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1963

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1. Introduction / Narrative

Many times, we as humans lose focus of the task we are working on. It may be doing homework, getting groceries, running errands, or even working on work that pays our quality of life. One of the biggest distractions in this day and age is located directly in our pockets, the smart phone. Anywhere you look people are texting, calling or playing angry birds while walking to class, waiting for their doctor's appointment or even driving. And this brings us to the motivation behind safe sight, in which we are aiming to reduce human distraction with completing tasks to make the roads safer for everyday commute.

1.1 Project Background

Humans are unquestionably the smartest beings on the planet. From the dawn of time there have been nonstop innovations stemming from fire to the world around us today. However, with such innovation stem new challenges to overcome. Technological advancements have come to aid humanity to live a more efficient life and spark innovation. In recent decades, one particular invention came to fruition, the SmartPhone. The SmartPhone has made communication via the internet possible with the combination of the cell phone which came decades prior. Being such a monumental piece of technology, we as a species have become reliant on them, looking at notifications for communication or browsing the internet for necessary information all at our fingertips. With such amazing technology came one of our biggest flaws, distractions. As consumers of smartphones, we are all susceptible to having our attention diverted by applications designed for our amusement and to focus on areas of non-importance. Such distractions that stemmed from the smartphone are social media, messages and games. These distractions get in the way of everyday life as we know it, continuing to shorten the attention span of the average consumer. Whether it be in a classroom, at work, cooking dinner or even waiting at the doctor's office, the smartphone and its captivating applications have infiltrated our daily lives at a grand scale. One daily task that it has invaded is commuting.

One of the biggest hassles people face on a day to day basis, often even multiple times a day, is commuting in their vehicle. In this day and age a normal traffic stop at a red light makes the general population believe there is enough time to catch up with their friends and family on popular social media apps like Instagram and Facebook. As quickly as they may perceive their phone usage at the red light, drivers often feel in a state of comfort when driving, oftentimes not remembering specific events on the road and just recalling arriving at their destination. This state of comfort leads directly to a lack of importance perceived from the driver and then in turn the brain looks for its favorite source of dopamine: the smartphone and the endless applications it holds.

After spending some time in traffic and looking around at the other drivers at a stop, nearly all drivers are tinkering on their cell phone whether it's changing a song, sending a text or responding to an email. When the world's drivers are constantly distracted from the traffic around them, this directly leads to a higher cause of accidents between vehicles and a higher danger to pedestrians. The goal with this product is to reestablish attention and bring awareness back to safety on the roads. Alongside, big automobile manufacturers have made efforts to keep the driver engaged while on the road in latest models. Many of the automotive companies like Hyundai and Tesla for example are implementing new sensors in their cars to encourage drivers to drive as intended rather than cause unnecessary delays. Many of these sensors include forward collision warnings, lane departure warnings, lane centuring assistance, and adaptive cruise control. Even though these technologies are made for aiding in the safety of the roads, they do not address the lack of attention that is growing in our society.

What if there were a compact device, no larger than a standard transponder, designed specifically to help drivers maintain focus on the road? Hence, came the idea of SafeSight, a device that is able to track traffic light changes, when the car in front of you is leaving, and take photo documentation of a trip so that drivers can realize how distracted they can be when commuting.

1.2 Project Motivation / Current Commercial Technologies

The motivation of SafeSight is to develop a device that brings the attention of the driver back to the roads, aids lack of response times, and helps ensure safety on the roads for commuters. SafeSight is a tool that leverages the advancements of modern technology and combines the existing technology in a matter to bring the integrity and efficiency of the roads back to a higher level than that of the time prior to smartphones.

For SafeSight to truly live up to the ambition we have for it, the team has come together to develop it in a way that allows for ease of access and compatibility with modern technologies. For instance we have limited the size of this device to be the size of a transponder that many individuals already carry in their vehicle for toll purposes. The technology in the device is also compatible with applications to store data from a commute to a user’s profile in order to encourage better driving practices whenever the user returns on the road. According to a recent study, 3,047 fatal crashes were caused by distractions. This number alone accounts for 8% of all fatal crashes in the United States. In addition to these fatalities, there were a total of 362,415 people injured from distracted drivers. Now, not all of these distractions are caused by smartphones, but rather a vast majority of them are. For this project to really be effective, the device would combat any distraction, alerting the driver and reducing the number of fatalities we see from such a preventable occurrence.

As we mentioned earlier, there are some technologies that do in fact help ensure safety but they do not attack the distractions. Moreover, these technologies are only installed into vehicles as of late, leaving nearly a century of automotive engineering without safety features. Our goal is for this device to be able to be implemented on every single vehicle, offering a much more intuitive and updated experience for every make and model on the road today. SafeSight will make the commuting process much more efficient and in turn reduce accidents, commute times, and unexpected obstacles from distracted drivers.

1.3 Project Function

SafeSight will utilize computer vision to classify and make connections between the driver and their attention towards the road. Cameras will continuously monitor the driver and outside traffic signals to then alarm the driver if they are not paying attention to the road. For example, a driver is caught at an intersection waiting for the traffic signal to switch to green. They suffer from a short attention span and resort to their mobile device to pass the duration of the red light. This distraction prevents them from properly reacting to the traffic signal switching to green, causing unnecessary delays and inefficient flow of traffic. These attention infractions made by the user of the vehicle will be acted upon by a sound alarm and recorded by the Safe Sight device. Safe Sight, in a manner, will make its user’s driving more efficient by increasing response time, reducing error when driving, and maintaining alertness to surroundings. SafeSight will actively track the user’s performance on the road by documenting how many times the user committed an attention infraction. The device will communicate with the user by projecting an audio signal outside of a speaker connecting to the PCB. This audio signal will serve as a sensory reminder to get off the phone or divert attention back to the road. Additionally, the computer vision will be trained to classify if the driver in the vehicle is looking down while the vehicle is in motion, where the device can then register and act upon an attention infraction. Our team must design a system that is both lightweight and compact in order for the device to function as anticipated, but also there comes the hardware necessary to make these ambitions come true.

2. Project Objectives, Requirements, and Goals

SafeSight is a smart in-vehicle monitoring system designed to bring safety and accountability back to the road by addressing one of the most dangerous habits behind the wheel—phone usage while driving. The primary function of SafeSight is to detect when a driver is actively using their phone and immediately alert them with an audible beep, encouraging them to stay focused on the road. Beyond just reacting to phone distractions, SafeSight aims to support drivers by monitoring behavior over time, providing performance feedback, and promoting responsible habits. By reinforcing driver awareness and reducing distractions, SafeSight contributes to safer roads, fewer accidents, and more efficient traffic flow.

2.1 Project Objectives

SafeSight will encompass a system that brings back driver integrity and safety to the traffic environment as a whole. With this comes an increase in efficiency from the traffic system as well, leading to reduced commute times with reductions in accidents and injuries caused on the roads. When a commute begins, the system should be started and acquire traffic data to give a numerical representation of a driver. From every traffic stop, lane merger, and cruising scenario, the SafeSight system will constantly provide feedback to keep the driver alert. This same system should also detect changes in a driver's performance, for example if a driver is appearing to swerve between lane lines, then the device will suggest taking a break due to restless sleeping habits. If the driver is taking longer than usual to respond to changes in a traffic light , the device will notify the driver to focus their attention back on the road. These behaviors can be recognized by the SafeSight system in order to properly assess the reason for the driver's lack of performance.

SafeSight should encompass a system that captures the current state of a driver and multiple sample points during a journey. This system will then process the world around the host vehicle and the data collected from the driver's performance to assess recommendations (if any) to the driver on how to be more safe and efficient on the roads. The system in itself should be able to detect pedestrians, change in traffic light patterns, stop signs, movement from the host vehicle, and distances from cars ahead with the help of computer vision algorithms. These algorithms will be tested through the hardware of the Raspberry Pi and the tests will be deemed successful if it efficiently identifies the change in traffic light colors where red = stop and green = go. The system should also correctly sound the auditory signal when the driver is idle for a longer than anticipated reaction time to a vehicle moving ahead of it. SafeSight should also be able to identify pedestrians crossing and offer a signal that the driver must come to a stop, this scenario is also expected at a stop sign.

SafeSight should encompass a system that knows when the driver should be ready to progress their journey or not. This will require for the system to be able to detect movement in the vehicle, notify the driver for longer than anticipated stop times.

All of the components of SafeSight should be modular, meaning that each component should have the ability to be individually tested prior to being integrated to the entire system. The components of SafeSight should be able to be assembled and should *not* be able to be disassembled quickly, as it needs to adhere to conditions of a moving vehicle and portable. The entire system should be able to fit on the windshield of a vehicle without obstructing the driver's view.

SafeSight is currently a self-funded project, and with that comes the ambition to make sure it is cost effective for someone to replicate themselves if another engineer found interest in doing so. For the lack of sponsorship, the team has an aim to make this device for under $300, so that each member does not contribute more than $100. In the scenario where significant changes are needed, the budget shall be adjusted accordingly.

2.2 Goals

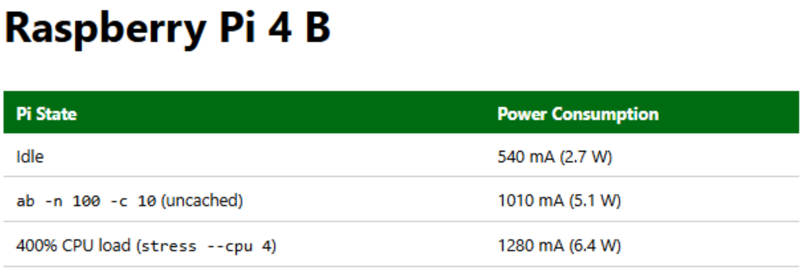
- SafeSight Goals:
  - Basic
    - Maintain drivers attention to the road at all times while the vehicle is in motion by setting off an alarm if the driver deviates their attention from the road. CV will be trained to classify if a driver is looking at the road or looking down (at their phone).
    - Analyze common traffic lights and alert the driver if they are not following them properly. Train CV to classify, depict the contours, and differentiate colors of common traffic lights.
    - Establish connectivity with all components of the final product: PCB and cameras.
    - Train CV and analyze/stream video at 15-30 frames per second
    - Using an established UART connection with the raspberry pi. Receive inputs from the computer vision indicating attention infractions and send an output signal to a speaker connected to the PCB board to alarm the driver.
    - Read register values from the inertial sensor to dictate whether the car is in motion or at a stop.
  - Advanced
    - Develop an application that will pair with the device to pull driver data that is collected along trips. For example, an application on a user's phone will keep a tally and download pictures of attention infractions that the user makes.
    - Take pictures using the cameras and stream video to the application for it to be accessed by the user.
    - Implement interrupt service routines to have the MCU operate in a low-power mode to conserve energy. MCU will be interrupted by an attention infraction and then alarm the driver of the vehicle by outputting an alarm signal to a speaker.
  - Stretch
    - Create a pre-collision alarm for the driver to notify them of imminent danger on the roadway. Utilize CV in a fast paced environment to depict the speed of incoming objects relative to the vehicle. Then, make a decision to alert the driver to react if they have not been responsive to their surroundings.

2.3 Requirement Specifications and Constraints

The previous sections in this report have described the ambitions and concepts encompassing SafeSight. In order to bring these ambitions into fruition, there are a certain amount of required specifications we must adhere to both hardware and software based. These requirements are what the SafeSight team believes are necessary to bring the project to its fullest potential. Let these requirements serve as a meeting ground for the members of this team and the advisors to all understand the goals and aspirations for what this project will be able to accomplish.

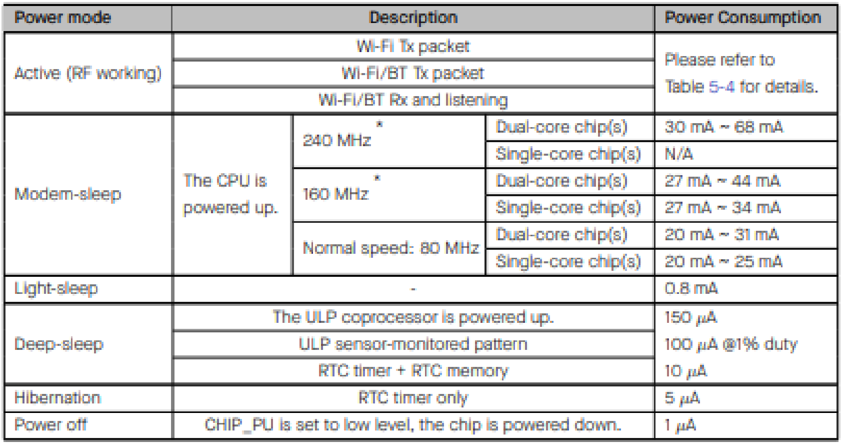
Initially, the first constraint that comes to mind with a compact mounted design is power. How will we power a raspberry pi computer and MCU executing real-time processing tasks including computer vision? Well, first we need to calculate roughly how much power in watts per hour will our execution of safesight require. Below are the average power requirements for the raspberry pi and ESP32 running at various demands.

ESP-32 MCU



Raspberry Pi 4 B

Pi State	Power Consumption
Idle	540 mA (2.7 W)
`ab -n 100 -c 10` (uncached)	1010 mA (5.1 W)
400% CPU load (`stress --cpu 4`)	1280 mA (6.4 W)



Power mode	Description			Power Consumption
Active (RF working)	Wi-Fi Tx packet			Please refer to Table 5-4 for details.
	Wi-Fi/BT Tx packet			
	Wi-Fi/BT Rx and listening			
Modem-sleep	The CPU is powered up.	240 MHz *	Dual-core chip(s)	30 mA ~ 68 mA
			Single-core chip(s)	N/A
		160 MHz *	Dual-core chip(s)	27 mA ~ 44 mA
			Single-core chip(s)	27 mA ~ 34 mA
		Normal speed: 80 MHz	Dual-core chip(s)	20 mA ~ 31 mA
			Single-core chip(s)	20 mA ~ 25 mA
Light-sleep	-			0.8 mA
Deep-sleep	The ULP coprocessor is powered up.			150 µA
	ULP sensor-monitored pattern			100 µA @1% duty
	RTC timer + RTC memory			10 µA
Hibernation	RTC timer only			5 µA
Power off	CHIP_PU is set to low level, the chip is powered down.			1 µA

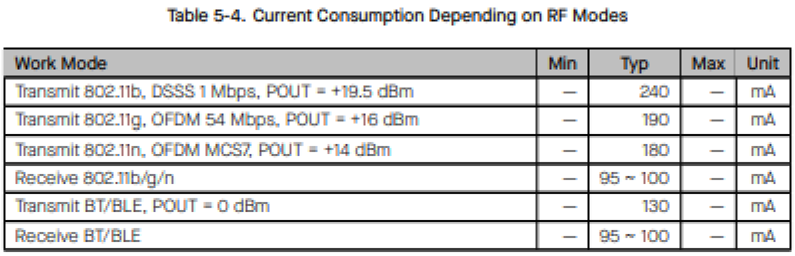


Table 5-4. Current Consumption Depending on RF Modes

Work Mode	Min	Typ	Max	Unit
Transmit 802.11b, DSSS 1 Mbps, POUT = +19.5 dBm	—	240	—	mA
Transmit 802.11g, OFDM 54 Mbps, POUT = +16 dBm	—	190	—	mA
Transmit 802.11n, OFDM MCS7, POUT = +14 dBm	—	180	—	mA
Receive 802.11b/g/n	—	95 ~ 100	—	mA
Transmit BT/BLE, POUT = 0 dBm	—	130	—	mA
Receive BT/BLE	—	95 ~ 100	—	mA

We need to choose the values that assume we are running every component in its most energy demanding mode so that when we choose our power source, all processes will be properly powered to assure performance of all components. Using the formulas below we can calculate our most demanding average power in watts per hour.

$$Average\ Power\ Consumption(Watts\ Per\ Hour)\ =\ V(Voltage)\ *\ I(Current\ in\ mAh)$$

$$Total\ Power\ Supply\ (Watts)/\ Average\ Power\ Consumption\ (Watts\ per\ Hour)\ =\ Operational\ Hours$$

The values chosen for our raspberry pi will be 5V and 1280mA, demanding 6.4 watts per hour. Additionally, our ESP-32 will demand 3.3V and 240mA which makes about 0.8 watts per hour. Finally, we can calculate our average power consumption and operational hours. If Battery powered, we will assume a 5V 10000mAh battery.

