs used to seal the case. This bolt pattern allows easy mounting and an unobstructed view of the rear area and rear axle housing with the rear differential as the focus point. The challenge here is that though relatively protected from heat this camera would also be relatively low and exposed.

Figure 51 Under Belly Camera 2

Figure 52 Under Belly Camera 3

An option for forward view showing the transfer case and front suspension components is the evaporation canister skid plate shown in the green circle at right. This bolt pattern would provide simple mounting and is high up with protection from impact and heat. Field of view allows proper focus but is more limited due to frame crossmember forward of the mount.

Rear camera mounting for coverage of blind spots is shown in the below figure. Through hole and surface mount options are available for the rear bumper with possible locations for the proximity sensors circled with the camera location boxed at the top of the bumper. The tailgate and vehicle top are removed in this image.


Figure 53 Rear Camera Mount Locations

6.7.4 HUD

Although the parts chosen for the HUD are very durable, we want to ensure they can withstand the vibrations that go along with driving an off-road vehicle. This is to ensure they provide clear enough images to the driver while in use. The idea behind mounting is to create one completely sealed box for all the HUD components. This ensures all the components are secure and mounted together so if any large variations occur all the components will shift together. A completely sealed box will also stop any outside sources of light from entering the lens system and creating unclear images for the user.

Since the HUD unit will be protected inside the cabin of the vehicle the best option would be 3-D printing utilizing durable Polycarbonate that can be utilized in 3-D printers. The utilization of 3-D printing will also allow us to add different features to the HUD mount. The option for different methods of mounting come to mind when coming up with a mounting solution. This is to allow the user to have more flexibility when choosing where the HUD will be placed in the cabin. Furthermore, the Design of the HUD includes an image that is slightly diverging so the user can chose to mount the HUD display slightly further from the combiner on the windshield for a larger image if they desire. Since this is a rather light and compact design some simple double-sided automotive tape may be used for the mounting of the HUD system.

Overall the design should be able to accommodate the mounting of the OLED display along with mounting the lenses at the corrected distances from each other. Then a mounting option for the HUD onto the vehicle. The area for mounting is shown below in a through cabin view and a side cross section view. These images have the doors, rear roof and interior headliner trim removed from the windshield and A-pillar areas.

Figure 54 HUD Mount Area

Figure 55 HUD Mount Area 1

7.0 Software

Our software will be constructed with mainly the Python and C programming languages. C programming will be used primarily for basic functions like monitoring the sensors and starting up different camera feeds. Python along with some SDL programming will be used to program the graphical interface that our user will interact with, Python is being used for its ease of programming and for its large libraries and support community to help.

7.1 Software Design

The goal is to have our interactive software simple to use and understand to allow our users easy access to the data and cameras they are looking for. We will have designated modes for our sensors and cameras. The first and default mode the software will run on is the "On-Road" mode, for use in driving and parking. This mode will be our default and primary as it provides the most benefit towards our users in situations that will occur more frequently than an "off-road environment". In both modes and environments what will show on the main display will remain the same. Without any sensors being tripped we will have an overall view of the cameras each with a segment of the display showing their camera feed.

There will be a graphical overlay laid out on top of the camera feeds, for our current prototype we are going to rely on buttons to navigate the interface, but in a future revision we could implement a higher end touch display for the user to interface with the system. On the interface will be our basic controls, such as changing between modes and selecting different camera feeds. We will also incorporate options to enable/disable the temperature sensor data for things like the engine bay. There will also be a mode that the user can get interface with that will show things to troubleshoot our system, such as the status of each individual Raspberry Pi.

The "On-Road" or street mode of our project will incorporate all of our sensors and cameras to work in conjunction with each other to assist a driver in normal driving environments. In this mode our goal is to alert the driver of any dangers that are out of his vision and show them the danger via a mounted camera on the exterior of the vehicle. During this preset mode the display will show the grid/array of cameras, each with a subsection of the display to show their video feed. It will also show the sensor data if enabled by the user. The way we will inform the user of danger will be an immediate alert followed by the display engaging the camera into a full screen view of whichever proximity sensor has been tripped with the determined threshold, we will achieve this via the incorporated HUD on the windshield of the vehicle.

We will display a flashing notification indicating which direction the danger is coming from, whether it be right, left, or behind. At the same time we will incorporate a function in our software that will remove all data and other camera feeds on the display to focus on the full screen view of the camera where the sensor was tripped on. After the danger is passed or avoided and the proximity threshold is passed the HUD will immediately stop flashing, however the display will continue to show the feed of the camera in question for approximately 5-6 seconds, to make sure the danger has indeed passed. One thing to keep an eye on while developing is to make sure during that 5-6 second window if another proximity sensor is tripped from a different part of the car it will immediately switch over to the new feed. This is extremely important in our on-road scenarios where you can easily over-correct being too close in another lane of traffic, which would put you in the corresponding opposite lane.

There will also be an "Off road" mode that will limit the HUD's functionality and proximity sensors to prevent excess tripping of sensors and cameras. Instead this mode will be strictly for monitoring cameras and temperature feeds. In this mode the user will by default will be presented with all the camera feeds, with the option to select different camera feeds to view them in full screen. A user would do this when they are off road and are trying to get past an obstacle and need a clear picture of the area of focus such as the rear-view camera. If we were to have the proximity sensors enabled in this mode they would constantly trip and show the view of the camera corresponding to the sensor, which would not be optimal for our users.

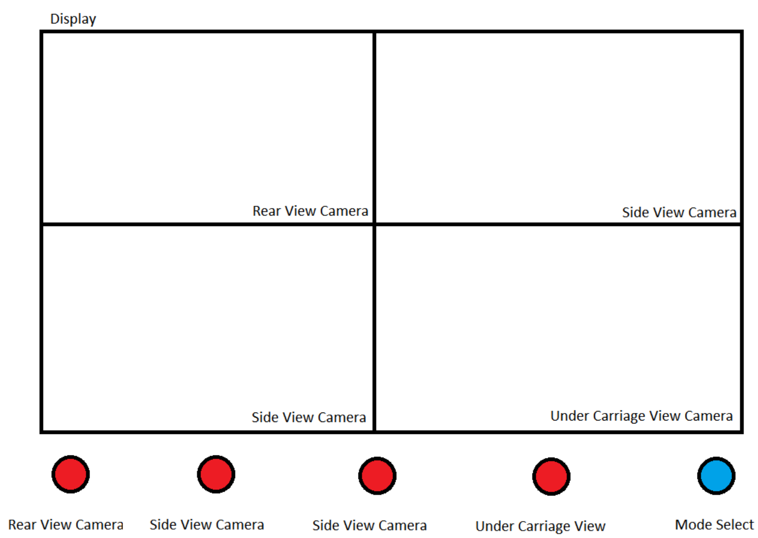


Figure 56 Software Design Sketch

7.2 Software Technologies and Libraries

Our software will incorporate many libraries within the Python and C languages as well as externally supported implementations such as Open Source Computer Vision Library or OpenCV. Open CV is an external library supported by the Raspberry Pis that allows us to easily incorporate our cameras into our program among other higher-level features. In using this we could even expand in the future to create a trained machine learning model that would allow us to use the cameras in "Off Road" mode and detect when an object is getting too close or if an object is out of place or position. To do this we would define certain objects and sizes within the focal range of the camera to be highlighted and announced to the user in "Off Road" mode. While this would be interesting to implement into our project, we will be using OpenCV to accelerate our camera feeds with the Pis incorporated ISP found when connecting a camera to the MIPI CSI2 port.

In our initial programming and creation of our prototype we will also be using the built-in software development tools found in the Raspberry Pi's rasbian OS. These will be beneficial in the initial creation of our prototype as if the software runs into issues, we will be able to see on the display and debugger what is happening to our camera feeds.

7.3 Clustering the Microcontrollers

For our project to have a proper amount of performance needed for the user to interact and view cameras in near real time we are implementing a Raspberry Pi cluster into our project. The goal of this is to use up to 6 Raspberry Pi's together and transfer data to achieve a seamless experience for our end users that will only be interacting with the display found inside the vehicle that will also be connected to our host Raspberry Pi.

7.3.1 Cluster Setup

In order to set up a cluster of Raspberry Pi's we will need to decide in software which device will be the host device or "Master" and which ones will be node devices or "Workers". For our setup we are going to configure the Pi closest to the inner display to be our master as that will also be where the user interacts with the Pi and where users will call upon specific functions we program, which are divided up by the master to perform on the cluster of workers. This model of clustering is used as a cheaper alternative to perform higher compute data workloads, such as simulations and in some cases a web server replacement. Our use case does not feature such workloads but will benefit from being essentially one unified operating system for our users and software team to program to.

In order to cluster Pi's in this manner we will be using standard ethernet cables in order to minimize latency and improve support for the user. The downside to using network cables as even though their latency is minimal it is enough to severely effect performance compared to theoretically having one overkill Raspberry Pi with many more cores. The Raspberry Pi's will have network cables that will all run to a central network switch, a 5 port netgear switch we have on hand which will allow all the Pi's to see each other based on their assigned IP addresses. We chose this switch for its low power draw and decent latency, with power draw being the larger concern since we are running power from the vehicle's battery. We will also need power run to each of the Pi's, which we will run at the lowest possible power setting with the performance we need rated at about 5-15W depending on network traffic in the switch.