Total Power Supply = 5*10 = 50 Watts **Average Power Consumption** = 7.2 Watts/Hour
Operational Hours = 50/7.2 = 7 Hours

Now that we have documentation on the requirements and performance of powering our product, we can conclude that a battery powered method of power delivery will not provide convenient usage of the product for the user due to frequent recharges needed from driving, roughly every 7 hours. However, our solution to this is to use the 12V charger port in the vehicle with a voltage converter circuit to properly power the device with no worry of any recharge.The wired design will drop our product in size and weight. Furthermore, Most car charger ports run 12V with a 10A fuse which provides 120 Watts of power! This is more than enough power that our device needs and will be the power source tapped into by our Safe Sight product.

2.4 Engineering Specifications

Specifications for each of the project’s subsystems are listed below:

Model Specifications:
- The device cannot be bigger than 8.5 inches x 7 inches to abide by federal highway safety regulations
- Should weigh less than 900 grams

MCU Specifications:
- Should power on the rest of the system when the 12V source is connected to the device
- Amplifies the excitatory signal from the raspberry pi and inertial sensor to the pcb speaker’s requirement of 50-100mV RMS.
- Properly transmits the excitatory signals from both the CV (raspberry pi) and the sensor around the rest of the system with the base UART rate of 5 Mbps.
- Maintains a connection to the user’s device that is housing the software via bluetooth from 1.5KB/s to 10KB/s.

RaspberryPi Specifications:
- Properly utilizes the CV algorithms to identify traffic distances and changes at a processing power of 2.4GHz.

- Captures and stores the instances when a driver is distracted via Image Signal Processor and transmits the data to the mcu.
- Executes the two cameras on their respective CV algorithms with no computational overlap with dual 4k display output.

CV Algorithm:

- Identifies the change in traffic conditions such as a moving vehicle, distance, and light changes.
    - Color detection through color thresholding
    - Distance calculation from size change analysis
- Facial recognition to detect when the driver is not looking straight ahead at the road, OpenCV.

Inertial Sensor Specification:

- Detect when the host vehicle has reached a net velocity of 0.
- Detects when the host vehicle has begun movement, immediately signaling the end of an excitatory signal to the MCU when inertia >0.

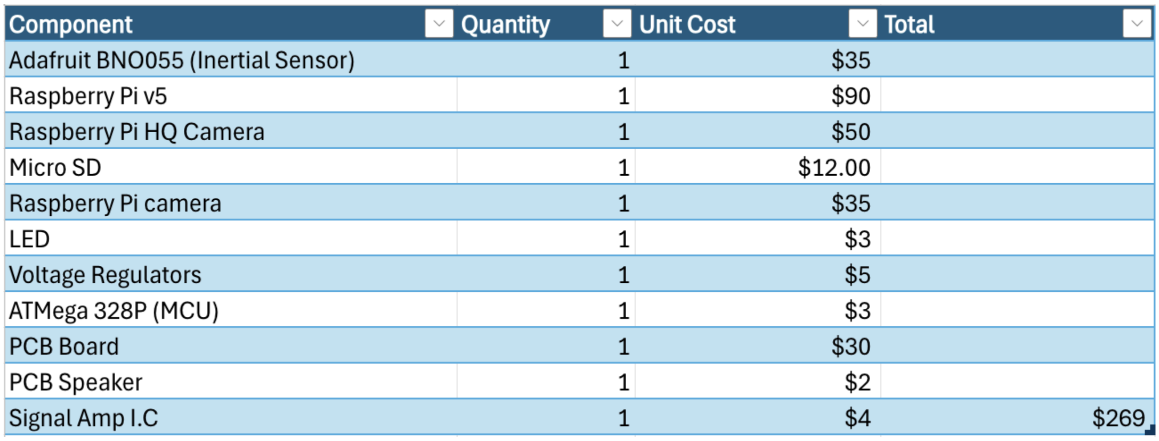
Software Specifications:

- Should be able to power on immediately when plugged into the 12V source.

Table 2.4.1 Hardware Component Specifications

Component(s)	**Parameter**	**Specification**
Application	Distraction tracking / Live camera feed	Tracks number of distractions and shows live camera feeds
Cameras, raspberry Pi, sensors	Car, light and motion detection	CV algorithms for color thresholding, size change analysis, and face orientation recognition.
Mini adafruit speaker	Beep sound/Action Delay	102dB +/- 3dB , 600 Hz to 10kHz
Power	Cigarette lighter adapter	12V
Led	To show what light is being detected	1-2 Lumens
Microcontroller ESP 32	Performs calculations and communicates with Pi. Transmits data to the application host device.	Data transfer >= 5Mbs
IC (integrated circuit)	Non-inverting Operational Amplifier to perform message signal amplification.	Gain of range from 50-100mV

Table 2.4.2 *Tentative* **Bill of Materials**



Component	Quantity	Unit Cost	Total
Adafruit BNO055 (Inertial Sensor)	1	$35	
Raspberry Pi v5	1	$90	
Raspberry Pi HQ Camera	1	$50	
Micro SD	1	$12.00	
Raspberry Pi camera	1	$35	
LED	1	$3	
Voltage Regulators	1	$5	
ATMega 328P (MCU)	1	$3	
PCB Board	1	$30	
PCB Speaker	1	$2	
Signal Amp I.C	1	$4	$269

2.5 System Diagram and Visualization

In an effort to bring our ideas to fruition we have drafted a visual representation of both the hardware and software of the system as a whole. These diagrams highlight not only the flow of our system but also references the engineers who are taking responsibility for overseeing the specific components in the system. All of the engineers who are working on Safesight will make equal contributions on all systems and their subsystems, however in an effort to diversify the workload and abide by the constraint of time, assignments to specific areas were made.

Table 2.5.1 Software Block Diagram

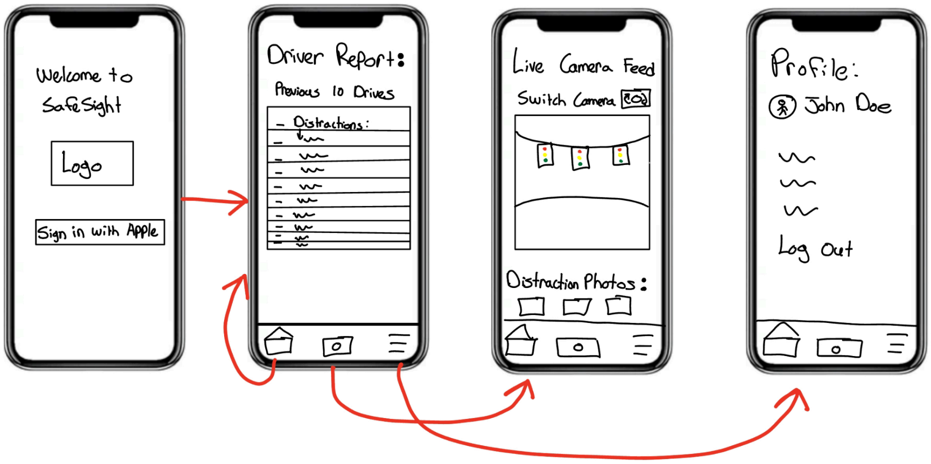
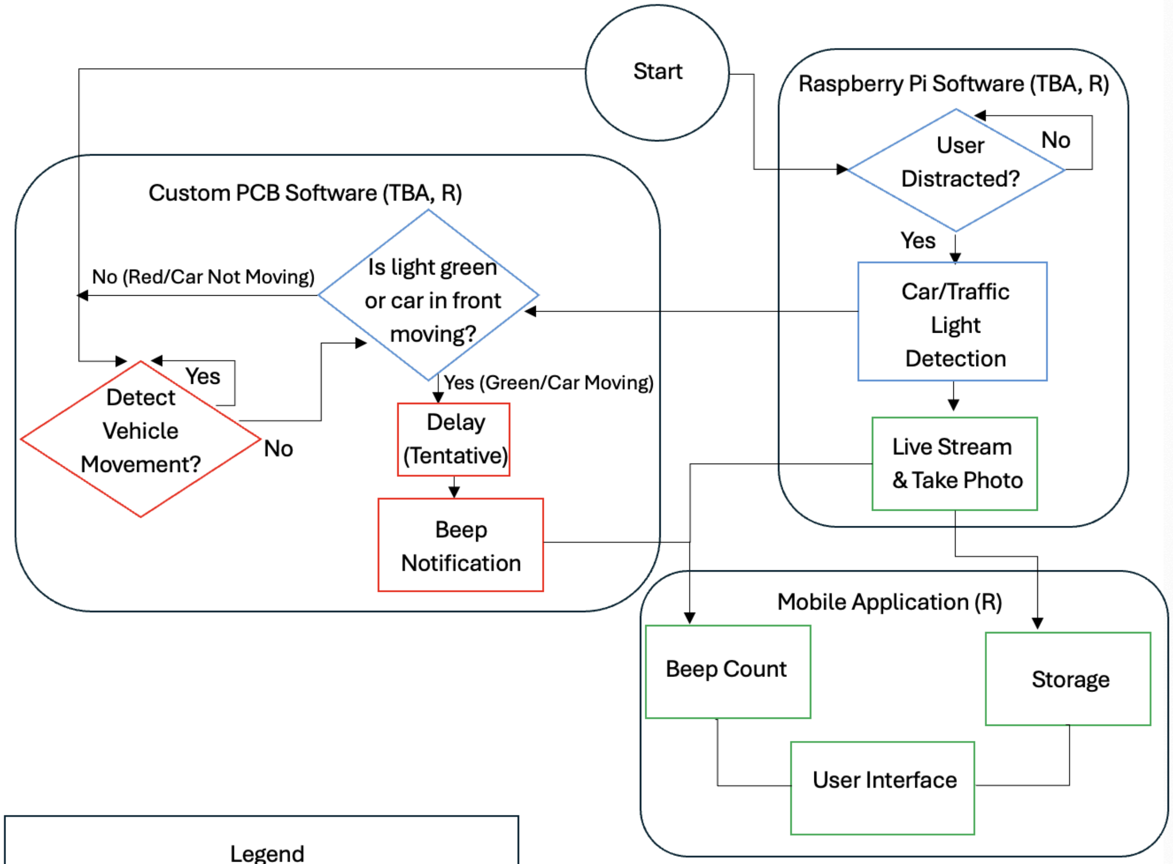


Table 2.5.2 Software Block Diagram (2)



Legend

Member Assigned to Block:

🟦 - Mahyar Mahtabfar

🟥 - Albert Lougedo

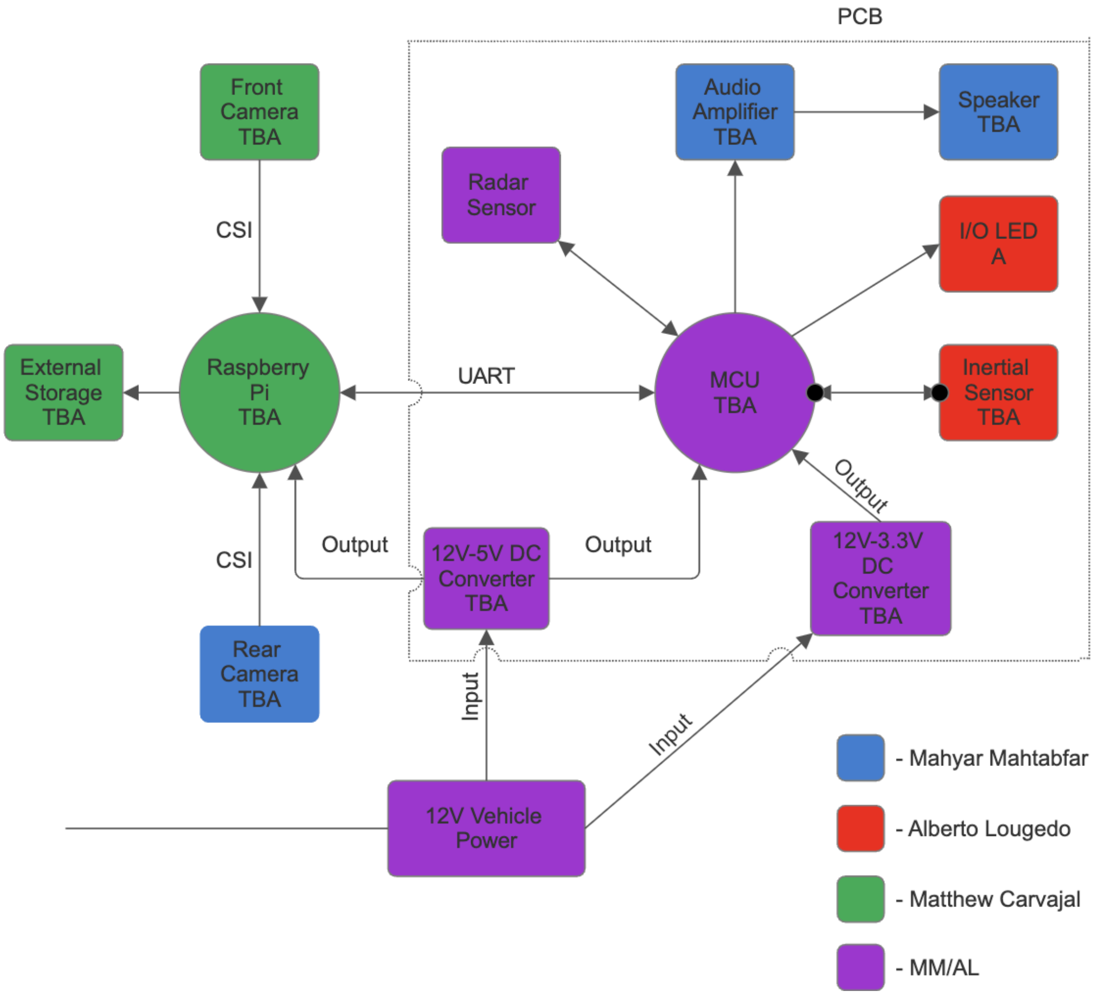
🟩 - Matthew Carvajal

Statues

To be acquired (TBA) - the block will be acquired

Research (R) – block design approach is being researched

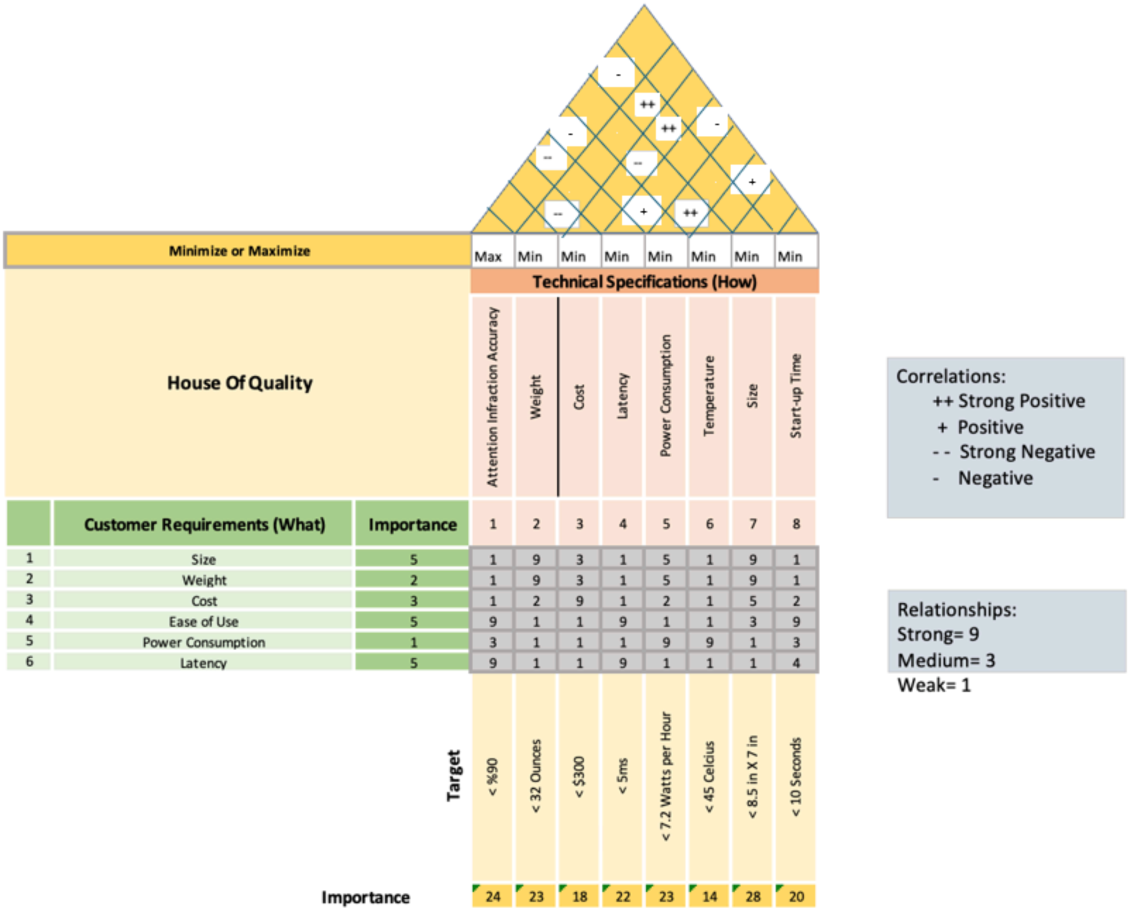
Table 2.5.3 Hardware Block Diagram



One consideration when designing the project is the needs of the customer. In an effort to take these needs into the design process we have to analyze the tradeoffs of our vision with that of the customer, thus a house of quality visuals was made. In the house of quality we utilized a numerical representation to represent the correlation we deemed fit for the technical specifications and the requirements made by the customer. At the roof of the house is our correlation of the technical specifications to each other. This portion demonstrates the tradeoffs we had to acknowledge outside of the customer's needs.

Figure 2.5.4 House of Quality

In the development of the SafeSight driver monitoring system, the House of Quality serves as a critical tool for aligning user needs with technical design requirements. This structured matrix helps the team translate essential customer demands—such as minimizing phone-related distractions, enhancing road safety, and providing real-time feedback—into concrete engineering actions. By identifying and prioritizing the relationships between what drivers need and how SafeSight can fulfill those needs, the House of Quality ensures a user-centered design process. It provides clarity during the early stages of product development, helping the team focus on features like accurate phone detection, timely alerts, and reliable behavior monitoring, all while maintaining usability and driver privacy. Ultimately, the House of Quality guides SafeSight toward delivering a solution that meets both safety standards and real-world driving expectations.



	Minimize or Maximize		Max	Min	Min	Min	Min	Min	Min	Min
			Technical Specifications (How)							
	House Of Quality		Attention Infraction Accuracy	Weight	Cost	Latency	Power Consumption	Temperature	Size	Start-up Time
	Customer Requirements (What)	Importance	1	2	3	4	5	6	7	8
1	Size	5	1	9	3	1	5	1	9	1
2	Weight	2	1	9	3	1	5	1	9	1
3	Cost	3	1	2	9	1	2	1	5	2
4	Ease of Use	5	9	1	1	9	1	1	3	9
5	Power Consumption	1	3	1	1	1	9	9	1	3
6	Latency	5	9	1	1	9	1	1	1	4
		Target	< %90	< 32 Ounces	< $300	< 5ms	< 7.2 Watts per Hour	< 45 Celcius	< 8.5 in X 7 in	< 10 Seconds
	Importance		24	23	18	22	23	14	28	20

Correlations:
++ Strong Positive
+ Positive
- - Strong Negative
- Negative

Relationships:
Strong= 9
Medium= 3
Weak= 1

3. Research

In developing SafeSight, our goal was to design a reliable and intelligent system that enhances driver awareness and promotes road safety. Drawing from the vast pool of available technological resources and research, we identified and implemented the most suitable components and methods to ensure the system functions efficiently and effectively in real-world conditions. To successfully build SafeSight, a variety of skills and knowledge areas were required, including embedded systems, wireless communication protocols, programming in Python and C++, and the implementation of safety-focused logic systems. The research and selections outlined in this section demonstrate how each component and technology contributes to SafeSight's mission: to assist drivers, enhance situational awareness, and improve overall traffic safety.

3.1 Technologies

To implement SafeSight successfully, a careful selection and integration of both hardware and software technologies is needed. Each component was chosen for its ability to meet the specific requirements of real-time data processing, environmental sensing, and wireless communication.

This section outlines key technologies that power the SafeSight system, including comparisons when it comes down to picking our main system, subsystem, MCU, etc. Understanding these technologies is essential to grasp how this system will operate, process input, and deliver timely feedback to improve driver safety and awareness.

3.1.1 Raspberry Pi

3.1.1.1 Raspberry Pi vs. Jetson Nano

The Raspberry Pi will be utilized because of its processing power, compact and robust design, and affordable price point to run the computer vision tasks in our project. However, how does the Raspberry Pi compare to its competitors? The Raspberry Pi and Jetson Nano are looked upon as competitors when it comes to application in a computer vision project requiring real-time object detection and image processing.

3.1.1.2 Availability and Efficiency

The Raspberry Pi, especially the newer models, is more affordable than the Jetson Nano, consumes less power, comes in a more compact and portable size, and has a better platform for development due to its popularity on a massive global user base. In our case, we will require our computer vision model to detect simple objects and classify between head posture, colors, and contours. These demands do not require the additional parallel computing power from the Jetson Nano which includes an NVIDIA Maxwell GPU with 128 CUDA cores. For intensive deep-learning tasks, the Jetson Nano will perform better when compared to the Raspberry Pi. For our application, since we do not require the extra computing power that makes AI and machine learning possible, provided by the Jetson Nano, and need a smaller more efficient design for application, we decided that the Raspberry Pi is the more ideal fit. When it comes to technology choices to run our required computer vision models in real-time, in a compact efficient design that our product requires, the Raspberry Pi trumps its competitor for computer vision tasks in this application.

3.1.1.3 Hardware Accessories

Other than the Raspberry Pi development board that houses the CPU, memory, and all access ports, there are a few additional accessories we need to consider when meeting the demands of our Safe Sight project. Many projects involving computer vision tasks will drive a high demand on the Raspberry Pi, involving complex calculations on image data that will generate more heat when compared to basic tasks. This calls for one of our accessories to involve a passive or active cooler so that our Raspberry Pi does not overheat. Overheating a Raspberry pi will cause it to throttle its CPU in an effort to lower its overall temperature and heat generation. Furthermore, if this thermal throttling occurs whilst the Raspberry Pi is actively attempting to run computer vision tasks, it will negatively affect performance of the Safe Sight product and inevitably result in the product failing. Additionally, camera accessories and their specifications will be crucial in managing demands on the Raspberry Pi and its heat generation. The goal with both the cameras is to have them capture at speeds and qualities that are efficient enough to prevent thermal throttling and effectively run computer vision tasks in real time.

3.1.1.4 Passive vs. Active Cooling

When it comes to cooling of electronic components there can be two ways: passive or active. Passive cooling utilizes natural conduction, convection, and radiation to cool off components. The use of materials and structures that work well dissipating heat to cool off elements is what passive cooling is all about. For example, passive cooling in small electronics is most commonly seen as a heat sink with thermal tape sticking it to components.

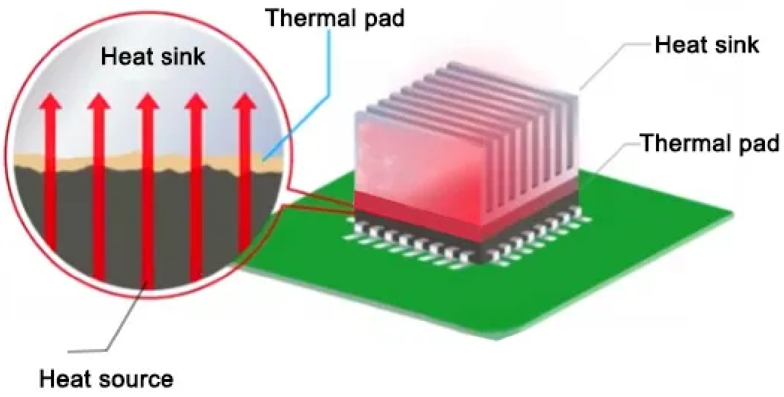


Figure 3.1.1.4.1 Heat Sink

On the other hand, active cooling involves using active components to cool down electronics. The biggest example of this would be a cooling fan that draws power from the electronics its cooling in an effort to dissipate heat through convection. On bigger more demanding electronics, water cooling and pumps might be used as another method of cooling, but for smaller electronics this is not needed.

The method of cooling we have decided to choose to meet our product needs is a mix of both. The Raspberry Pi active cooler uses a combination of thermal tape, metal heat sinks, and active cooling fans to effectively dissipate heat and prevent the thermal throttling effect on its CPU. The Raspberry Pi will begin throttling its CPU at 80℃ and increase the effect once it reaches its maximum temperature of 85℃. Considering that our Safe Sight product will be running demanding applications and will be located in a vehicle, we believe that it is only appropriate that we use a combination of the best active and passive cooling technologies to keep our device at optimal running temperatures.

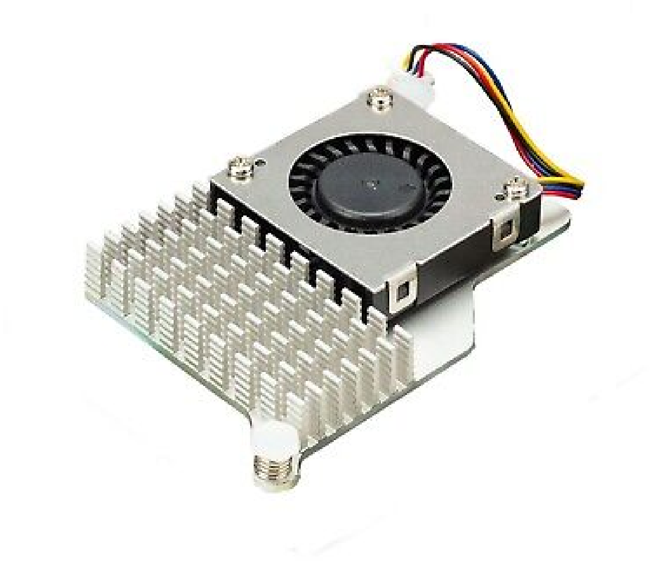


Figure 3.1.1.4.2 Raspberry Pi Active Cooler

3.1.1.5 Camera Accessory

To achieve a product that can process traffic lights and also the drivers posture we will require two cameras. The front road-facing camera will need to operate at a higher resolution than the camera facing our driver. A higher resolution allows for our front road-facing camera to process contours and objects at further distances due to a greater image quality. Since our vehicle position on a traffic light stop most times will not be first, a greater resolution will be required to confirm an accurate interpretation of the traffic light from our computer vision algorithm.

The camera facing the driver will capture video at a much lower resolution since the camera will be a set distance at all times from the driver, making it so the camera can be orientated to have its subject fill in the frame of video capture. Now that the driver makes up most of the frame of capture, a significantly smaller amount of pixels can be utilized to represent their appearance since they are closer to the camera and their posture represents most of the capturing frame. Capturing video this way will alleviate stress from the Raspberry Pi’s CPU and allow us to utilize more of its computing power to run the more demanding road-facing computer vision algorithm.

For the driver camera, we have decided to choose the Raspberry Pi Camera Module V2 due to its hardware compatibility and compact size.