7.3.2 Cluster Hardware

As mentioned in our setup we will need a network switch for our system. But at the heart of our system we are going to use 4 Raspberry Pi 4 Model B's in a 1 Master 3 Worker configuration. This model of Pi has the performance we are looking for to drive our cameras, sensors, and display without drawing excessive amounts of power from our vehicle battery. This is important as we will be powering our Raspberry Pi's and all their connected components using stepped down 5V DC power from the vehicle's battery. The maximum current that the Pi and all its peripherals can draw is 3.0 A where 1.2 A is dedicated to powering peripherals attached through GPIO, CSI, and USB. We will be using a mixture of USB and CSI compatible cameras for our project, where we will use the CSI connected cameras in areas close to the Raspberry Pi due to the length limitations of the CSI ribbon cables itself, and only resort to USB where necessary, as USB cameras consume much more of our CPU resources to encode and process each frame where the CSI connection can be directly processed by the Raspberry Pi's on chip GPU. The reason for this difference in camera processing is the CSI connection has direct access to be processed in our memory with the GPU. We are also looking into taking advantage of additional accessories that would expand our CSI connections and even convert the connection to use HDMI cables to further our reach and durability of our camera connections.

7.3.3 Cluster Software

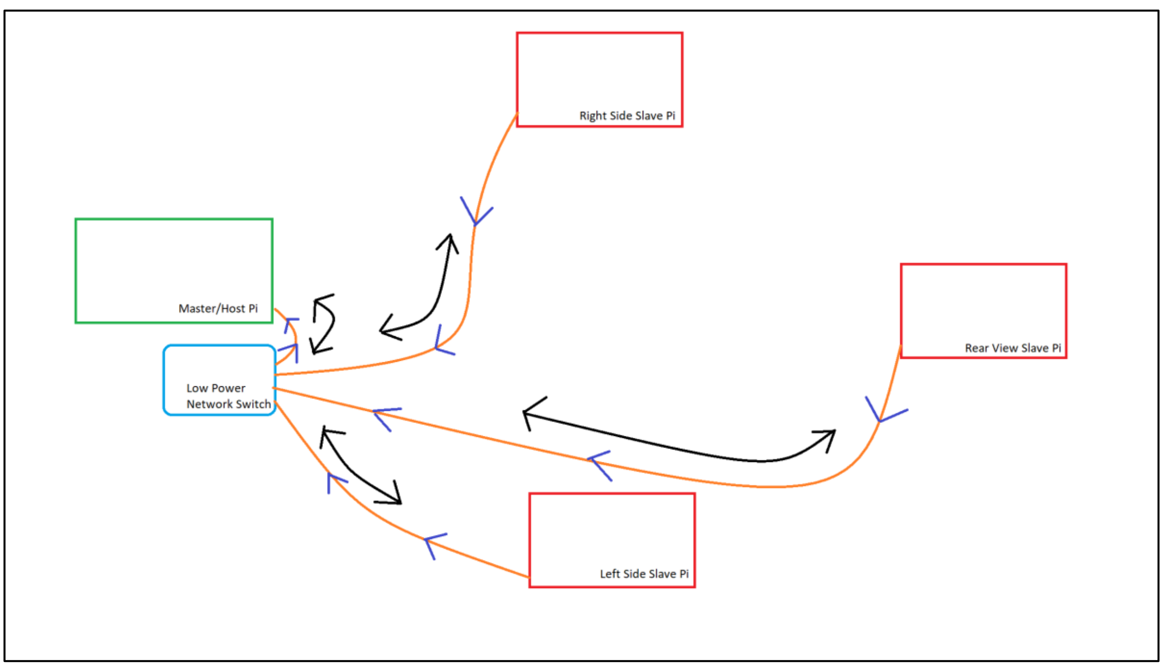
To communicate with each other the Raspberry Pi's are all going to be configured with the SSH (secure shell) network protocol where the workers authenticate and transfer data to and from the master. We will need to configure the Pi's to have a fixed network IP address in order to keep it running without any IP dynamic switching found in many switches and is on by default in the Raspberry Pi 4 Model B. While we are currently only focused on a real-time model for our project we will still need shared storage between the Raspberry Pi's to hold configuration files and shared code used by one or more of the Pi's. This storage medium will only be 32 GB and run on the USB 3.0 bus in order to have the lowest latency and highest transfer speeds. This also resolves the issue of the limitations of MicroSD cards with their less favorable performance compared to USB, even though each Pi will still need a microSD card to boot to. In a future revision of our project we could expand upon this storage using a more reliable hard drive or better yet solid state storage to enable recording and playback of footage captured.

We will be controlling our dataflow and operations through the SLURM workflow manager, a piece of software that schedules tasks for the workers through the master node. This piece of software is not only used for small compute units like this but also in large data centers where a similar master and worker configuration is used. It can even be incorporated to take advantage of GPU's within workers, like if we were to incorporate one of Nvidia's Jetson products. This software will allow us to execute code on our worker Pi's such as running our proximity sensors and triggering cameras which would then trigger the master to display that camera. We could individually configure each Pi the same way and achieve a similar result, but that can create more latency and troubleshooting headaches, especially as code becomes more complex between each Pi and updates have to be made to each Pi individually. We can also set up our cluster to be more reliable, where if a worker goes down the rest of the system can still run and inform the user that a worker as stopped responding, which would also result in an easier reconfiguration of the worker Pi, as since they are using a shared storage model the code and configurations will remain intact with just the worker Pi's MicroSD card needing to be reflashed to be added back to our cluster network.

All of the Raspberry Pi's will start with the August 2020 desktop OS version of Raspberry Pi OS, we will use this for initial development and coding of cameras and sensors. This will allow us to run an IDE on a GUI interface to debug and troubleshoot on the fly rather than constantly re-uploading code to the devices. Once we have a final version of the software we can run the "lite" version of Raspberry Pi OS, which features very minimal features, without a desktop GUI and just a command line. This is something we will want as we do not want background processes to be running and drawing more power when they are not necessary to the features of our project. The only Raspberry Pi that may continue to use the desktop OS is our main controlling Raspberry Pi that will run our interface for the user. The reason to continue using the desktop OS on this Pi is it will allow the user to troubleshoot themselves to discover any issues found between the Raspberry Pi's. This will also allow us to easily programmable interface for the user to interact with that will show full screen of the display.

Below you can see how we will incorporate clustering for our given project. The green master Raspberry Pi will be the one connected to and controlling our display and also be responsible for taking any input command found within the GUI. We have all the Raspberry Pi's connected to a low power network switch in order to allow intercommunication between the Pi's, this also allows the master to send and receive data as shown with the black arrows. The orange represents the ethernet CAT5 cables we will need to use to allow for longer lengths without compromising on data integrity. The blue arrows represent the data flow of our camera feeds, which our master will take in and display and make logic choices based on the given sensor situation.

Figure 57 Cluster Dataflow Representation



8 Imaging System Design

Now that the display for the HUD has been figured out next is to find a way to project the images of the display onto the windshield. To accomplish this a lens system will be created that has a magnification to achieve the display area. As mentioned, a big issue will be the display becoming hard to see in high light level situations. So, the use of a reflective thin film on the windshield will be used to make viewing easier. The position of the projection for the display will also aid in the visibility as most vehicles have a sun visor tint at the top portion of the windshield. By utilizing the space on this tinted area, it provides a nice dark background for the image as there will be more contrast along with being a darker area in general for easier visibility of the display projection.

8.1 Lens system

There are many factors to take into consideration when coming up with a solution to our heads up display. This means there are also many ways to achieve the same outcome. So for this case the budget constraint will be the biggest factor when coming up with a lens system design. Time constraints will also be an issue so a system will need to be created with lenses available to us as ordering custom lenses to be made is very time consuming and costly.

Lenses have many characteristics to consider when choosing the right lenses and the cost of lenses can add up very quickly. Some factors to consider in a lens system include the shape of the lens, the materials, the type of lens used, the configuration/orientation of the lenses, and aberrations in the system. Ideally, we would like to design a simple lens system that provides us with the clear magnification of the display that we are aiming for. Using too many lenses will cause aberrations to add up and distort the original image quality of the OLED display.

8.1.1 Type of Lens

There are a wide variety of lens types to choose from. The first two simple shapes that will be looked into are plano concave and plano convex lenses. Meaning one lens is a flat plane along with one curved side. Concave lenses have a negative radius of curvature and have negative optical power. Where convex lenses have positive radius of curvature and have positive optical power. Furthermore, there are Bi-convex and Bi-concave lenses that have curved sides on both sides of the lens. Usually, these lenses are simple and generally cheaper than other more complex lenses that will be discussed. However, the performance is not as great as other types of lenses due to aberrations that can occur. However, these performance gains may not be a big deal for our application since we need a simple lens system at a reasonable budget.

There are also types of lenses called achromatic lenses and aspherical lenses. There are many types of lenses in this category, but they are all made to achieve the same goal. That is to achieve more clear imaging by reducing aberrations. This is done by varying the shape of the lens or by combining different lens types into one small compact package. For example these lenses could be designed to work better when an object is not perfectly placed on the center axis with the lens. They are also designed to correct chromatic aberrations which occur when different colors of light refract at slightly different angles. Depending on how our test system works we may come and revisit some of these lenses if our image is not clear enough with the simple lens systems.

8.1.2 Glass Material

For the glass used in the HUD we chose to use N-BK7**.**Choosing a glass material to suit our project needs was an easy task as N-BK7 glass is the most popular glass used for optical systems in the visible and near IR wavelength. With a refractive index around 1.517 this glass has very efficient transmission in the 300nm to 2000nm range. Which is perfect for our application as we are only working in the visible light range spectrum. Another reason to use this glass would be price, it has a very good price to performance which attributes to its popularity in optical systems. N-BK7 is also a very durable glass that can withstand many physical and chemical stress tests. Considering the application of our lens systems the durability isn't much of a priority since the lenses will be securely encased in the HUD system but it is always a nice feature to have good durability just in case any harsh vibrations or drops occur.

Another contender for glass would be NSF-11. It has many comparable qualities to the N-BK7 and is also a very popular choice in lenses. With a slightly higher refractive index at 1.785 and a range slightly larger than N-BK7, NSF-11 glass may be another good choice for our application.

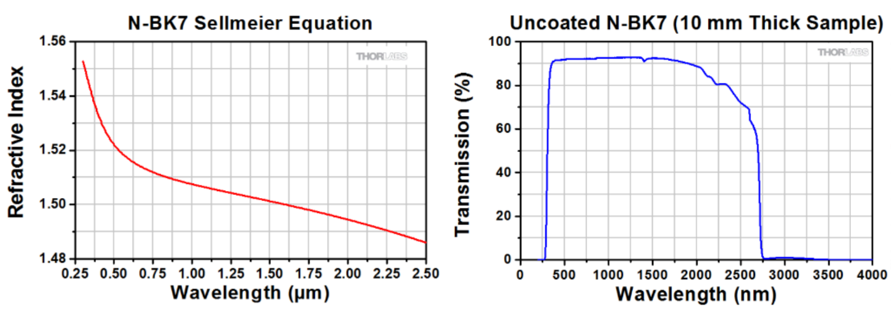


Figure 58 Plots displaying transmission and refractive index properties of N-BK7 glass

8.1.3 Optical Aberrations

As mentioned before it may be a challenge to design a simple enough lens system while also avoiding optical aberrations. Too many aberrations in a system may cause the final image to be very blurry and even unrecognizable to the user. As mentioned there are lenses that can be used to avoid these aberrations but these come at a greater price. Although most optical systems use curved symmetrical lenses because they are easy and cheap to produce they are not ideal for accurate imaging as spherical curves do not produce a perfect point of focus. This is called a spherical aberration and lenses such as best form lenses are created to perfectly focus light to a singular focal point while still being able to use a curved lens. This type of aberration can cause blurry imaging and is something we must consider when designing a lens system.

Another aberration that can occur in a lens system are chromatic aberrations. Since refractive index is based on wavelength this may cause a slight shift in all the colors in an image. As the image is passed through the lens system the colors will shift slightly based on their color. If too many elements are used this slight shift in refraction angle can add up and thus produce an unclear image if the colors have shifted enough compared to each other.This would cause the image to also appear blurry along with slightly shifting the colors and distorting the image. In this case Achromatic Lenses may be considered to reduce chromatic aberrations if the image is too unclear.

8.1.4 Lens Distributors

These Lenses are not common products that can be found anywhere so it is important to explore different lens distributors to consider when ordering our glassware for this project. Thorlabs is a big name for CREOL undergraduates as they provide affordable quality products. Having personally ordered from Thorlabs before they are a strong choice for using their products in this project. They also offer great customer service along with more budget-oriented elements that will be perfect for the application of this project. For these reasons we have chosen to use Thorlabs products for our project.

Some other well-known names we looked into include Edmund optics and Newport. Although there are many other great optics companies these are the most well-known and are known to reliably provide quality products to our area. As we face time and budget constraints these three companies are all viable options for us. However, Newport is known to provide more quality products but at a higher price. Same is true for Edmund optics as well. We simply could not justify modifying the budget to order from these companies after checking all their catalog of lenses.

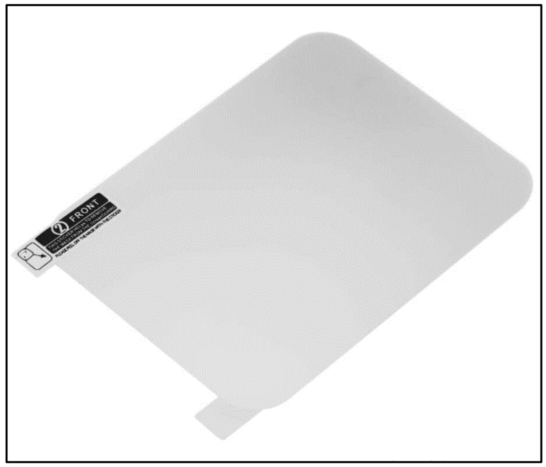
Overall Thorlabs seems to the best option for this project as they can quickly provide budget friendly options for our applications.

8.2 Combiners

When considering the combiner to be used in our system there aren't very many practical options due to our budget and time constraints. The first type we could utilize is a thin film that can be placed in the windshield that provides an image utilizing fresnel reflections. The image quality may not be perfect when going with this option but it will be cheap and effective enough for our application. As mentioned before there are also Holographic optical elements (HOE) combiners that could be utilized that will provide much clearer images and can be customized for our setup. However after further research the time and money required to implement these into our HUD will be impractical.

The standard film utilizing fresnel reflections will be good enough and will help provide clear images to the driver even in bright settings as the film will help reflect more light compared to just a bare windshield. This along with a small tint on windshield will help to reduce the brightness around the image area. This will add to the overall visibility of the Heads up Display image and create a good viewing experience for the user. After researching more into combiners it was a clear option to use a thin film combiner that utilizes fresenel reflections.

Figure 59 Thin film combiner that will be utilized on the windshield



8.3 Designing the Lens System

This part of the project ended up being a big challenge to face considering all the parameters that go into designing an optical system from scratch. As an undergraduate student who has never created their own system a lot of time was dedicated to learning new skills such as using Zemax for this project.

9.3.1 Using Zemax

In this project we will utilize the software Zemax to create a design for the imaging system required for the Heads up display unit. We would like to magnify the image of the display so it is easier to see on the windshield of the vehicle. This program is a good aid in simulating many different optical setups so we have more freedom when designing an efficient system for the HUD unit.

Zemax is being used because it allows the user to enter in the basic required parameters such as object size, aperture sizes, wavelengths and length. The program will then simulate and give the user back the calculated results of the optical system. The magnification and F number of the will be given back for each simulated lens system.Zemax also includes the catalogs for major optics distributions companies so all the lens data needed can be uploaded directly into the program. This will allow us to simulate many different optical setups to find one that will work best for the application of our product as we do not need to go out and test many different setups. We can simply simulate them before moving onto the testing process.

Through this process of designing a lens system we have learned some of the limitations of Zemax. This program took a very long time to learn how to utilize to create a simple system and even then not all the features were clear. So it is very unintuitive at first but once the basics are learned it is a great program for designing systems.

9.3.2 The Lens System Design

Designing a lens system from scratch is a very daunting task as there are so many option and parameters to think about in an optical system. It is first important to think about the goal of the system we are designing for before proceeding further. For this application we want a system that can magnify the image from the OLED display by at least 1.5 with minimal aberrations. Our display will not be displaying very detailed images so this system doesn't have to be perfect. This means we can be more lenient on the budget constraint and choose more budget oriented options when it comes to lens choice.Another goal is to have the system be under 15 centimeters long to keep the unit compact and easily mountable to the vehicle.

There are many factors to a lens system that need to be thought about when designing a lens system. As mentioned we would like image magnification of at least 1.5 but to start we can define our object size. The OLED display we have chosen has dimensions of 27mm x 27mm for the active area. So we can first try and design a system that accommodates that size of object while also providing the magnification required. It would also be ideal for the image to be mostly collimated so the mounting option can be more flexible. Ideally the image would be slightly diverging to give the user the option to have a larger image if desired by simply varying the mounting distance from the windshield by a few centimeters.

There are two different systems that came to mind when designing a system like this. The first being a common beam expander system called a Galilean Beam Expander. Which involves a convex lens and a concave lens in that order placed at a distance that is the sum of their focal lengths. This provides a collimated image with the benefit of a compact system. Since this method involved a convex lens where light is dispersed this raises concern for the image quality however. As the images may become stretched and even start to mix with each other as the light is diverging after the concave lens. The figure below displays a Galilean Expander lens system that fits the parameters provided. It accommodates the size of the display while also providing 2x magnification at a distance of 5cm. The size from the object to the last lens is also only 10cm long so the system is compact enough as well.

The image is also slight diverging to provide different magnifications at different distances if desired. However the fall back mentioned can be seen in this simulation. The image deverges very quickly between the lenses and this can cause the images to look stretched and blurry along with images mixing and causing unclear imaging as well. This is a solid option for our group because as mentioned we do not plan on displaying very detailed images. With this in mind the lenses in this simulation are from Thorlabs and are very budget friendly as they are some of the cheaper options.

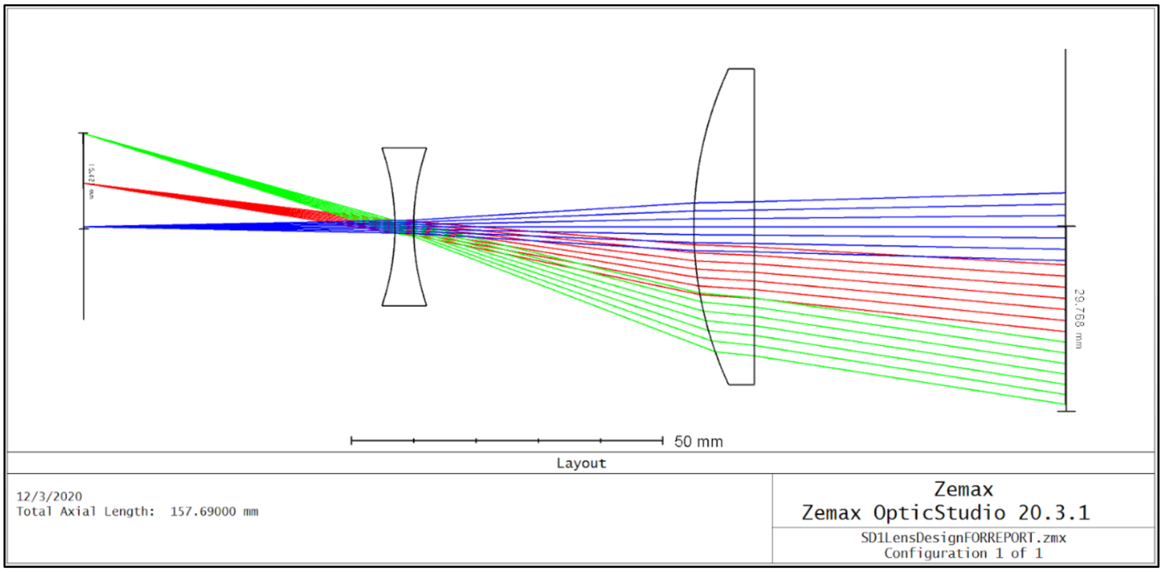


Figure 60 Zemax design of Galilean expander that fits requirements

The second system that came to mind is based off a Keplerian Beam Expander. This set up involves a bi-convex lens with a plano convex lens. For this set up to be collimated it requires the lenses to be separated by the sum of the focal lengths as well.This system will suffer from less image dispersion so the images will look much more clear. This design was also altered to provide a slightly expanding image for the output to allow the user to adjust how big they would like their images to be. Similar to the first lens set up this system provides a 2x magnification at 5cm from the last lens.