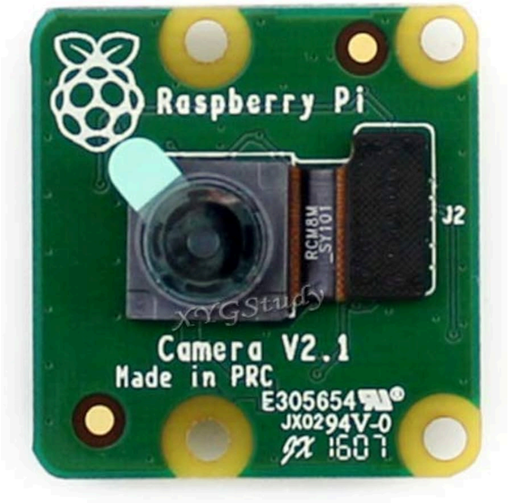
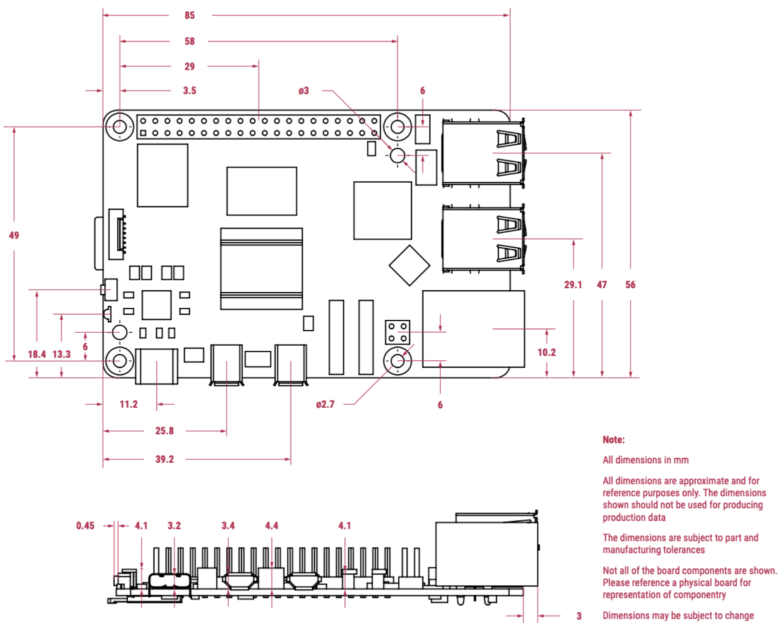


Figure 3.1.1.5.1 Raspberry Pi V2 Module

3.1.1.6 Raspberry Pi 5 Physical Diagram

The Raspberry Pi 5 physical diagram provides a detailed visual representation of the board’s layout, including key components, ports, and connectors. This diagram is essential for understanding the physical structure of the Pi's printed circuit board (PCB), enabling users and developers to identify component locations, plan hardware connections, and troubleshoot issues effectively. For projects like SafeSight, where the Pi serves as the central processing unit for sensors and feedback systems, having a clear grasp of its physical layout ensures proper integration of peripherals, efficient use of GPIO pins, and organized wiring. Ultimately, the physical diagram helps bridge the gap between design and implementation, reducing errors and streamlining the development process.

Physical specification



Note:

All dimensions in mm

All dimensions are approximate and for reference purposes only. The dimensions shown should not be used for producing production data

The dimensions are subject to part and manufacturing tolerances

Not all of the board components are shown. Please reference a physical board for representation of componentry

Dimensions may be subject to change

Figure 3.1.1.6.1 Raspberry Pi 5 Physical Diagram

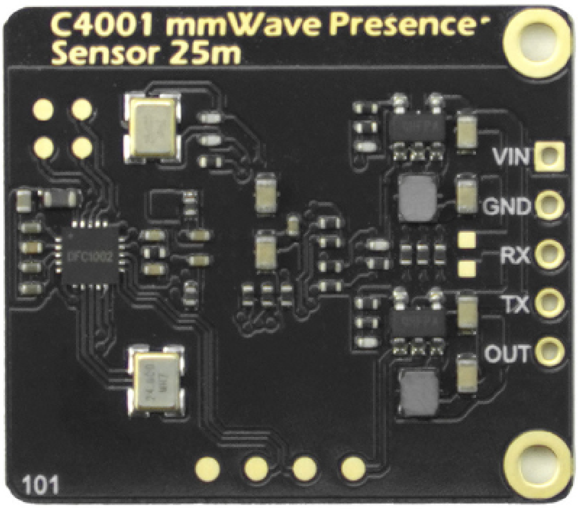
3.1.2 mmWave C4001 24GHz Human Presence Detection Sensor

When looking at the system we are planning on designing, there are many factors we must take into consideration before we make an executive decision on the components at hand. In conjunction with the inertial sensor, which we will be going over in 3.1.3, a radar was suggested by the advisor in order for us to properly address the need for a crash prevention system running off of our PCB.

When conducting our research for the right radar to implement into the board there were many requirements that had to be satisfied. The first major subject was the distance for which the radar can detect moving objects, but this was accompanied with the hurdle of detecting objects through a window. Immediately, the prospect of using an ultrasonic sensor was eliminated. Since the ultrasonic sensor functions by emitting high-frequency sound waves out from the emitter and waits for the waves to bounce back, a windshield will directly send the ultrasonic waves back to the receiver of the sensor. This reflection from the windshield will prevent the waves from reaching any object beyond the glass. The glass in itself has a specific acoustic impedance compared to air, this mismatch in impedance causes most of the sound energy to be reflected at the air-glass interface. This hurdle left us with options such as an optical sensor, Lidar, and camera-based systems. Due to the subsystem of the raspberry pi loading all of the CV conditioning we are throwing at it, the camera based system was not in the picture as we are avoiding the use of a third algorithm for distance detection, thus came into question the Lidar. The Lidar is a sensor that detects light, often working through glass. While a Lidar may seem like the solution to finding the distance of objects ahead of the host vehicle, one big consideration was the reflection/ refraction of light that the windshield glass will reflect on the lasers used from the Lidar. This refraction can cause reduced signal strength while making an effort to reach objects beyond the glass and potential false readings from reflections. Another fault in the Lidar system is that the signal must pass through the windshield twice, once out and another returning. When taking into account robustness of the system we are trying to engineer, having these scenarios of increased margin of error has convinced the research to look at other options. Thus, we have inevitably turned to the radar.

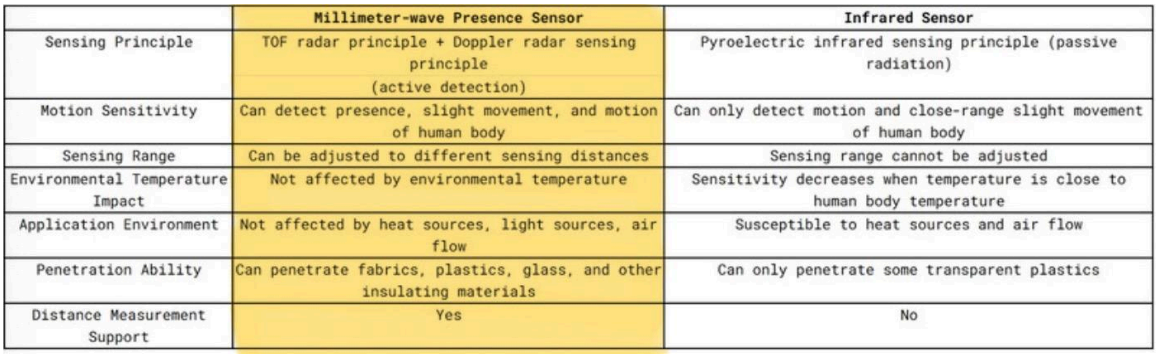
The radar, as a broad technology, serves to identify the presence of objects, determining distance to said object, and thanks to the doppler effect, measures velocity. One functionality we will be utilizing the radar for is collision avoidance, in order to warn the driver using the safesight device of impending impact. Many modern vehicles incorporate radars within their automotive safety system, and these radars have standards we took into consideration when looking for the right radar to implement. Based on the specifications used in the industry, the radars used in these vehicles utilize a frequency band of 77-81 GHz, range capabilities of 1-30 meters, and about 15W for power. These radars utilize advanced signal processing for object detection and these signal processing techniques help with all weather performance which is one thing we have to take into account as well. The radar we have found is the DFRobot C4001 millimeter-wave presence sensor. This sensor is capable of emitting a 24GHz wavelength signal with a range of 25 meters.

Figure 3.1.2.1 DFRobot C4001 Radar



The differences between the mm- wave presence and the infrared sensor are detailed in the following chart:

Figure 3.1.2.2 mm-wave sensor vs Infrared Sensor Comparison



	Millimeter-wave Presence Sensor	Infrared Sensor
Sensing Principle	TOF radar principle + Doppler radar sensing principle (active detection)	Pyroelectric infrared sensing principle (passive radiation)
Motion Sensitivity	Can detect presence, slight movement, and motion of human body	Can only detect motion and close-range slight movement of human body
Sensing Range	Can be adjusted to different sensing distances	Sensing range cannot be adjusted
Environmental Temperature Impact	Not affected by environmental temperature	Sensitivity decreases when temperature is close to human body temperature
Application Environment	Not affected by heat sources, light sources, air flow	Susceptible to heat sources and air flow
Penetration Ability	Can penetrate fabrics, plastics, glass, and other insulating materials	Can only penetrate some transparent plastics
Distance Measurement Support	Yes	No

We decided to compare the functionality as justification for the reasoning of choosing the millimeter wave sensing technology. Since we are implementing this radar for distance detection for a short term alarm with the ambitions to implement a safety crash collision notification, and to sense vehicles moving ahead of the car hosting the device. The 25m distance is more than efficient for our uses paired with a speed measurement range of 0.1 to 10m per second. One other aspect of this radar that makes this system as robust as we would like is that the radar itself is unaffected by snow, haze, temperature, humidity, dust, and light. Ensuring that the radar will be able to withstand weather conditions beyond the windshield.

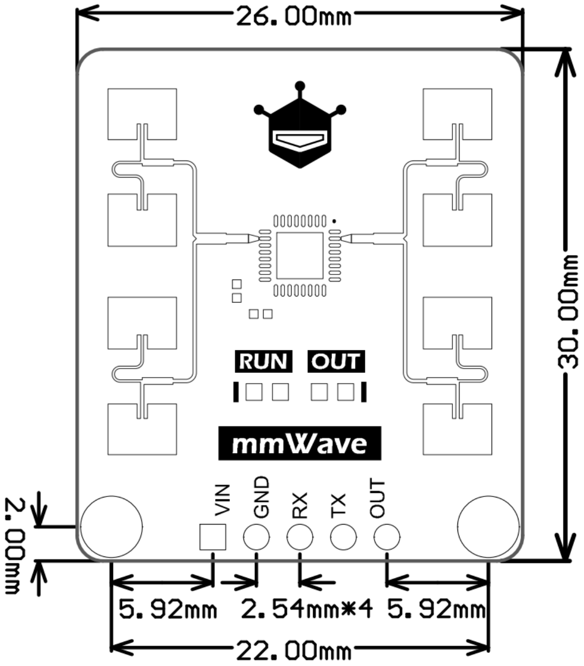


Figure 3.1.2.3 Dimension Layout for C4001 mmWave Sensor

Embedded in this radar we have chosen is the Frequency Modulated Continuous Wave (FMCW) radar technology. Some notes to mention on this technology are the advantages of simultaneous range and velocity measurement, superior range resolution, and extended detection range. With the simultaneous range and velocity measurement, the advantages of measuring both variables can lead to the implementation of our equations for crash detection and other notifications to the driver of the vehicle. For example, the measured vectors will be labeled as two subcomponents variables to the whole system, where we will introduce feedback in the system in order to measure constant distance recordings of a vehicle in front of the host vehicle. This will then compare the values of our ideal distance, being at maximum range of the radar's constraints, to the actual distance recorded. This feedback will then apply the data to the system where velocity and distance from collision are taken into account. From the FMCW, this can be seamless with simple algebra ringing a notification to the user.

The FMCW's range resolution implements a frequency modulation technique known as the triangular frequency. This modulation pattern involves both the increasing and decreasing frequency linearly, creating a triangular waveform. This separation of the difference frequency from the doppler frequency makes it useful for simultaneous range and velocity measurements to be carried out effectively as compared to the application of an ultrasonic sensor. This modulation technique is crucial for crash detection systems as it provides a comprehensive understanding of the surrounding vehicles' positions and movements. As that is stated, one of the biggest challenges in crash detection is the ability to distinguish doppler shift and frequency shift, and this FMCW technology's inclusion of the triangular modulation enables better discrimination between stationary and moving objects, proving vital for accurately identifying potential collision risks in a dynamic traffic environment. In the talks of the traffic environment there are also a variety of different conditions that require a robust system. With robustness, there are multiple complex, uncontrollable factors that dictate the system to respond effectively and one of these factors is the ever changing conditions such as weather and lighting. The versatility and integration offered by the FMCW's triangular modulation allows for an increase in reliability in order to overcome these various conditions that are ever so changing, improving the reliability and robustness of the system as a whole. By leveraging these benefits triangular modulation in the FMCW radar significantly enhances the capabilities of crash detection systems in cars, and being able to get this technology to operate on a portable system such as the safesight will be ideal for the system we plan to implement.

Another major aspect as to why we chose this radar as stated before is the distance for which the FMCW is capable of detecting. FMCW radars can utilize large bandwidths on relatively small hardware, allowing the system of safesight to detect preventable accidents in a traffic environment. Outside of the frequency modulation we went in depth for, there are multiple signal processing techniques used within the FMCW that allow for this system such as the beat frequency analysis, fast fourier transform, and the use of advanced algorithms. Beat frequency analysis is a crucial technique used in FMCW radar systems as it is used to determine the range and velocity of targets. This analysis involves measuring the frequency difference between the transmitted and received radar signals, the delta (difference) is the beat frequency and it is directly proportional to the target's distance and relative velocity. The received signal is mixed with a portion of the transmitted signal in the radar's receiver which then produces a signal with a frequency equal to the difference between the transmitted and received frequencies (beat frequency). From obtaining the beat frequency, that signal is then converted to the frequency domain using the Fast Fourier transform (FFT). The FFT efficiently converts the time-domain beat signal into its frequency components as we just stated. This transformation allows the radar to identify multiple targets at different ranges simultaneously. This is accomplished with spectral analysis, which provides a spectrum of frequencies present in the beat signal. Peak detection in the FFT output corresponds to potential targets; these peaks represent the beat frequencies. Threshold application is

also applied to the FFT output to distinguish significant peaks from noise, allowing for focused and important data that is not going to alter the performance of the system.
The FFT algorithm efficiently converts the time-domain beat signal into its frequency components, allowing the radar to identify multiple targets at different ranges simultaneously. To detect the threshold, the FFT output is analyzed to find frequency peaks above a certain threshold which correspond to potential targets. The range calculation is the result from this complex process and is how we will be implementing the range calculation into our CV (computer vision) algorithms. The FFT allows for computational efficiency, multiple target detection and high resolution. To achieve multiple targets simultaneously there are many algorithms to implement but we will focus on these two; One algorithm is used here in the FFT processing known as the Cell Averaging Constant False Alarm Rate (CA-CFAR) algorithm. This algorithm enhances detection in complex environments by dynamically adjusting detection thresholds based on local clutter levels, reducing false alarms caused by background variations and calculates a weighted average of clutter data in reference windows. The Multiple Signal Classification (MUSIC) algorithm improves target detection and tracking. This is done by using eigenvalue decomposition of the received signal's covariance matrix and estimating direction of arrival (DOA) of target signals. The MUSIC algorithm in particular is effective in reducing interference from stationary and moving clutter sources.

On the subject of algorithms, the FMCW radar technology can be effectively integrated with computer vision algorithms to enhance object detection, tracking, and classification capabilities. The FMCW radar provides precise range, velocity and angle information. Computer vision on the other hand, offers rich visual features and object recognition. Because of these computer vision algorithms using radar data to improve object localization and tracking, this allows the combination of the two technologies to coexist in an effort to overcome challenging lighting and weather in a dynamically changing environment such as traffic. Mask R-CNN and other similar deep learning models can identify and locate human objects in visual data. The positions of these detected objects are used to guide the FMCW radar in targeting specific areas for vital signal extraction. The versatility of the Convolutional Neural Network (CNNs) can be used to process both the radar and visual data, extracting these complementary features from each modality. The type of algorithm we will be using will be discussed more in the RAspberry Pi section of this documentation, where we will address the CV demands in correlation to the rest of the hardware being used in the system.

Limitations:

In the research for this specific radar technology, there have been many findings that provide a lot of evidence to support the claim that this radar technology is perfect for the use we intend to implement on our system. However, alongside this research came some drawbacks we will have to work to overcome in the talks of this radar. For example, the radar technology we have mentioned contains limited range and doppler resolution, hindering the radar's ability to distinguish closely related objects and detect vulnerable road users, particularly pedestrians. The goal of identifying pedestrians has been a far-reached goal in itself in order to really execute an effective collision detection system. The main intended use for this radar is to detect bigger, automobile objects in the hopes that the driver will be able to react in a reasonable time. In order to accurately achieve the targeting for these vehicles in traffic and to propagate the signal to the driver, the problem of insufficient resolution must be addressed as well. Even in the higher bandwidths, > 4 GHz, the range resolution may not be sufficient for operating some targets in dense traffic conditions as we see everyday commuting to UCF, stores or experiences. This requires additional separation in the doppler dimension.

Interference with congested environments. In scenarios with many vehicles operating radars in the 76-81GHz band, the power from other radars can significantly exceed the power of echoes from intended targets. This interference can reduce the effective range of the radar to a fraction of its normal capacity. Alongside this interference comes noise. This interference from other radar systems can elevate noise levels, potentially drowning out weak targets as well, meaning that there is a loss on the overall detection rate. This detection interference can lead to ghost targets as well, leading even to false readings. With all of these possibilities in the world of target detection, it is imperative for the team to simulate many different scenarios in an effort to accomplish these hurdles and prove the system to be robust over these challenging circumstances.

These limitations highlight the need for improved radar technologies at the size and thresholds that we are aiming to utilize this specific radar, the mmWave C4001 24GHz Human Presence Detection Sensor. Even though this sensor's technologies and interference mitigation techniques can do the job we are tasking it to do, some modifications can be made in these technologies to enhance the accuracy and reliability of FMCW radar systems in complex traffic environments. For the sake of this project however, the technologies will be sufficient for the main goal, some alterations will be needed for our stretch goals.

3.1.3 Inertial Sensor

In the scenario where a driver remained idle at a traffic stop and they are not the first driver in line, the system lacked in being efficient in this case. That was until we decided to implement the interital sensor. Prior to this decision being made there were many theoretical approaches to how this problem could be tackled. One of which was implementing a CV algorithm in the hopes that it can determine the distance of the vehicle ahead of us in order to let the driver of the host vehicle know that it is time to go. However effective this may have been, the design lacked complexity and as a result, relied heavily on the subsystem of the Raspberry Pi. So, with that being said the inertial sensor found its purpose. One of the major issues with adding an inertial sensor are the constraints we need in order for the device to be effectively integrated into our system. Firstly, we need a sensor that is ideal for automobile velocity measurement. This is because in order to determine the inertia constant of a vehicle that is driving, there needs to be some sort of temperature threshold and endurance. This is because the dynamically changing environment of traffic can be ever changing from location, time of day, amount of cars around, etc. Being that the environment we are used to is in Florida, this temperature endearment is crucial as we need a sensor that can withstand temperatures of a car as it gets hotter when the car is idle and off. Another constraint is the sensor's ability to be compatible with the ESP32 and can adapt to UART communication to remain consistent with the rest of the hardware in the system as displayed in the hardware diagram earlier in this document. And finally, the last two constraints we demanded to meet were affordability, and compact sizing.

Table 3.1.3.1 Inertial sensor comparison

Feature	MPU-6050	MPU-9250	ICM-20948	LSM6DS3
Manufacturer	InvenSense (now part of TDK)	InvenSense (now part of TDK)	InvenSense (now part of TDK)	STMicroelectronics
Axes	6 (3-axis accelerometer, 3-axis gyroscope)	9 (3-axis accelerometer, 3-axis gyroscope, 3-axis magnetometer)	9 (3-axis accelerometer, 3-axis gyroscope, 3-axis magnetometer)	6 (3-axis accelerometer, 3-axis gyroscope)
Gyroscope Range	±250, ±500, ±1000, ±2000 °/s	±250, ±500, ±1000, ±2000 °/s	±250, ±500, ±1000, ±2000 °/s	±125, ±250, ±500, ±1000, ±2000 °/s
Accelerometer Range	±2g, ±4g, ±8g, ±16g	±2g, ±4g, ±8g, ±16g	±2g, ±4g, ±8g, ±16g	±2g, ±4g, ±8g, ±16g
Magnetometer	No	Yes	Yes	No
Digital Motion Processor (DMP)	Yes (6-axis)	Yes (9-axis)	Yes (9-axis)	No
Interface	I^{2}C	I^{2}C, SPI	I^{2}C, SPI	I^{2}C, SPI
Operating Voltage	2.5V to 3.6V	2.4V to 3.6V	1.71V to 3.6V	1.71V to 3.6V
Package Size	4×4×0.9 mm QFN	3×3×1 mm QFN	3×3×1 mm QFN	3×3×0.9 mm LGA
Status	End of Life (EOL); replaced by ICM-42670-P	Obsolete	Active	Active
Notes	- Integrated 16-bit ADCs- External magnetometer interface	- Integrated 16-bit ADCs- Improved performance over MPU-6050- Integrated magnetometer	- Integrated 16-bit ADCs- Lower power consumption- Enhanced features over MPU-9250	- Integrated 16-bit ADCs- Low power features- Pedometer functions

Many different sensors were able to work for the demands we needed, at one point the team was considering a sensor optimized for the functionality of a smartphone or other portable electronic device. This was a step in the right approach as our system was to be idealized inside of a small component that is transferable from motor vehicle to motor vehicle, but it did not meet the compatibility of UART, cost, or physical constraints for the dynamic environment as we mentioned earlier. Thus we went ahead to find another alternative, the MPU-6050 Accelerometer and Gyroscope. The MPU-6050 Accelerometer and Gyroscope features a 3-axis accelerometer and 3-axis horoscope. These two additives to the hardware are efficient in measuring acceleration, angular velocity, and temperature. The sensor also communicates via I2C, but it can be adapted to UART using additional components. Since the ESP32 is the microcontroller serving the whole system, it is important that our components are compatible with that microcontroller. In the efforts to ensure that the sensor we finalized was going to be ideal, we had to take into consideration physical constraints, power, and introducing other complexities. Now the limitation of the MPU-6050 being the absence of UART functionality and absence of a built-in velocity calculation (resulting in an integration of acceleration data to estimate velocity) caused the choice of the sensor to be this MPU-6050. The main communication protocol being the I2C offloads the UART pins on the ESP32. This is ideal as we have the radar and the Raspberry pi, as aforementioned, already utilizing the UART pins.

3.1.3.1 MPU-6050

The MPU-6050 inertial sensor is an ideal inertial sensor for detecting movement in a device such as the safesight because of key features and advantages over other sensors. First, the MPU has various degrees of freedom (6) with the integration of a 3-axis accelerometer and a 3-axis gyroscope, enabling it to measure both linear acceleration and angular velocity. This combination provides a comprehensive formulation for motion data, which is what we need in order to track the motion of an automobile efficiently. The sensor's 16-bit ADC for high resolution measurements ensures precision in regard to detection of motion and orientation. This offers configurable sensitivity ranges for both the accelerometer (±2g to ±16g) and gyroscope (±250°/s to ±2000°/s), allowing adaptation to varying dynamics of a moving car. The compact size of this sensor is also a very needed constraint that it meets. The dimensions of just 25 x 20 x 7 mm and low power requirements allow the sensor to fit and operate with fatal constraints. Alongside the use of the ESP32 microcontroller we have chosen for this hardware, the MPU-6050 utilizes a I2C communication interface. This is ideal given that we will be communicating to the ESP32 as we will be communicating through the Arduino interface. This allows not only for the software to smoothly communicate but also for the implementation on the hardware as a whole. The ESP32 has only a specific number of pins to communicate with UART, which is already ideal for the Raspberry Pi's integration for the system. The freedom of using I2C allows for such hardware, like the MPU-6050 to be implemented. And finally, the MPU has "shock tolerance" which means it can handle the vibrations of a car moving through traffic (up to 10,000 g), making it robust enough to handle vibrations and impacts in such a dynamic traffic environment.

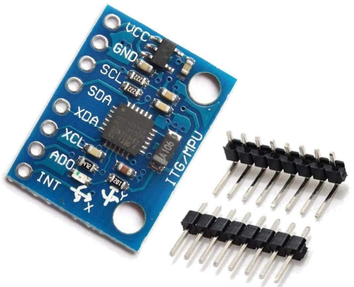


Figure 3.1.3.1.1 MPU-6050

From the visualization provided above, there are specific pinouts shown and hence this section of the document will go in depth on the functionality behind every pin. The VCC and GND pins supply the input voltage and the grounding nodes, respectively. Since this sensor allows for an activation voltage of 3.3V-5V, this makes it ideal for the sensor to be implemented given that the ESP32 provides a 3.3V pin for the rest of the circuit board, allowing utilization of the pin to provide the 3.3V to a node for all 3.3V components. The main connection and pins we will be doing work on are the SCL, SDA, and INT pins. Here in the SCL pin we will be utilizing the I2C communication to provide clock pulses and to establish a connection to the microcontroller's SCL pin. This will enable synchronizing data transfer between the MPU-6050 and the microcontroller. The SDA pin will connect the SDA pins between the sensor and the microcontroller, allowing for bidirectional data exchange between the two components. For the INT (interrupt) pin, this pin generates an interrupt signal when new sensor data is available. This pin is useful for our application because it allows for the real time data processing without constant polling, allowing the stress of processing power to be brought down.

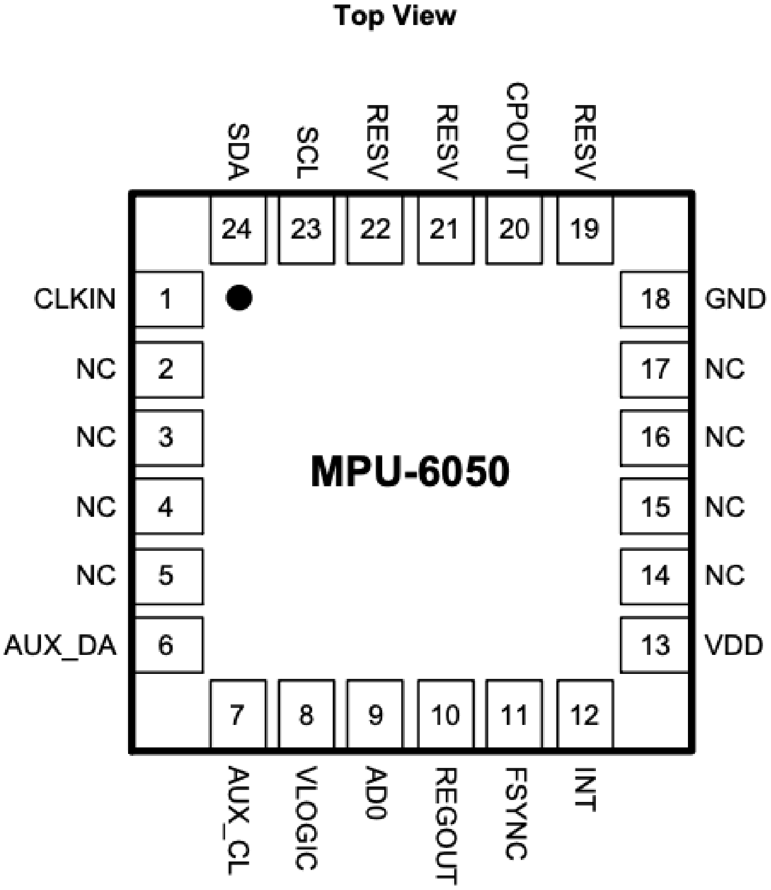


Figure 3.1.3.1.2 MPU-6050 sensor pinout

3.1.3.2 Sensor Limitations

Initially in this section we went over other possible sensors, why they were not a good fit and why the MPU-6050 was the better sensor overall for our application. However, it is also important to note that the MPU-6050 also has its drawbacks. For example, the MPU-6050 has limited accuracy and reliability. The sensor can produce some unreliable readings during rapid or harsh environments. Such changes in pitch or angle may initially result in incorrect outputs before stabilizing which can be problematic in a very intense traffic scene. While we did mention the robustness to shock earlier as a reason for our decision, the sensor struggles with vibrations over 10,000 g. This can lead to erratic readings or clipped values, meaning that we would need to find a way to work around that in order to properly perform data acquisition. On the subject of high G forces, it is also important to note that there is a clipping of the forces when the G force is +/- 16g. This can prove to be insufficient for detecting extreme impacts or crashes. This would have to put the responsibility of the crash detection into the CV or the radar to detect when objects have collided with the vehicle in order to implement crash detection.

Working with I2C is a must with the expected usage of the UART pins for the microcontroller being taken, meaning we have a constraint on what sensors we can implement due to the CV module. Being inI2c communication, the data transfer rate is slower than other communication protocols such as SPI-based sensors. This limits its ability to handle high-speed applications requiring faster sampling rates if the environment is too much for the sensor. The I2C communication is not robust over long distances over 1 meter without additional measures like shielding wires and lowering pull-up resistor values, this can lead to complications in the integration for our system if we alter the dimensional constraints.

The MPU-6050 is also prone to noise and requires careful calibration to achieve accurate measurements. Without proper calibration, readings can oscillate and deviate significantly from expected values. This affects the accurate motion tracking which often requires external libraries for sensor fusion algorithms.