This system was also designed with having a similar length to the first one. Using lenses with short focal lengths we achieved a system that is also about 10cm long. It is also important to note that with this system the image will become inverted. Usually a correction lens is placed in the middle of the two lenses to correct the image but in our case we can simply rotate the screen in the mount so the drive will see upright images. With this in mind this second design seems like a much better option for our project as it will provide the required magnification with clear enough images along with meeting the size constraint. The prices are also very similar for each setup with the Kelparian set up coming out to around $65 before shipping and tax.

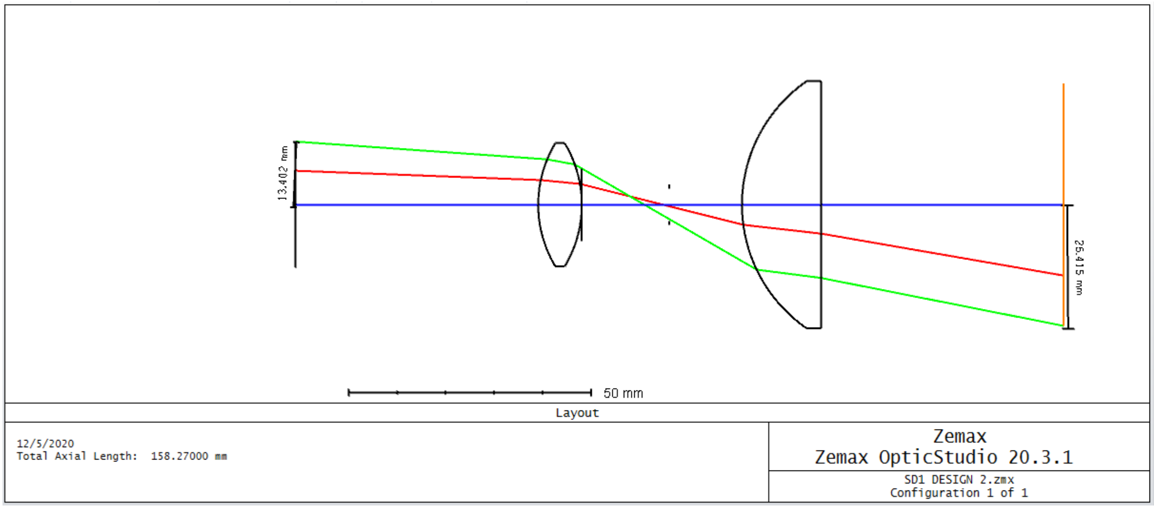


Figure 61 Zemax design of Keplarian based expander that fits requirements

The table below covers the design parameters of the two designs. Design two that is Keplarian based was chosen.

Table 17 Lens Design

Parameters	Design 1 Galilean based	Design 2 Keplarian based
Cost	65$	65$
Image Quality	Questionable quality due to concave lens design	Much more clear image quality
Magnification at 5cm	2x	2x
Length of system	10cm	10cm
Lenses	bi-concave to plano convex	Bi-convex to plano convex
Brand lenses used	Thorlabs	Thorlabs
1st lens	LD2297	LB1761
2nd lens	LA1050	LA1401

9.0 Project Prototype Testing Plan

In order to have our project prototype deliver a safe and comfortable user experience it will need to undergo thorough testing over the course of many days. These tests will ensure reliability and stability in our system in different environments and within our different modes.

9.1 Circuit Protection Testing

Low Voltage and Reverse Polarity Testing Procedure:

The component to be tested here is the low voltage cutoff and the reverse polarity protection feature. The regulated power supply will simulate the vehicle battery in a controlled manner. The circuit protection components to be tested are our low voltage cutoff and the reverse polarity protection function. An LED light will act as the simulated load and is a visual indication of if power is being cutoff or allowed to reach the end. The test is divided into a low voltage disconnect and a reverse bias test.

LVC

1. Gather materials, test LED to ensure function by connecting to power supply directly to ensure function bypassing the circuit protection.

2. Hook up circuit protection device to Regulated power supply, connect other end to simulated load with test light. Be sure connections are tight and common ground is set.
3. Set power supply to 12.8V, verify load is receiving power by visual inspection of LED (on)
4. Step down voltage in 0.1 V increments until LED turns off. The action should be immediate. The LED should not receive power when the power supply is below 12.2 V.

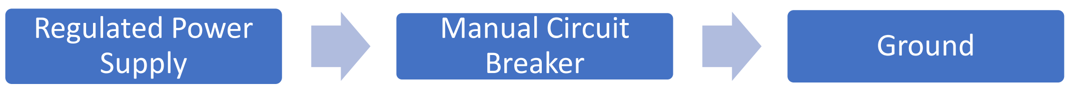
Reverse Polarity

1. Gather materials, test LED to ensure function by connecting to power supply directly to ensure function bypassing the circuit protection.
2. Hook up circuit protection device to Regulated power supply, connect other end of circuit protection to simulated load with test light. Be sure connections are tight and common ground is set.
3. Set to 12.8 V and observe light function. If LED is illuminated go on to step 4.
4. Reverse the connection so that the power source polarity is reversed. LED should not be illuminated. If not proceed to step 5.

5. Reset properly, verify circuit is now receiving power via visual indication of an on LED.

Manual Circuit Breaker Testing Procedure:

A simulated short will be set-up by connecting the test device to the regulated power supply with a maximum current rating of delivering over 15 amps without a load. The device should trip interrupting the flow of current due to the fact that the simulated battery is shorted and delivering it’s maximum current and it is over the interrupt point. If the power supply can act as a current source a current of over 15 amps should be applied. The device should function again after being reset. In order to test function again a load should be added (test LED). The resettable fuse should allow the flow of power across to the LED now that it has been reset.



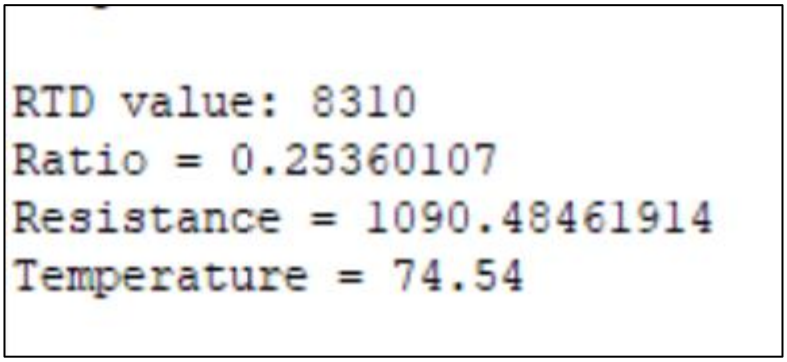
DC-DC Step Down Test Procedure:

This test is to verify that the DC to DC conversion is happening as required.

1. Gather materials, hook up DC-DC step down device to regulated power supply. Be sure connections are tight and common ground is set.
2. Send 14.4 to 12.2 V from the DC power supply. Probe circuit with digital multimeter to determine if the output terminals are showing 5V. The voltage should be steady regardless of input voltage withing the given range.

9.2 Testing of RTD Sensor

For testing of the Arduino with the temperature sensor. For the initial test we are just going to be using the USB cable to the PC to ensure that everything is functioning properly. So once everything is hooked up to their respective pins the next thing is to go ahead and start the Arduino IDE. Once this is done the next thing that needs to be done is the baud rate of the com port needs to be adjusted for a baud rate of 115,200. This will make sure that there is proper reading of the sensor and transfer of data. If the baud rate is not set correctly then there will just be junk values displayed on the screen. Or the next phase of the test we will be using the raspberry pi instead of the USB cable We have not been able to test this at this time due to the fact we are waiting on our level shifter to come in. But the plan will be to use the TX and the RX bus of the Arduino. Then connect them via the level shifter to the pi. So that way when we connect via the level shifter, we can have the proper voltage readings going to the raspberry pins. A test had been conducted trying to make just a level shifter using resistors but that did not work out well. So, when the level shifter comes in, we will be testing that over the brake. For that test we will be using the temperature sensor with the amplifier to the Arduino and the raspberry pi along with the level shifter. We will just have the result displayed to the COM of the raspberry PI. Then for the final test we will connect it to our HUD when that is completed. To display the values of the ambient temperature data of the engine bay.



```
RTD value: 8310
Ratio = 0.25360107
Resistance = 1090.48461914
Temperature = 74.54
```

Figure 62 Print out of the RTD senor test

9.3 Testing of Ultrasonic Sensors

So, for the testing of the ultrasonic so far, they all have been tested. Each one has only been tested independently. For the test we just connected the ultrasonic to the raspberry pi. For the pins we used pin 10 and pin 5. Pin 10 is the RX pin for receiving info from the ultrasonic sensor. Then pin 5 is the SCL for serial communication. Then for the power and the ground pin was connected as needed. The power pin used was the 5 V to supply the sensor. For the next steps in testing of the ultrasonic sensor we need to connect all of the ultrasonic. One ultrasonic sensor to each of the Raspberry Pis. Then hook them up to the master Raspberry pi. Then just have the distance value printed on the terminal. But once the HUD is complete the final test will be to. Connect the Pi up to the HUD and have the value printed on the HUD.

9.4 Testing of the IR sensor

For testing of the IR sensor a few files had to be downloaded to the raspberry pi. Once the package files had been downloaded. The next step was to configure some of the raspberry pi needed to be changed. Then after doing that the next step was connecting the raspberry pi to the sensor itself. Each pin will be connected to the respective pin on the raspberry pi. To power the sensor the 5V pin connect will need to be made. The reason for this is because the sensor requires 5V to run. Then once all the pins are connected the next thing is to. Just set the files up to run. Then also check the sensors address in the raspberry pi. The address that should register is the 5A this is the same as in the data sheet. Once all that is done the only thing left is to run the code. Then when the senor is running it will then display the reading in the Com port on the Pc. The next step in testing is to replace the Pc for the HUD and have it out put the value on to the HUD itself.

9.5 Software Testing

We will need to test each component of our software to make sure it provides the user with the safety features we are incorporating, otherwise the user might as will not even have our assisted features to help them. In our testing we will need to test both On and Off-road behavior to see what occurs when in each mode and make sure the user knows which mode they are in at all times. We will envelope testing at each point of software development and when the finalized prototype software is complete to make sure each part works together without interference.

In "On Road" or "Street" mode our suite of testing we will need to conduct will include stress testing the whole system to ensure the driver is fully aware of the surrounding objects in given situations. Our primary test case for stressing our software will be parking, as there are many objects found within parking situations that would alert and stress our sensors and cameras while also testing our logic to make sure the proper things display at the proper time. We will especially need to strongly test the 5-6 second incorporated window to make sure that a user is not in danger.

We will conduct our tests outside the vehicle before instillation of the system as this will allow us to adjust and reprogram certain variables on the fly. In order to do this we will set a constant distance within our software which we will intentionally trip our sensors, this will allow us to also conduct sensor testing within our software, once we trip off our sensor we will then look at the display to make sure that the corresponding display comes up when the sensor is triggered.

We will also need to test to ensure that the "Off Road" mode switch works and works responsively so the user is not left hanging when switching modes unable to figure out what is happening in the background. We will test in the "Off Road" mode to ensure that the proximity sensors do not constantly trip and prompt alerts on the HUD and display. If a proximity sensor is within the limits of our "On Road" mode we will ensure that when in the "Off Road" mode that it does not change the view on the display of the camera array and layout or change the view of the specific camera the user has chosen to look at. In the "Off Road" mode our user should also still be able to interact with our GUI via the buttons to display which ever camera they want.

In all of our modes the HUD in front of the driver will show the temperature from our IR sensor in the engine bay, and it should continue to show no matter what situation pops up for the user, either in street or off-road mode. The HUDs reading of the temperature sensor also needs to be accurate for our users in diagnosing any problems they may have with their vehicle.

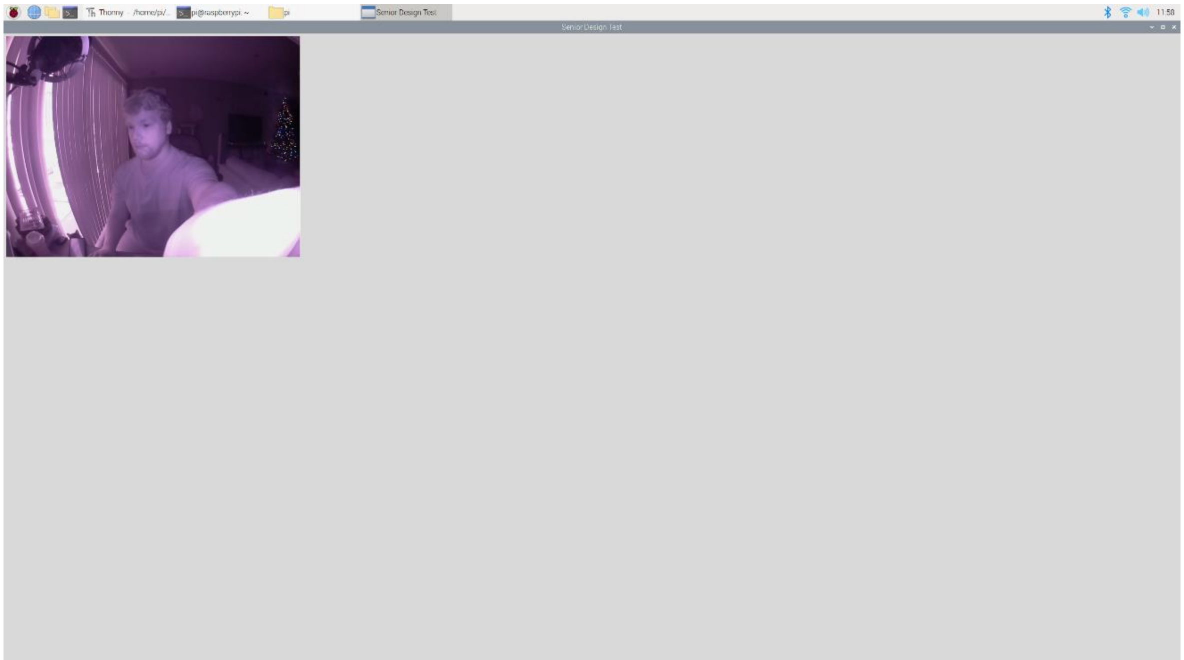


Figure 63 Initial Software Testing with 1 IR Camera in a grid alone (appears small but the connected display used was higher resolution, unlike our chosen display)

9.5.1 Summary of Software Testing

The table below describes the different use cases and testing we will perform on our project, there will be functions of our software that will be more important than others and those are signified with a '*', these specific functions will be required to pass when testing our software, as they are part of the core functionality of our system. In the event a required core function does not pass we will need to double back and figure out what happened in the system. If we cannot figure out what went wrong in one of our core functionalities we need to reconsider what the core function does and how to change it to the scope of our project.

Given the importance of reliability of our project, software testing will need to take place over the course of many days, to ensure that the system is stable for our users and does not crash. If it were to crash our user would be at risk of not being aware of their surroundings, leading to possible harm. If we can get the system to work reliably 3 consecutive days in 3 separate occasions this will prove to be reliable enough for our prototype and move to the next stages of our design.

Table 18 Software Testing

Software Testing Table		
Functionality	**Pass Description**	**Pass/Fail**
Display*	The screen functions and displays what is expected of it	Pass
Mode Change	When user hits button the mode changes	Pass
Camera Change*	When user hits button the camera will display in fullscreen	Pass
Sensor Trip “On-Road/Street”*	When sensor trips, the camera next to that sensor will display, a warning will flash to the HUD	Pass
Sensor Trip “Off-Road”	When the sensor trips, nothing will change, it will be ignored	Pass
HUD Functionality*	HUD displays corresponding icons properly	Pass
Temperature Sensor	The temperature sensor properly reports an accurate reading to the user via HUD or the Display	Pass
ATMEGA 238P Serial Communication	The ATMEGA microcontroller can successfully communicate to our pi’s via serial communication	Pass
Temperature to ATMEGA 238P to Master Pi*	The dataflow from the temperature sensor to the ATMEGA microcontroller to the Raspberry Pi is successful in getting a reading	Pass
Reliability	The system must be able to run for 3 consecutive days, on 3 separate occasions	Pass

Software Testing Table (to be filled in when tested).

10.0 Administration

This section covers the carrying out of the organizational tasks needed for successful project completion. The financial report for the project, personnel directory, alongside scheduling information are found in the pages that follow.

10.1 Accounting

The financing for this project was carried out by the team members themselves without outside assistance. Payments were made by individual team members to suppliers. A group account was created and balanced with cash, PayPal, and Venmo being used to share payments between one another.

10.1.1 Budget Planned

Estimated Cost varied widely based upon desired functionality and manner of implementation. Current team budget is set at a max of $200 per team member ($800 total) with less being desired. The scope of this project idea has been left intentionally broad so as to be progressively narrowed based upon research into our ability to implement in time and within budget. Looking at a period of roughly Sept 30th 2020 to April 15th 2021 to work in research, design, construction, and testing this project idea must be cut down to something achievable within the time frame. Team members have discussed current work, school, and family responsibilities and are in agreement to the amount of time available for senior design.

So, for teams and meetings and budget we are trying to accommodate everyone time along with budget. So, for the budgeting each member has been ordering the parts they need or will test. Then for methods of payment we have been using PayPal or other electronic pay services. So far, we have been staying on track with the budget and components that we need. The team has also been highly responsive to keeping track of the money spent as seen down below in the budget table. The reason needing for us to keep a good track of the money spent is. Because we did not have any kind of sponsor or other outside help as far as money. So that has been even more of a reason we had to keep the project budget low and really keep track of budget. We had initially thought about reaching out to some sponsors. Some of the ones we thought about reaching out to was Ford, GM and, Jeep. We thought Jeep would be the best option. Due to the fact that the project is going to be on a Jeep. But one reason we were not to keen on reaching out to look for sponsorship was we did not want to have to be tied down to someone's requirements. We also did not want to have to have the extra hassle of having to set meeting with the people at the company. Or having to report to them every change that we made due to time and design constraints. This might interfere with peoples schedules because they have work and class and it might also be to big of a burden. So, them are some of the reasons we decided not to include a sponsor or anything like that into the project we felt it overall would be best not to have them extra issue. So, the project was decided to be self-funded.