3.1.4 Alarm System

The Alarm System in SafeSight is designed to provide real-time alerts that enhance driver awareness and safety. This feature actively monitors for signs of driver distraction or unsafe driving behavior, such as prolonged eye movement away from the road. When such conditions are detected, the system immediately triggers a visual and/or auditory alarm to notify the driver and prompt corrective action. The goal of this system is to reduce the risk of accidents by keeping the driver engaged and attentive during each trip. This proactive alert mechanism is a key component in delivering a safer and smarter driving experience with SafeSight.

3.1.4.1 Speaker and Amplifier

For a sound to be replicated at any time by electronics, a digital sample of the sound signal needs to be stored and then converted, on demand, as an analog signal to then be heard through a speaker. The conversion process from digital signal to analog signal is in need of amplification after conversion. Now, the basis and need for amplification is to take a weak electrical signal and increase its strength, allowing this stronger signal to be sent to the speakers and produce a loud vibration sound to be heard clearly through the speaker cones.

3.1.4.2 ESP 32 Compatibility

The ESP 32 includes two 8-bit DAC channels, which can be used to produce more complex audio output. These DAC channels are hardwired to specific GPIO pins and utilize the reference voltage as output (3.3V). Now, DAC speakers driven by the ESP32 provide more flexibility with sound application. However, the 8-bit resolution provides only 256 discrete voltage levels which is considerably less than CD quality's 16-bit resolution (65,536 voltage levels). This means that distortion will be heard at some levels amongst the signal due to insufficient voltage levels to represent the overall signal. In addition, amplification will be required when utilizing an ESP32's DAC due to its low signal strength not being able to drive most speakers effectively. This additional hardware adds more complexity and significantly increases power consumption. For implementation that requires diverse audio feedback with a range of tones and volumes, DAC driven speakers are perfect for providing this versatility with sound, being able to create alarm sounds, voice instructions, and pleasant tones.

3.1.4.3 Piezo Electric Buzzer

The term "piezoelectric" derives from the Greek word "piezein" which means to "squeeze". This terminology directly reflects the fundamental principles that these devices operate upon. When certain materials are mechanically stressed, they will generate an electric charge. Similarly, when the same materials are energized, they will deform. Piezoelectric material usually consists of ceramics like lead zirconate titanate or lead magnesium niobate. When these materials receive electrical signals, they transfer the energy into mechanical movement at remarkable efficiency and speed, making them ideal for sound generation and application. Piezoelectric buzzers utilize DC to create a piezoelectric effect that creates vibration sound. The buzzer consists of a multi-resonator, piezoelectric plate, impedance matcher, resonance box, and a housing.

3.1.4.4 ESP32 Compatibility

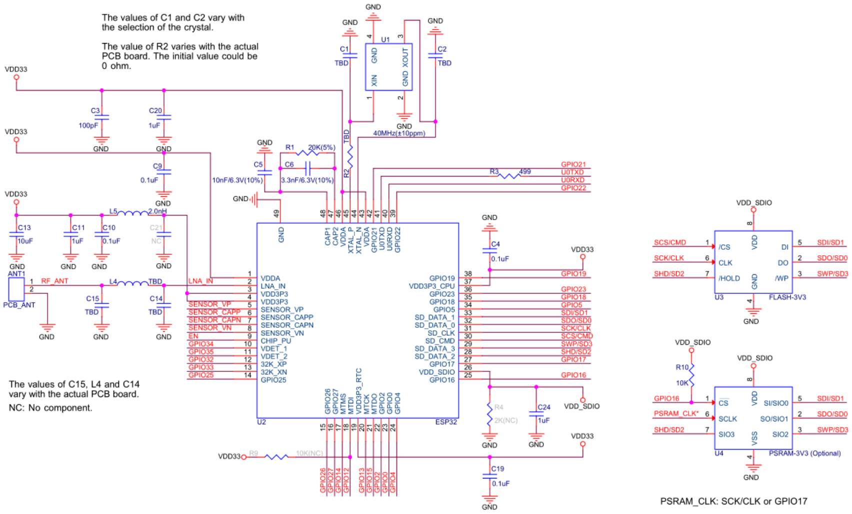
Piezoelectric buzzers are fully compatible with MCUs, especially the ESP32. Coming in passive and active configurations, piezoelectric buzzers are simple in their hardware configuration. Only having two leads and either requiring a simple DC input where the internal oscillator converts this signal to alternating current. Furthermore, the passive configuration requires an oscillating signal at the input provided from the MCU, allowing for different tones to be created instead of just changing voltage for volume in dB. Whether using active buzzers for plug-and-play simplicity or passive buzzers for greater control over sound characteristics, these components offer valuable audio feedback capabilities for a wide range of electronic projects. Understanding the principles, electrical characteristics, and implementation considerations of piezoelectric buzzers enables engineers and hobbyists to effectively incorporate these components into their designs, creating everything from simple notification systems to sophisticated audio interfaces. As electronic devices continue to permeate our daily lives, the humble piezoelectric buzzer remains a critical component for bridging the gap between digital systems and human perception.

3.1.5 MCU

When it comes to picking the right microcontroller, there are many things that need to be considered. Questions arise such as: “What is the price of the MCU?”, “How much power does it consume?” or “Is this MCU even compatible with my system?”. These are all very important questions that must be answered when picking the right microcontroller for your project. Below, some, if not, all of the questions will be answered so that this project can have the perfect MCU that will accomplish all of our tasks.

3.1.5.1 ESP32

The ESP32 is a popular and versatile system-on-chip microcontroller that offers a range of features suitable for many different IoT and embedded systems projects that was developed by Espressif Systems in September 2016. This MCU contains a Tensilica Xtensa LX6 32-bit dual-core processor with a clock speed up to 240 MHz. This processor can provide enough processing power for the most demanding applications. In regards to memory, it holds 4 MB of flash memory with 520 KB of RAM. It has the most amount of memory compared to the rest of the microcontrollers that are going to be discussed. This will allow it to support complex tasks with large amounts of data. One of its key advantages is built-in Wi-Fi and Bluetooth connectivity, enabling seamless wireless communication for IoT applications. Additionally, the ESP32 has a wide variety of GPIO pins, analog-to-digital converters, digital-to-analog converters, pulse-width modulation, I2C, SPI, UART, and capacitive touch sensors, making it highly adaptable for different types of projects.



The values of C1 and C2 vary with the selection of the crystal.

The value of R2 varies with the actual PCB board. The initial value could be 0 ohm.

The values of C15, L4 and C14 vary with the actual PCB board.

NC: No component.

PSRAM_CLK: SCK/CLK or GPIO17

Figure 3.1.5.1.1 ESP-32 Schematic for applicational use

Thanks to its high processing power, wireless connectivity, and wonderful energy efficiency, the ESP32 is well suited for this project due to its ability to enter low power modes and being able to operate on battery power for extended periods, making it an excellent choice for remote monitoring systems such as Safe Sight. The ESP32 is compatible with a variety of operating systems and development platforms. These platforms include Arduino IDE since it is probably the most widely supported MCU in the Arduino community. It allows users to program in the common Arduino C++ framework with the help of the ESP32 Arduino Core. It can also handle being developed on Linux, MacOS, and Windows operating systems as well. Making it the perfect MCU for all developers, no matter their choice of operating system. The creator of the ESP32, Espressif Systems, has their own software called Espressif IDF. It is the official development framework from Espressif, offering low level control and optimization for advanced projects. It is best suited for developers who need to build firmware from scratch while having full control over the hardware interactions. Therefore, the combination of affordability, robust performance, capability, and having such a strong developer community, makes the ESP32 a go-to decision for most projects.

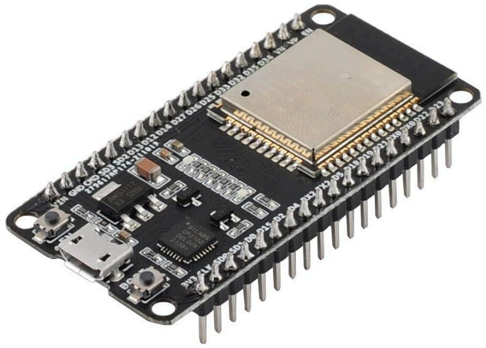


Figure 3.1.5.1.2 ESP32 Microcontroller

3.1.5.2 Raspberry Pi Pico

The Raspberry Pi Pico is a versatile and low-cost microcontroller board developed by Raspberry Pi in January 2021. It is Raspberry Pi's first board based upon a single microcontroller chip. It has a dual-core ARM RP2040 processor that runs up to 133 MHz with 264 KB of RAM and 2 MB of on-board flash memory. You can imagine the Pico as a smaller version of the Raspberry Pi, even though it is similar to the ESP32, as it implements much of the same features as the ESP32 including WiFi and Bluetooth connectivity. However, it does have a different architecture and development ecosystem than the ESP32. Unlike traditional Raspberry Pi boards, which can run full operating systems, the Pico is designed more for embedded systems applications and runs bare-metal code with lightweight runtime environments such as MicroPython and CircuitPython.

With the price range of $4-$10, the Raspberry Pi Pico comes with a Programmable I/O (PIO) system, which allows for efficient handling of custom I/O protocols without putting too much strain on the CPU. It has 26 multi-function GPIO Pins, including 3 analog inputs that support interfaces such as I2C, SPI, UART, PWM, and ADC, making it one of the most ideal MCU's for hobbyists. The Raspberry Pi Pico has been optimized for low power consumption as well, making it a good option for this project due to low power consumption. It supports an input voltage of 1.8 - 5.5 V of DC power and can operate in temperatures from -20℃ - 85℃, making it a perfect microcontroller for all conditions.

Multiple programming languages are supported on the Raspberry Pi Pico. Languages such as MicroPython, CircuitPython, C/C++, etc. For beginners, MicroPython is a popular choice due to its simplicity. With MicroPython, you can develop in a high-level programming environment, while writing simple, easy to learn code. Unlike C/C++, MicroPython doesn't require setting up a development environment and a compiler, MicroPython allows users to write and execute code interactively using the REPL (Read-Eval-Print Loop) interface using a serial connection. Beginners and advanced developers can develop code super efficiently because there is no need for recompilation. MicroPython also has straightforward syntax for controlling multiple interfaces (GPIO, I2C, etc.) with built-in support for plenty of peripherals, reducing the complexity of embedded programming. On the other hand, Circuit Python is a beginner-friendly version of MicroPython that was designed to simplify programming microcontrollers such as the Raspberry Pi Pico. One of its most popular features is its drag-and-drop programming model. This allows users to plug up a MCU to the computer, view it as a USB storage device, and edit their code directly in a text editor, without needing to compile or run any flash tools. Like MicroPython, CircuitPython includes built-in libraries and modules that make working with peripherals a breeze. Finally, developing in C/C++ on a Raspberry Pi Pico offers immense control, efficiency, and performance compared to high-level languages like MicroPython or CircuitPython. The Pico's official development environment is C/C++ for the SDK. This provides a long list of libraries that are able to interact with the Picos different interfaces. Developers use C/C++ for highly optimized, low-latency applications, which is great for real-time processing. C/C++ is also very versatile as it can be compiled on various RP2040-based boards, without the need for modification. This is extremely useful in case the Raspberry Pi Pico isn’t the right board for your project. You can easily move to another RP2040-based board with more or less features and save time writing new code. Although C/C++ has a stronger learning curve than Python based languages, it is often the best choice for projects that prioritize efficiency and deep hardware control. Therefore, developers love the Raspberry Pi Pico due to its versatility, features, cost and power consumption.

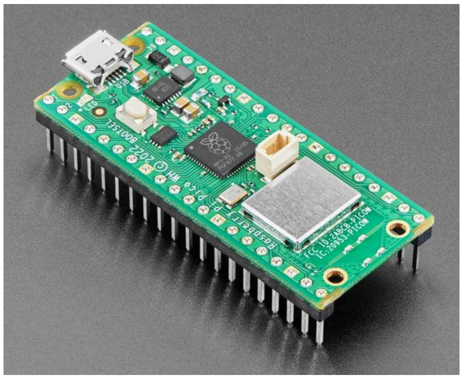


Figure 3.1.5.2.1 Raspberry Pi Pico Microcontroller

3.1.5.3 STM32 Series

The STM32 microcontrollers have been developers' go-to choice for various electronic projects for a while. The family of microcontrollers was developed by STMicroelectronics in 2007. They are based on ARM Cortex-M processors that can range from 24 MHz to 480 MHz. Each MCU from STMicroelectronics consists of ARM processor cores, flash memory, static RAM, debugging interfaces and various peripherals. In particular, the STM32H742 MCU features the highest clock speed and memory capacity out of all of the STM32 series. With a clock speed of 480 MHz and 512 KB of RAM with 2 MB of flash memory, this MCU is a beast for most embedded systems and electronics projects. If you are looking for a microcontroller with extreme low-power consumption, the MCUs with the Cortex-M0/M0+ are perfect for applications that focus on saving power (STM32L series). Some of the MCUs can operate as low as 1.7 Volts which is perfect for devices that need to be active for long periods of time. If you are looking for super high performance out of an MCU, you can look for models with the Cortex-M4/M7. These models offer high performance with DSP (Digital Signal Processing) and FPU (Floating-Point Unit) capabilities. Depending on your needs, the STM32 series microcontrollers can run anywhere from $5-$30, making it one of the more pricer options on this list.

Even though there is a higher price point for the STM32 series microcontrollers, they do come with an abundance of peripherals, including GPIO Pins, ADC, DAC, PWM, UART, SPI, I2C, CAN, USB, and Ethernet. Many models also have hardware accelerators for cryptographic functions, making it perfect for applications that need security. Some high-end STM32 chips even have graphics acceleration for display based applications. Like the ESP32, there are even some wireless STM32 options that have Bluetooth as well, making it suitable for this project. The STM32 series microcontrollers can be used in a variety of development environments too. These environments include STM32CubeIDE, which is STMicroelectronics official IDE for the STM32 series microcontrollers. Some businesses on the professional side, use Keil MDK and IAR Embedded Workbench, which are perfect for embedded system development. Some hobbyists use Arduino IDE for some STM32 programming because it is user friendly and compatible with a variety of other microcontrollers. Like the Raspberry Pi Pico, a select number of STM32 series microcontrollers can be programmed with MicroPython for efficient development. Therefore, the STM32 microcontrollers offer high flexibility, performance and extreme power efficiency, making them a go-to choice for beginners, hobbyists, and advanced developers alike.

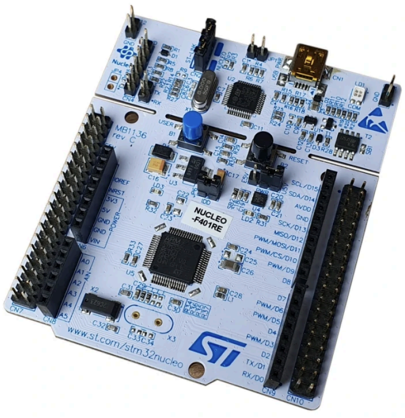


Figure 3.1.5.3.1 STM32 Nucleo F411RE Microcontroller

3.1.5.4 Arduino Nano

The Arduino Nano is a compact and versatile microcontroller that was released in 2008 by Arduino. It is based on the ATmega328P processor and offers similar functionality to the Arduino Uno, but in a more compact form factor. It features a 16 MHz clock speed with 2 KB of RAM and 32 KB of flash memory. With an operation voltage of 5 V, it has a wider compatibility with most sensors and modules compared to other microcontrollers.

Many of the older sensors, LCDs, and modules (ultrasonic sensors, character displays, etc.) are designed for 5 V operation which will eliminate the need for modifying the voltage via level switching when communicating with these interfaces. The Nano is probably one of the most breadboard friendly boards out there today. This allows prototyping of components to be super easy. Strictly because most prototyping components are designed with 5 V in mind. This will make integration of components easier without the need to voltage regulation during the prototyping process. The Nano is also one of hobbyists most recommended MCUs right next the ESP32 due to its capability to power more powerful peripherals. This is because with a higher operating voltage, it can output more current per pin, which other lower-voltage microcontrollers can’t do.

Since the Arduino Nano has one of the best operating voltages, that means that it can have more pins. The Nano offers 14 digital I/O pins (input/output), which can support 6 PWM and 8 analog input pins. Unlike the Arduino Uno, the Nano relies on USB power (via USB Mini-B) rather than a DC power jack. The Nano can be programmed in Arduino IDE with the came code as other ATmega328P-based boards. The only downside to the Arduino Nano is that it only supports one UART, one I2C, and one SPI interface. This is due to its compact size and microcontroller limitations. Compared to other MCUs like the ESP32 and the STM32, where they support multiple UARTs, I2C, and SPI buses. However, there are ways to expand its communication capabilities. You can use a SoftwareSerial that allows for additional UART communication using digital pins. This method is slower and less reliable than traditional hardware UART. For I2C, you can use I2C multiplexers that enable multiple I2C buses on a single Nano. For SPI, you can use SPI Chip Select Management which allows for SPI devices to share the SPI hardware bus by using different chip select pins, allowing for multiple devices on one SPI interface.

Overall, the Arduino Nano has been deemed one of the best by hobbyists and developers alike. This is due to its power, compact size, and user friendliness. It has the same performance as the Arduino Uno with the processor and memory specs, just at a smaller size. With the cost anywhere between $5-$20 dollars, it makes it one of the average priced MCUs for small form factor projects. Some companies have even cloned the Nano to make it even cheaper. While all of this sounds great, the Nano does lack some I/O pins strictly due to its size but, if you need a MCU that is reliable, tiny, and overall very versatile, the Arduino Nano is for you.

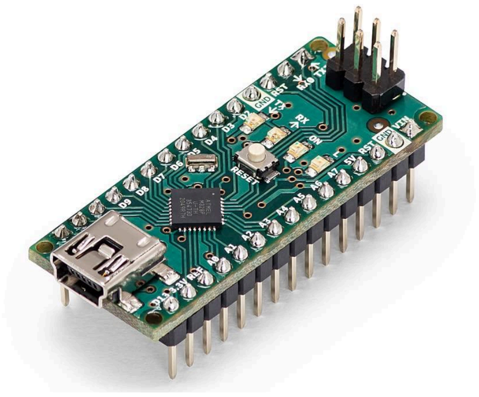


Figure 3.1.5.4.1 Arduino Nano Microcontroller

3.1.5.5 Teensy

The Teensy is a powerful and compact microcontroller development board that has gained massive popularity among hobbyists and embedded system developers. It was designed by PJRC in 2008 when the Teensy 1.0 microcontroller was released. The recent Teensy family (Teensy 4.1) features a ARM Cortex-M7 processor running at a clock speed of 600 MHz. It also has 1 MB of RAM with 8 MB of flash memory, making it suitable for a wide range of applications. The Teensy 4.1 features additional features like Ethernet and microSD card support as well. Don’t let its compact size fool you, this family of MCUs has many capabilities, with numerous GPIO pins and support for various interfaces including UART, SPI, I2C, CAN, and USB.

One of the Teensy's key strengths is its compatibility with the Arduino IDE through the Tennsyduino add-on feature. This feature allows for easy and seamless programming in C/C++. It also operates at a voltage ranging from 3.3 V - 5 V, making it super compatible with a wide range of sensors and peripherals. The Teensy is flexible enough to be used in high-performance applications requiring maximum clock speed, to low-power scenarios where conserving energy is top priority. This accessibility, combined with its high performance, make the Teensy a wonderful choice for projects that involve real-time systems. Its vibrant community and extensive documentation resources make the Teensy super appealing to developers, providing ample resources for beginners and experienced developers to explore its full potential when it comes to embedded systems.

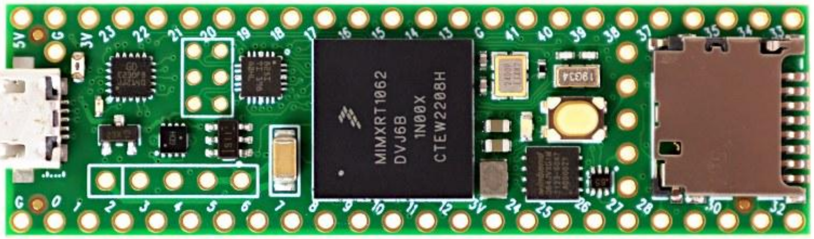
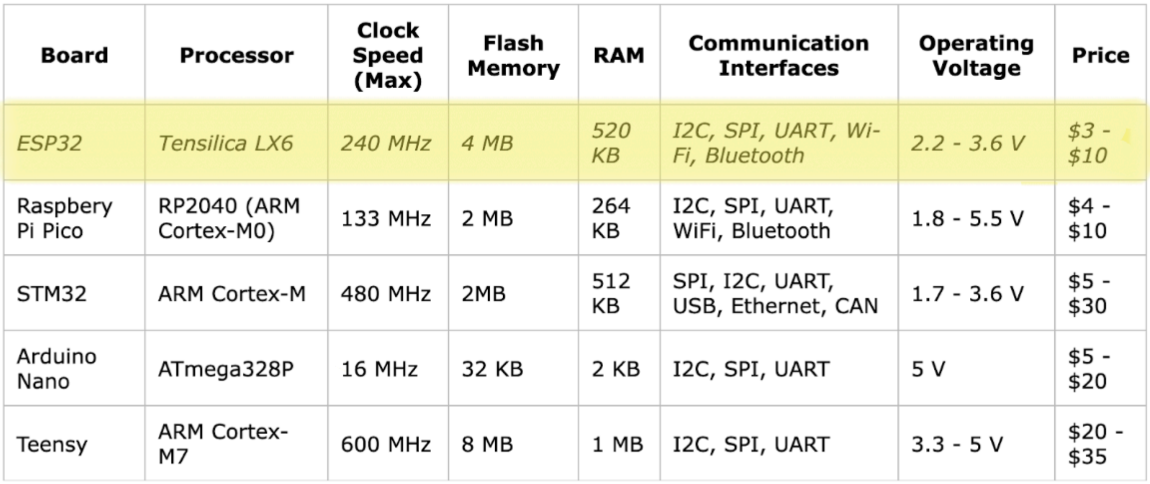


Figure 3.1.5.5.1 Teensy 4.1 Microcontroller



Board	Processor	Clock Speed (Max)	Flash Memory	RAM	Communication Interfaces	Operating Voltage	Price
ESP32	*Tensilica LX6*	*240 MHz*	*4 MB*	*520 KB*	*I2C, SPI, UART, Wi-Fi, Bluetooth*	*2.2 - 3.6 V*	*$3 - $10*
Raspbery Pi Pico	RP2040 (ARM Cortex-M0)	133 MHz	2 MB	264 KB	I2C, SPI, UART, WiFi, Bluetooth	1.8 - 5.5 V	$4 - $10
STM32	ARM Cortex-M	480 MHz	2MB	512 KB	SPI, I2C, UART, USB, Ethernet, CAN	1.7 - 3.6 V	$5 - $30
Arduino Nano	ATmega328P	16 MHz	32 KB	2 KB	I2C, SPI, UART	5 V	$5 - $20
Teensy	ARM Cortex-M7	600 MHz	8 MB	1 MB	I2C, SPI, UART	3.3 - 5 V	$20 - $35

Table 3.1.5.5.1 MCU Comparison Chart

3.1.5.6 Our Selection: ESP32

With all of the Microcontrollers that we compared, our group ended up going with the ESP32 for our microcontroller of choice. This was because of a multitude of reasons. The main reason was because it is one of the only MCUs that we researched besides the Raspberry Pi Pico that offered bluetooth. Bluetooth was essential for us because we need to connect our Safe Sight device to our app in order to view the data that it is going to capture. Also, it does offer 520 KB of RAM which is more than capable to handle our Raspberry Pi that will be our secondary system for computer vision. Even though the speed on the ESP32 isn't the highest out of all of the other MCUs that were researched, 240 MHz will be perfect for processing the data needed for the sensors and the information coming from the Raspberry Pi since all the ESP32 is going to handle is our beep sensor and the radar that is going to be installed on the PCB. Therefore, with budget in mind, we decided to go with the ESP32 for its overall power and compatibility with a majority of the other systems in our project.

3.1.6 MCU Communication Protocols For Components

3.1.6.1 UART Communication Protocol

UART stands for Universal Asynchronous Receiver and Transmitter. UART communication utilizes a serial approach, sending data bits one at a time over a wire. This protocol is asynchronous, meaning that each device relies on its own internalized clock speed and configuration to maintain the same baud rate or data transmission speed for successful communication. All devices that are compatible with UART communication will have pinouts labeled TX and RX, standing for transmitting and receiving. These pins will be cross connected to each device meaning that the RX node on one device will lead to the TX node on another. Additionally, UART communication in embedded systems is packaged into frames for efficient transmission.

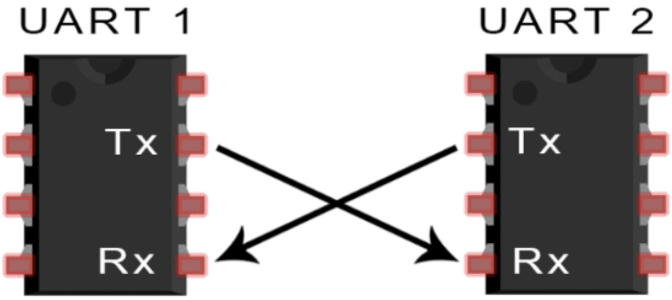


Figure 3.1.6.1.1 UART Configuration

Now the size of a serial frame being interpreted by a device in communication can vary (5-8 data bits or 1-2 parity bits). However, each and every frame being sent or received includes a starting bit, data bits, parity bits, and stop bits. Start bits are first received and are always 0, they signify the start of incoming data bits and represent a low-voltage wakeup call for the receiving device that a transmission is incoming. Furthermore, data bits in a frame are received in the order from least significant bit first to most significant bit last. Depending on the n amount of bits in the data transmission you will have 2^n amount of unique transferable characters. Leading after the most significant bit, the parity bit is set to either check for even or odd parity based on the amount of 1s in the data transmission. This parity bit is compared with the receiving device's own parity calculation bit when reading the data bits and is able to make a decision on whether or not there is a mismatch error. If the parity bit in transmission does not match the receiving device's parity bit from deciphering the frame, then a conclusion can be made that there is a transmission error. Finally, the last bit in the UART communication protocol frame is the stop bit. Opposite from the start bit, the stop bit represents the end of transmission and is always a high-voltage signal. The stop bit is 1 and following its interpretation, the receiver can prepare for the next incoming frame.

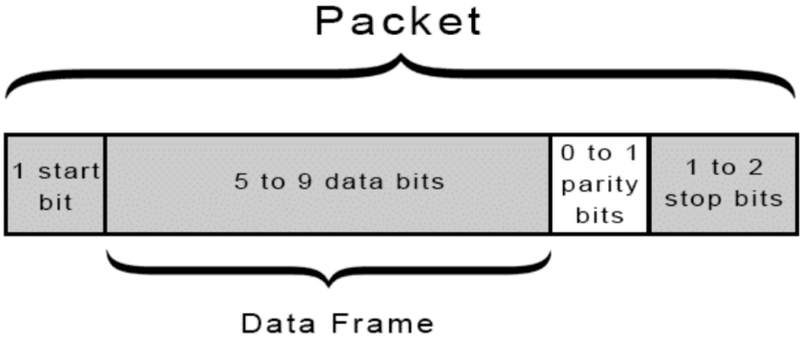


Figure 3.1.6.1.2 UART Frame

When compared to I2C and SPI, UART is slower due to its asynchronous nature but makes up for this in its universal implementation. Overall, UART communication protocol is a popular and sought after choice in utilization in embedded systems applications. Its asynchronous protocol and simple wiring design for communication provides much needed efficiency and accessibility when debugging and implementing new components and systems.

3.1.6.2 SPI Communication Protocol

SPI stands for Serial Peripheral Interface and is a synchronous type of data communication, meaning both devices are coordinating their clock speeds to run at the same transmission rate. Additionally, SPI is beneficial when compared to I2C or UART because it allows for data to be transmitted without interruption. Instead of needing to be packaged into frames and transmitted, data bits in SPI protocol can be transmitted and received in a continuous stream. The hardware consists of four different nodes for communication making it more complicated to configure. However, each node is vital in its contribution to the system.

A system communicating using SPI will have a master and slave dynamic. The master device will serve as the controlling center in this communication protocol and communicate with its individual or multiple slave devices. SPI allows for multiple devices to be connected and communicate with one another and provides a platform for complex systems to operate as one. In its configuration, SPI consists of MOSI, MISO, SCLK, and SS/CS nodes. MOSI and MISO lines of communication are for the master device to send data to the slave (Master Out Slave In) and for the slave to send data back to the master (Master In Slave Out). SCLK represents the wire for the serial clock synchronization, and SS/CS is the master select line where the master selects which slave to send data to in the case of multiple slaves.

The clock signal for this type of synchronous communication is generated by the master device and is connected to each slave to operate upon. The clock signal in SPI can be modified by using the properties of clock polarity and phase. For example, clock polarity can be set by the master to allow for communication bit signals to be sampled or transmitted with the rising or falling edge of the clock cycle. If the system using SPI has multiple slaves, they will all share the same clock node wired in parallel and have individual nodes for SS/CS to be individually accessed from the master.