Estimated Cost		
Item	**Quantity**	**Estimated cost**
IR sensors	7	$30
Temperature sensors	4	$20
Proximity Sensors	6	$54
Wire		$20
All PCB(s) built	4	$70
LCD screen	1	$0 Already have
Camera	4-5	$120-$150
Mounting material for sensors		$30
PCB Housings	8-10	$40
LED lights		$15
3D Printed HUD Housing	2-3	Provided by UCF
Power Distribution Supplies/Chips for DC/DC conversion		$80
Raspberry Pi(s)	3-5	$60-$100
Total:		$539-$609

10.1.2 Budget Actual

This section tabulates the cost of key system components. See the below table.

Table 19 Bill of Materials

Parts List				
Part	**Part Description**	**Quantity**	**Cost per unit**	**Total Cost**
MLX90614 3V-5V Manufacturer- Melexis	IR Temperature sensor non-contact Works with I2C	1	$15.95	$15.95
Bi-Directional Logic Level Converter	Convert 5v to 3.3	1	$2.95	$2.95
MB 1003 HRLV	Ultrasonic sensor	3	$37.95	$113.85
PT 1000 3 Wire	Temperature sensor	1	$14.95	$14.95
Max 31865 RTD PT 1000 Amplifier	Amplifier	1	$14.95	$14.95
Raspberry Pi	Manage Video Feeds	4	$35	$140
Fuse	Prevent over current	2	$12.99	$25.98
Low Voltage Cutoff	Prevent draining vehicle battery	1	$22.33	$22.33
12-15V DC to 7.5 V DC	PCB	1	$13.99	$13.99
12-15V DC to 5V DC Step Down Conversion	Provide Power to Microcontrollers	4	$2.99	$11.96
Reverse Polarity Protection Circuit	Prevent damage in the event battery is hooked up incorrectly, one way connectors	1	3.99	$3.99
Wire	Electrical connections able to handle up to 3 amps over a 15-foot run, 16 amps 1-foot run	2 ft 14 AWG 60 ft 16 AWG	X	$20
Wire Sheathing	Prevent wire damage	70 ft	X	$40
Connectors	Allow easy assembly and disassembly	24	X	$35
Video Display	SunFounder 7	1	$60	$60

Enclosures	House PCB/ Main Panel/ Cameras/ HUD	6	X	$80
PCB	Microcontroller Integration	5	X	$17.40
HUD Display	Image display for HUD	1	$16	$16
Lenses	For HUD imaging	2	$30	$60

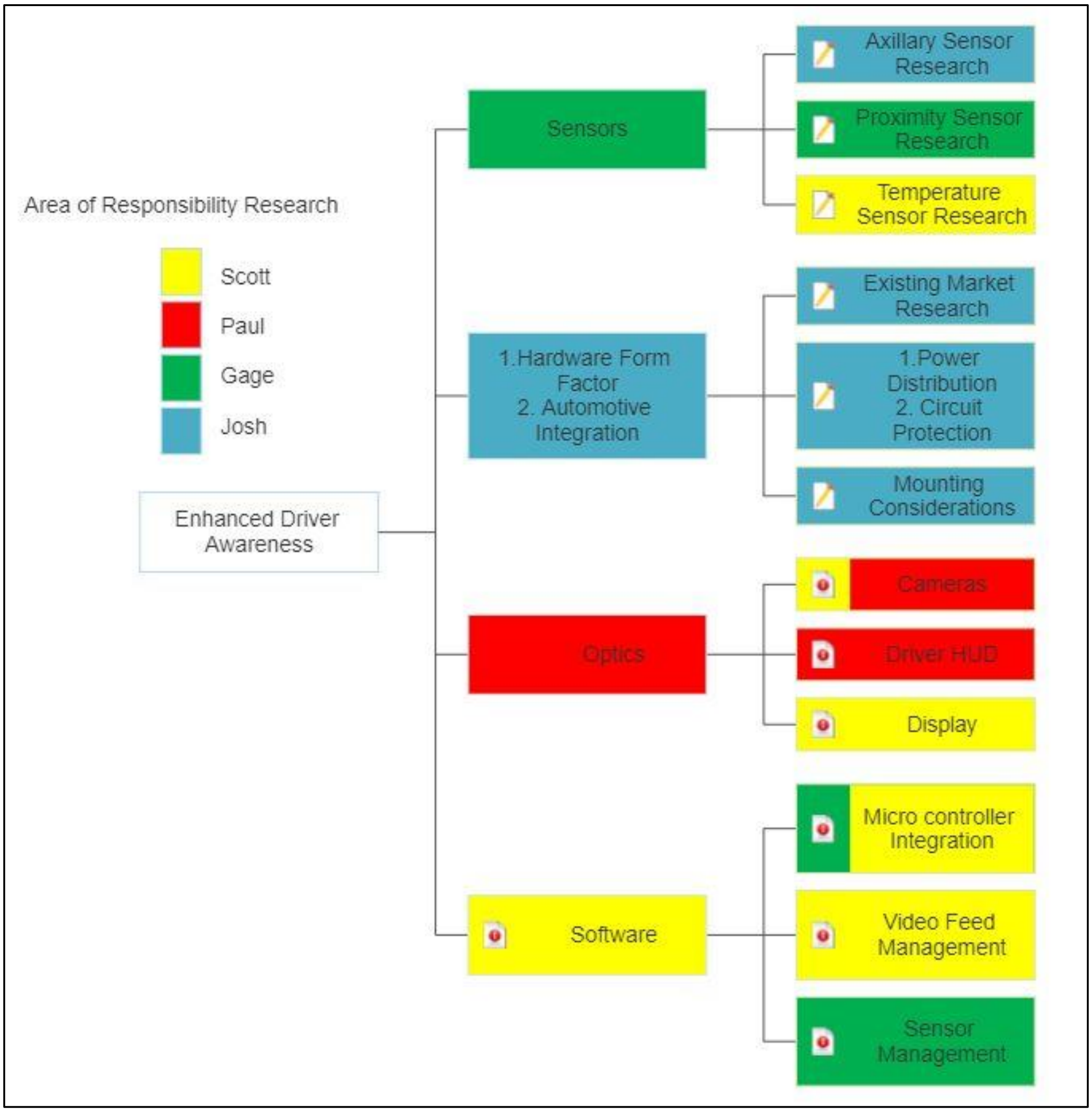
10.2 Scheduling

The team set-up a regular schedule of meetings that was adjusted as needed. After work in the evenings on Thursdays, during class time on Tuesday mornings, and quick decision-making meetings occurred as the need arose. The demand changed throughout the semester, yet work was paced so as to be able to meet deadlines without excessive work in the days right before deadline. Discord was the primary meeting place with zoom being used as a back-up and official meeting space.

Timetable	
Milestone	**Week**
Submit Divide and Conquer	0
Decide on a Project	1
Start Designing process	1-5
Order parts	7
Assembly for development board test	8
Test on development board/debug	8
Work on schematic for PCB	7
Schematic ready for PCB	9
Send out for PCB	9
Senior Design 2 Starts	
Test PCB	1
Plan for a resend out for PCB	2
Start Assembly	4-7
Finish prototype and Start Debugging	7
Testing final design	7-11
Presentation	12

10.3 Areas of Responsibility

The project workload was divided amongst individual interest and talents. The primary team member for each area of development is the main color in the table below. Secondary team members are visible as a lesser color patch in the map. Work was also divided for the feature sets where each individual has the most experience/knowledge. We made the back up for each section in areas each member would like to gain more knowledge in. Or in places where they had some knowledge already to that could supplement the other person knowledge who was the primary for that section. For incorporating our display inside the cabin and navigating the software we have Scott Jokela since his interests and studies lie along Computer Engineering. For incorporating sensor technology into our system that will communicate with our HUD and display we have Gage Libby since his interests are focused on sensor studies and Electrical Engineering. Researching and developing our HUD system we have Paul Ramos, who is our Photonics and Optical Engineering major with experience in lens design. Incorporating our overall system design and integration we have Josh Weed, our electrical engineer with high experience with incorporating tech into automobiles even before this project began.



10.4. Biographies

Gage Libby

Gage Libby attends University of Central Florida in Orlando, Florida. He is currently pursuing a bachelor's degree in Electrical Engineering in the Power and Renewable Energy Track. Gage was Originally born and raised on the West coast of Florida. Went to high school in South West Florida and graduated in 2013. This is where he gained an interest in the energy field in high school. They offered a class on renewable energy and the study of different ways renewable energy is used and generated. Then joined the army in 2013. After the army in 2015 Gage enrolled in community college at Florida South Western. Then in the fall of 2017 he moved to Orlando Florida and enrolled in the Electrical Engineering program at UCF. He is due to graduate in the spring of 2021. With desire to work in the power industry working either in the design aspect or as a field engineer.

Josh Weed

Joshua Weed attends the main Orlando campus at the University of Central Florida. He is on track to graduate May of 2021 with a bachelor's degree in Electrical Engineering on the comprehensive track. A long time 4x4 enthusiast, this project provided an outlet for combining personal interest and academic requirements. This project provided an application for concepts learned during the course of his time at UCF. His exposure to vehicles began when working general automotive repair at ABC Automotive in Niceville Florida followed by vehicle modification at Restylers in Fort Walton Beach Florida during high school. At UCF from Fall of 2015 to December of 2017 Josh was a member of the Society of Automotive engineers Baja team. Working with this group of engineering students paved the way for the job at Oshkosh Defense from January to August 2018 in Oshkosh Wisconsin. At Oshkosh Josh was rotated amongst various stages of testing, development, and production for the Joint Light Tactical Vehicle (JLTV) that is replacing the Humvee for the US and some Coalition armed forces. Returning to full time studies in Fall of 2018, Josh managed to take five classes with Dr. Chan and still remain at the university. The desire for working with ground vehicles has remained and is the primary search sector for post graduate employment.

Paul Ramos

Paul Ramos is on track to graduate from the University of Central Florida with a B.S in Photonic engineering from CREOL in 2021. Having lived his whole life in Orlando and graduated high school with an IB (International Baccalaureate) diploma he was highly motivated to choose a major that would satisfy his ambitions to work in a field that has the potential to change millions of lives. The motivation behind this project started when his passion for cars was introduced when he was 15 years old. Since then, he has worked on many car related projects and has learned many new skills along the way. With the goal of creating a product that involved optics and photonics and his passion for cars it was an easy decision to decide to join this group due to their similar passion for vehicles.

Scott Jokela

Scott Jokela attends the University of Central Florida and is on track to graduate in the Spring of 2021 with a BS in Computer Engineering following UCF's comprehensive track. He currently pursues and actively engages in topics of computer architecture and computer vision focusing on hardware-based acceleration from GPU's and other accelerators, with a focus on Nvidia's offerings. Scott originally attended Valencia College before transferring through direct connect to UCF. Interestingly he was not always a Computer Engineering Major, as he originally focused on Computer Science for his first year and a half of schooling. After looking deeper, he found more opportunities that focused on his interests in the Engineering field rather than the Computer Science field. He does enjoy occasional programming but finds it much more interesting to view and dissect what happens inside microprocessors and their data path. Like Josh, Scott did manage to take Dr. Chan during his first semester at UCF, this however did not go in his favor and discouraged him at first before bouncing back with a more manageable schedule. Scott throughout all of college has worked a full-time job and somehow still managed to graduate in 5 years. This project attracted him due to the fact it incorporated some key fundamentals of high-end self-driving cars, some of which are used by large tech giants like Nvidia and Tesla, the leaders in the field of self-driving hardware and software.

11.0 Project Summary

In summary, the Enhanced Driver Awareness and Detection System (E.D.A.D.S.) set out to provide data to the driver of the vehicle in order to enable better information for decision making. The project is designed to provide a proof of concept for future development. The steps outlined within this report give the guidelines and plans for action to be taken during Senior Design Two semester to realize this prototype. The plan will be to deliver a working proof of concept that is well documented so that the idea can be built upon in the future.

Our system has chosen to showcase three elements of what could be a larger vehicle information system. They were chosen based upon priority to the driver and the constraints our team was operating under. Cameras, proximity sensors, temperature sensors, and an ergonomic manner in which to share the collected information with the driver were selected for this prototype.

The cameras are mounted around the vehicle focusing on the most vulnerable and needed regions for traversing obstacles. The feeds are collected and sent to a central hub for processing and display. The central in cabin hub consists of the hardware needed to process and display the data on our chosen display as well as provide needed warnings via our heads up display. A heads up display specifically designed for the dimensions and space available in a Jeep JKU cockpit was engineered by the optics and photonics team.

Due to budgetary constraints the ideal proximity sensors were not feasible. As a result, a proof-of-concept approach was adopted in order to provide needed input to the heads up display and standard display to enable a working prototype. The proximity sensors were utilized in the rear of the vehicle in order to assist in object detection and avoidance when reversing.

The temperature sensors included in this project are designed to act as a showcase for the potential of adding sensors to aid in diagnostic, trouble shooting, and data collection for research purposes. Though not a full complement of needed sensors the ones chosen best fit within our constraints and needed priorities.

Due to the comprehensive nature of the ideal system the prototype acting as a proof of the concept was designed in a similar manner. The resulted in the decision to provide a vehicle specific hard mounted solution. This allowed for optimization to the vehicle. The vehicle power supply was to be used for the project and necessary steps were taken to prevent interference with the factory electrical, sensor, and safety systems. Leaving the driver in control was the desired course of action as opposed to automation of the task. This project stayed true to that goal by enabling data driven decisions by the driver and not making those decisions for the driver.

11.1 Conclusion

As a team we learned more about engineering practice and ourselves over the course of this project. The challenge of designing components that must interface with others that are yet to finalized is difficult. Multiple people working on separate tasks that must come together at the end requires organization and communication. The current pandemic happening in the United States also proves to be a large challenge when trying to design a complex system with many pieces in which each are focused on development by 1 or 2 people before coming together. This will also prove to be a challenge when Senior Design 2 comes around and we need to physically build our prototype for testing and production. Meeting virtually will not satisfy these constraints so we will see how we can incorporate design production while also remaining safe from the current pandemic of COVID-19. When working on a vehicle space is limited and as a result integrating components can be a challenge.

The contrast between desired and actual outcomes were stark for this project. It was a strong lesson in engineering constraints and the way they shape a project. Many changes were made along the way as we did more research and development of our system. These changes were both positive and negative as we were able to learn more about systems to integrate and other ways we could incorporate such systems into other products. Our system has been planned to enable construction during the second semester. With proper timing and scheduling with deadlines/goals we were able to create a fully functioning protype by the end of the Spring 2021 semester.

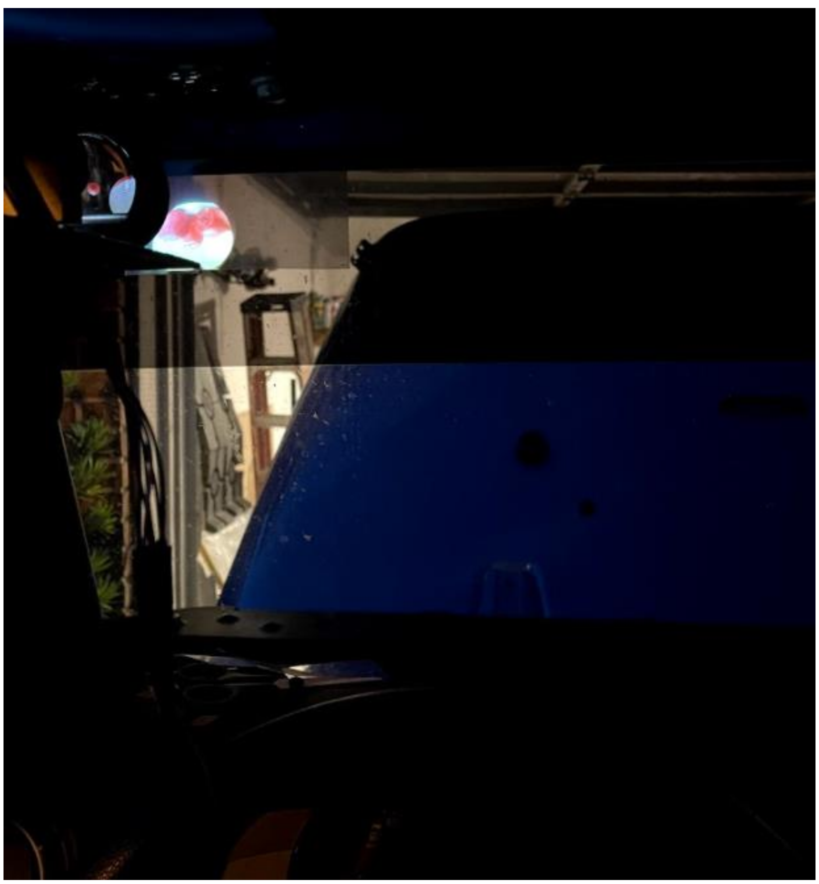
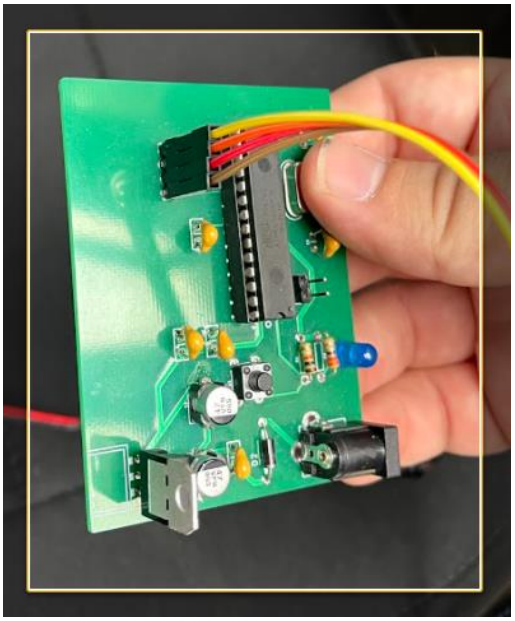


Figure 64 HUD Projection



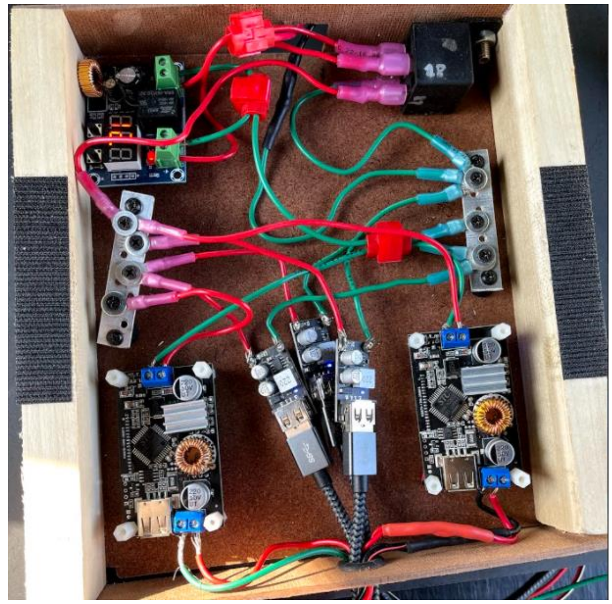


Figure 65 Power Distribution

Figure 66 PCB

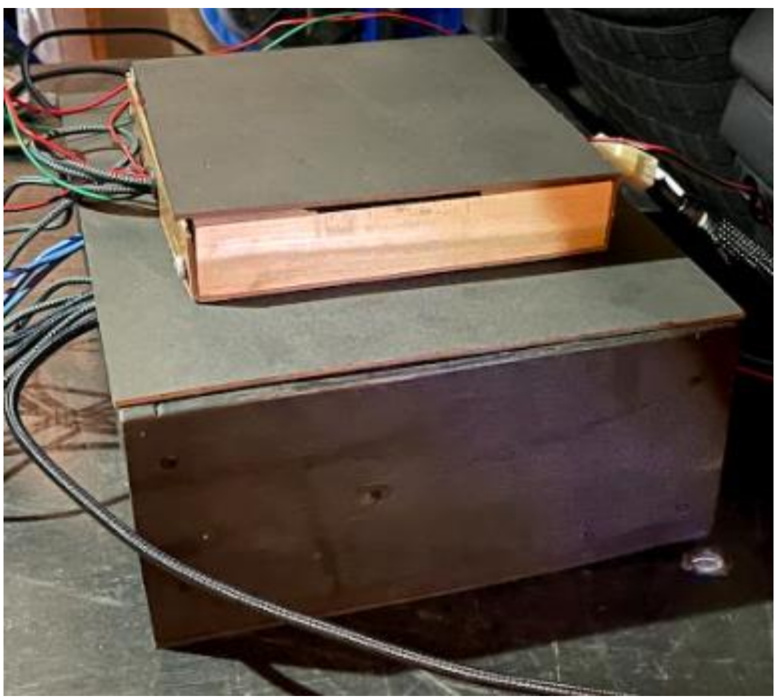


Figure 67 Main HUB

Figure 69 Final Display

Figure 68 Forward Cameras

Figure 70 Late night in Garage

12.0 Appendices

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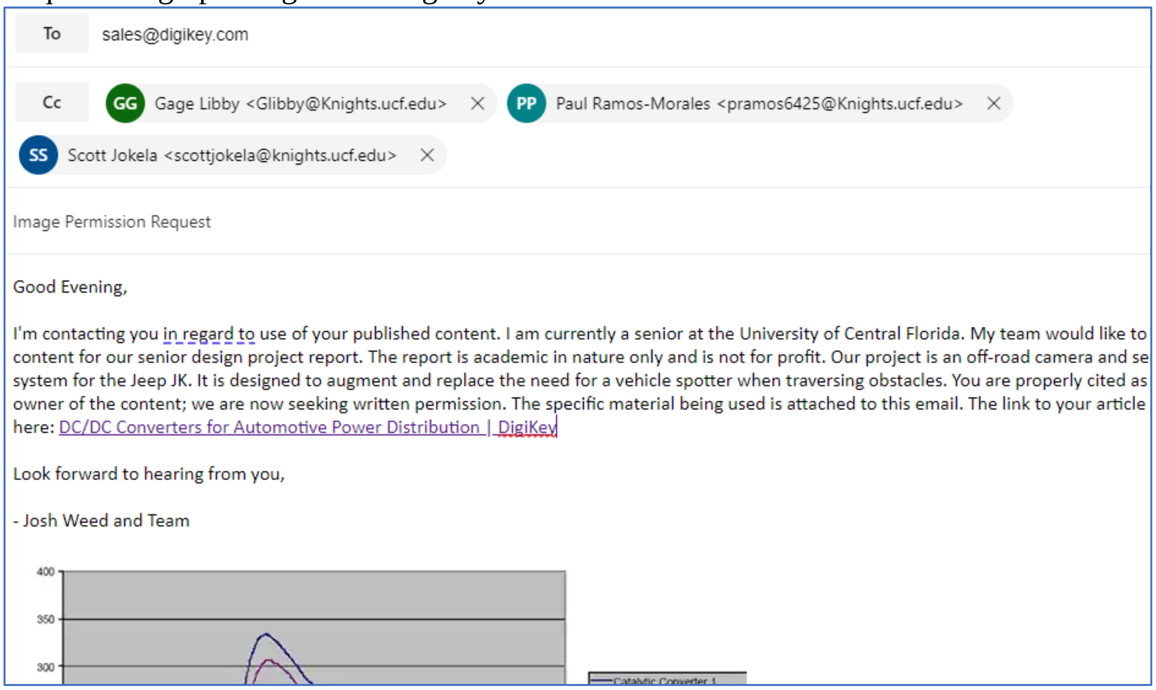
12.2 Permissions Requests

In this section requests for use of copyrighted or protected material are included. Many were sent and not responded to by time of publishing.

Request for graph usage from Digikey North America Editor author Bill Schweber.



To sales@digikey.com

Cc Gage Libby <Glibby@Knights.ucf.edu> Paul Ramos-Morales <pramos6425@Knights.ucf.edu> Scott Jokela <scottjokela@knights.ucf.edu>

Image Permission Request

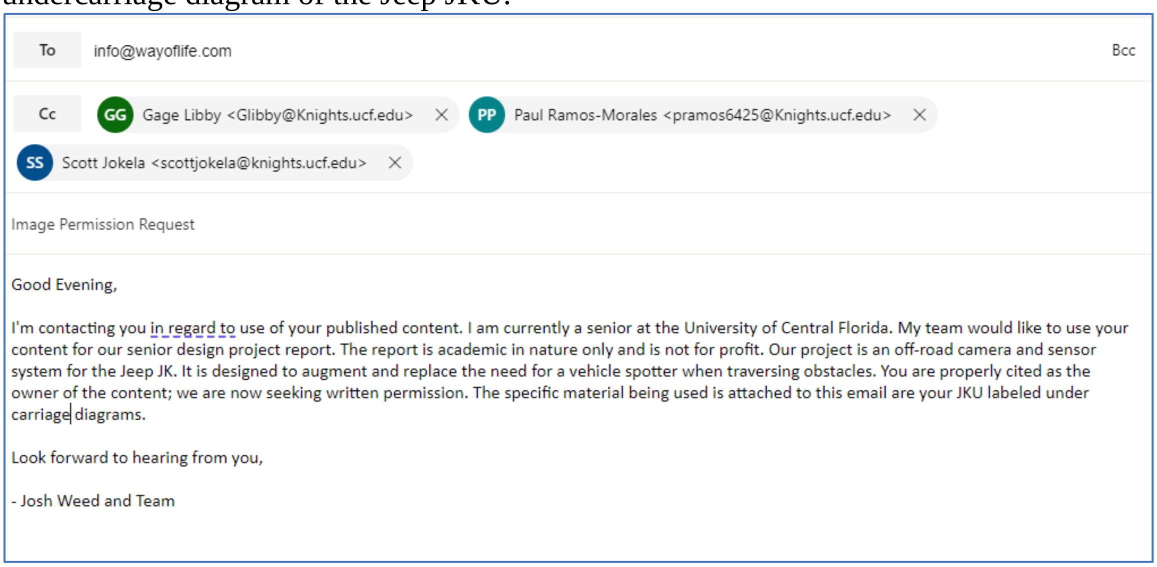
Good Evening,

I'm contacting you in regard to use of your published content. I am currently a senior at the University of Central Florida. My team would like to content for our senior design project report. The report is academic in nature only and is not for profit. Our project is an off-road camera and se system for the Jeep JK. It is designed to augment and replace the need for a vehicle spotter when traversing obstacles. You are properly cited as owner of the content; we are now seeking written permission. The specific material being used is attached to this email. The link to your article here: DC/DC Converters for Automotive Power Distribution | DigiKey

Look forward to hearing from you,

- Josh Weed and Team

The request for use of forum Way of Life content that was the labeled suspension and undercarriage diagram of the Jeep JKU.



To info@wayoflife.com Bcc

Cc Gage Libby <Glibby@Knights.ucf.edu> Paul Ramos-Morales <pramos6425@Knights.ucf.edu> Scott Jokela <scottjokela@knights.ucf.edu>

Image Permission Request

Good Evening,

I'm contacting you in regard to use of your published content. I am currently a senior at the University of Central Florida. My team would like to use your content for our senior design project report. The report is academic in nature only and is not for profit. Our project is an off-road camera and sensor system for the Jeep JK. It is designed to augment and replace the need for a vehicle spotter when traversing obstacles. You are properly cited as the owner of the content; we are now seeking written permission. The specific material being used is attached to this email are your JKU labeled under carriage diagrams.

Look forward to hearing from you,

- Josh Weed and Team

The following request is for use of the cover page photo of the report from a Car and Driver magazine article. This was used to illustrate the purpose of our project. The contact is Rich Panciocco at Car and Driver.

To: CDRTAccolades@HearstAutos.com

Bcc

Cc: Gage Libby <Glibby@Knights.ucf.edu>; Paul Ramos-Morales <pramos6425@Knights.ucf.edu>; Scott Jokela <scottjokela@knights.ucf.edu>

Image Permission Request

Good Evening,

I'm contacting you in regard to use of your published content. I am currently a senior at the University of Central Florida. My team would like to use your content for our senior design project report. The report is academic in nature only and is not for profit. Our project is an off-road camera and sensor system for the Jeep JK. It is designed to augment and replace the need for a vehicle spotter when traversing obstacles. You are properly cited as the owner of the content; we are now seeking written permission. The specific material being used is attached to this email. Writer Ezra Dyer's article The Wide World of Off-Roading (caranddriver.com)cover page image.

Look forward to hearing from you,

- Josh Weed and Team