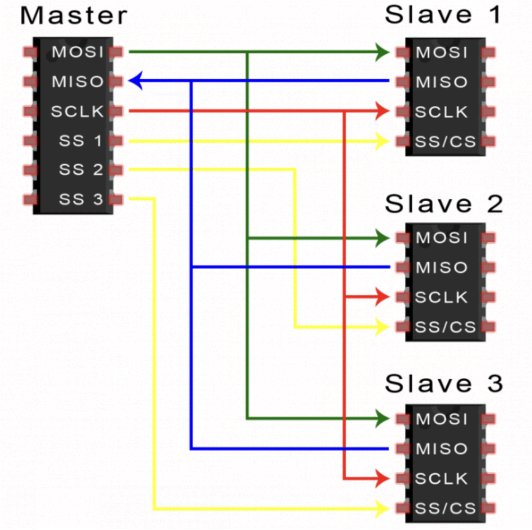


Figure 3.1.6.2.1 SPI Configuration

Disadvantages of SPI include its complicated implementation and hardware setup, absence of a method for error checking (parity bits), and configuration only allowing a single master. However, advantages of SPI include its exceptionally high speed, full-duplex communication, and no need for start and stop bits.

3.1.6.3 I2C Communication Protocol

I2C protocol (pronounced I squared C) stands for inter-integrated circuit, it is a synchronous protocol which allows for multiple slaves connected to a single master (similar to SPI) or multiple masters connected to one or multiple slaves. Similar to UART, I2C sends its data in messages that are then broken down into frames of data. Each message has an address frame that contains the binary address of the sending device and a frame containing the actual data. Furthermore, the message also includes start and stop conditions, read/write bits, and ACK/NACK bits between each data frame.

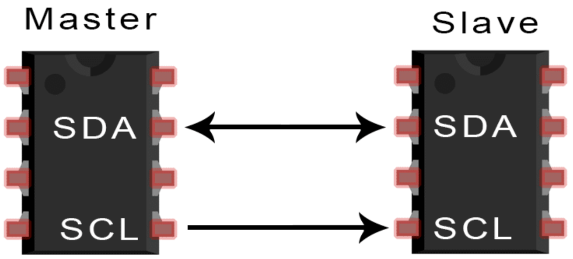


Figure 3.1.6.3.1 I2C Configuration

A scenario where a message would be sent from a master to a slave would play out as such. The master will send a message to another device connected to the SDA line by first setting the SDA line from high to low voltage and as the start condition for the message to be sent. Then, the address frame will be sent to single out the specific device that wants to be communicated with followed by a read/write bit. A read bit sent means the master will want to pull data from the receiver, and a write bit signifies that data is being sent to the receiver. After the address frame including the read/write bit is received by the receiving device, an ACK/NACK bit needs to be sent back to the master to signify that the data frame was received correctly. Now that a connection has been established between the two, data has to be sent in 8 bit frames followed by ACK/NACK bits for confirmation. Finally, when the exchange comes to an end between the two devices, the stop condition signifies the SDA line changing from low to high voltage.

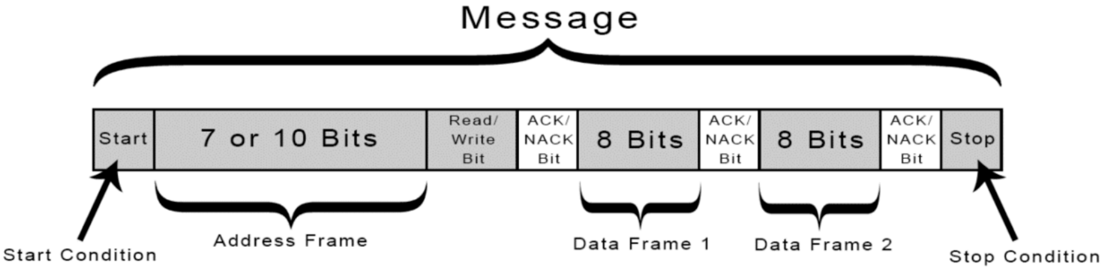


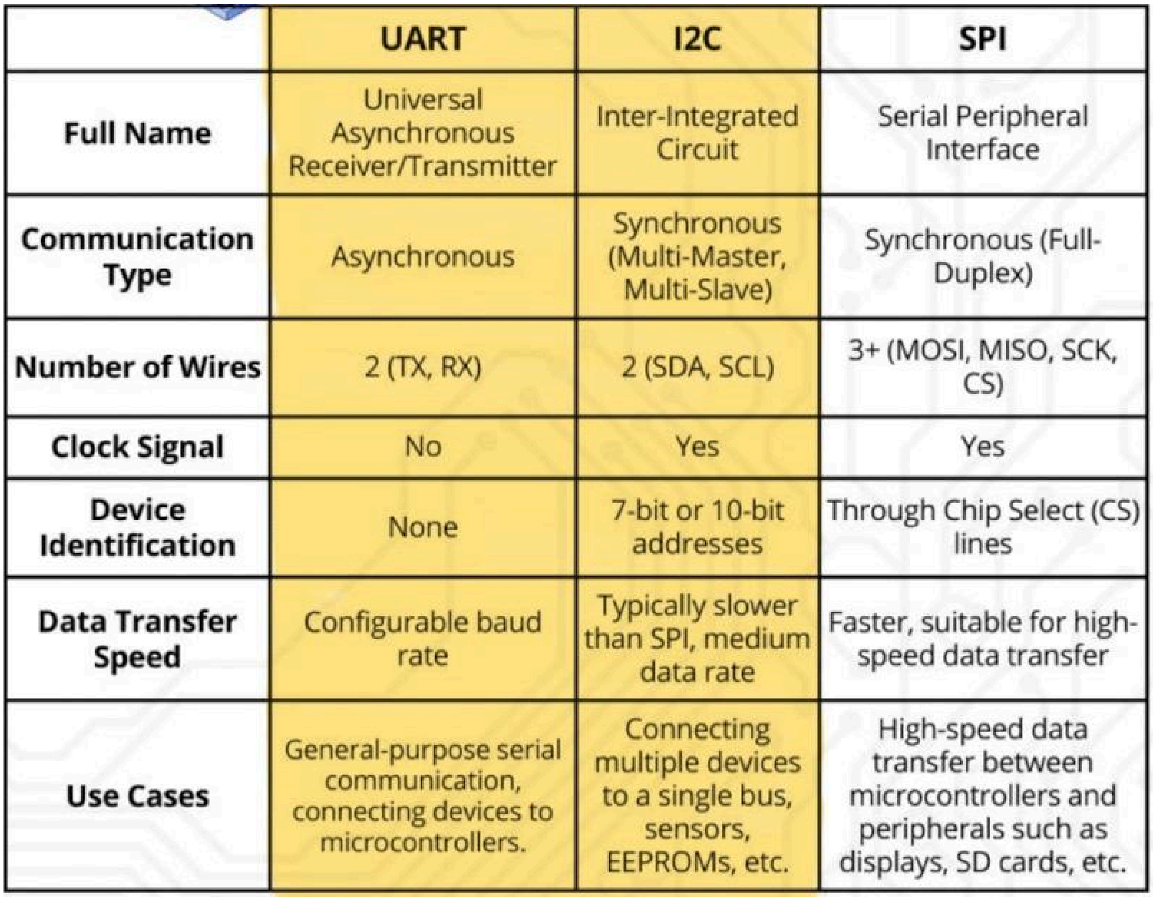
Figure 3.1.6.3.2 I2C Frame

I2C is widely used in embedded systems for its simple hardware configuration and welcoming implementation when working with multiple devices at once. Only requiring two wires and its ability to support multiple slaves and masters in one system makes it a strong choice in embedded systems projects. Hurdles with using I2C communication protocol will arise when the message being sent exceeds 8 bits and requires quick processing/speed. However, I2C is one of the most popular methods for synchronous communication amongst electronic devices.

3.1.6.4 Summary

All of the common embedded systems communication protocols discussed in this section are excellent choices, each excelling in specific applications depending on the project’s requirements.

For example, UART (Universal Asynchronous Receiver-Transmitter) is a straightforward and reliable option when an application demands basic communication with minimal setup and quick execution. It is particularly well-suited for simple, point-to-point data transfer scenarios. On the other hand, SPI (Serial Peripheral Interface) surpasses UART in situations where ultra-fast data transfer between two devices is critical throughout the application. Its high-speed capabilities make it a preferred choice for projects requiring rapid and continuous data exchange. Finally, I2C (Inter-Integrated Circuit) stands out as the ideal protocol when an application involves connecting multiple devices on the same data line bus to communicate synchronously. This makes it highly effective for systems with numerous peripherals that need to share a common communication channel efficiently. Each protocol has its strengths, and selecting the right one depends on the specific needs and constraints of the project at hand.



	UART	I2C	SPI
Full Name	Universal Asynchronous Receiver/Transmitter	Inter-Integrated Circuit	Serial Peripheral Interface
Communication Type	Asynchronous	Synchronous (Multi-Master, Multi-Slave)	Synchronous (Full-Duplex)
Number of Wires	2 (TX, RX)	2 (SDA, SCL)	3+ (MOSI, MISO, SCK, CS)
Clock Signal	No	Yes	Yes
Device Identification	None	7-bit or 10-bit addresses	Through Chip Select (CS) lines
Data Transfer Speed	Configurable baud rate	Typically slower than SPI, medium data rate	Faster, suitable for high-speed data transfer
Use Cases	General-purpose serial communication, connecting devices to microcontrollers.	Connecting multiple devices to a single bus, sensors, EEPROMs, etc.	High-speed data transfer between microcontrollers and peripherals such as displays, SD cards, etc.

Table 3.1.6.4.1 Communication Chart Comparison

3.1.7 Development Environment: Languages and Repositories

In developing SafeSight, we explored a range of programming languages and repository management tools to determine the most suitable environment for our system.

Languages such as C/C++, Java, and Python were considered based on their respective strengths in embedded systems, cross-platform application development, and rapid prototyping. Each language offered distinct advantages depending on the component of this project that was being worked on, whether it involved low-level hardware control or high-level decision-making logic, we knew what environment to use to make sure our development constraints were met.

In addition to language considerations, we needed a way to share and keep track of our code. With that being said, we examined repository platforms such as GitHub and Bitbucket to support version control, team collaboration, and streamlined development workflows. These tools play a critical role in managing code across multiple contributors and maintaining project integrity over time. The following section outlines our evaluation and final selections for the SafeSight development environment.

3.1.7.1 C/C++

C is a general purpose programming language developed by Dennis Ritchie in the early 1970's. It was originally created for constructing utilities running on Unix and later used to re-implement the Unix operating system kernel. C has since become one of the most widely used programming languages due to its efficiency, portability, and versatility. One of the main features of C is that it has low-level access to your machine. C provides direct access to memory and hardware, making it suitable for low-level programming at the system level. Static typing is also mandatory in C where the variables must be declared before use, with their respective types stated. C has often been described as a low-level language just because it is very easy and simple to use. Unlike true low-level languages like assembly, C offers a higher level of abstraction, making it more of a "middle-level" language in some contexts. Because of this, C does need to be compiled in order to be translated to assembly and then machine code in order to finally be executed and run the program. Compared to other languages like Java, C does not have many object oriented components involved in it. C is rather used more for hardware development, compared to Java, especially in embedded systems and semiconductor programming. Over time, C has significantly influenced many modern programming languages, including C++, Java, and C#. Its syntax and concepts serve as a foundation for other programming languages which is why some people refer to it as the "mother of programming languages".

3.1.7.2 Swift & Swift UI

Swift is a modern, general purpose programming language that was developed by Apple Inc. in 2010 for iOS, macOS, watchOS, and tvOS app development. It was first introduced in 2014 and has since become a primary language for Apple platform development. Swift is known for its safety. It was designed with a feature called optionals, this feature handles null and undefined values without the risk of runtime crashes. This was designed in order to eliminate entire classes of unsafe code therefore, reducing risk. Swift offers high performance compared to other C-based languages. Apple claims that search algorithms in Swift can be up to 2.6 times faster than Objective-C and up to 8.7 times faster than Python 2.7. Swift also uses a very modern syntax that results in very clean and well organized code. This allows a programmer to write less code to perform the same tasks as other languages. Compared to C, Swift uses Automatic Reference Counting (ARC) to handle memory allocation and deallocation automatically. ARC is a memory management mechanism that automatically tracks and manages the app's memory usage. It ensures that objects are kept in memory as long as they're needed and released once they are no longer in use. ARC has a reference counting style. Every instance of a class keeps track of how many strong references point to it. When a new strong reference is made, the reference count increases, and when a reference is removed, it is decremented. When the reference count hits 0, then the object is automatically deallocated, freeing up memory unlike many other languages where you have to use free() to deallocate memory manually. Since 2015, Swift has become open-source, which has gained a massive community and ecosystem of developers all around the world.

Swift UI is a user interface toolkit introduced by Apple in 2019. It allows developers to design and develop user interfaces for all apple platforms using Swift. Swift UI uses Swift as its main programming language. While SwiftUI focuses on the UI construction, Swift is used for all aspects of app development, including logic, data handling, and backend operations. This toolkit brings over Swift's declarative syntax. This allows developers to state what the user interface should do, making the code more intuitive and easier to read. SwiftUI offers a real-time preview of your interface as you code, so you don't have to build and compile your code each time you want to test, therefore, making the development process more efficient. With all of the different features Apple offers to their clients, SwiftUI has support for Dark & Light Mode and Localization just by a simple toggle. Reducing the amount of code that developers need to write. The only downside between Swift and SwiftUI is compatibility. Since these frameworks are a part of the Apple ecosystem, when it comes to Android development, there is little to no compatibility for application development, the developer would need to seek other options to develop for all platforms. However, since this project is a prototype, we can focus on developing for the masses later on after our prototype is complete. Therefore, these two platforms together provide a powerful toolset for developing applications across Apple's ecosystem, offering improved safety, performance, and developer productivity.

3.1.7.3 Java

Java is a versatile, object-oriented programming language developed by James Gosling in 1995. It is both a programming language and a software platform that has become one of the most popular development platforms worldwide. Due to Java's portability and versatility, it has been deemed as a "Write Once, Run Anywhere" kind of language. Since Java is an object-oriented language, it makes it easy to organize and structure code in classes. Java code can be compiled and ran on any platform with a Java Virtual Machine on it without the need to recompile. Once the Java code is compiled into machine code (Java Bytecode), it is then executed on the machine using a JDK (Java Development Kit). Some key concepts of an object-oriented language like Java are classes, objects, encapsulation, inheritance, polymorphism, and abstraction. All of these processes make any project that is developed in Java, reusable, scalable, and easily collaborable. Reusability is important because it allows users to create an object only once throughout the project, and reuse it as many times as needed, without having to rewrite it. Scalability is important because it allows developers to debug easily while testing individual classes separate from one another. This can make a group project easy to scale due to everyone being able to test their own class or object without interfering with other developers' code. Collaboration is important work can be delegated super easily, by giving each developer separate classes and objects, making it easier to work on. Java is mainly used in Web Development, Android mobile applications, machine learning, etc. In 2022, Java is still one of the most popular programming languages, ranking third on the GitHub list. For new developers, Java is super easy to learn and it is secure so developers don’t have to worry about compromised data. In conclusion, Java’s combination of simplicity, portability, and robust features have ensured its continued relevance in the evolving world of programming languages.

3.1.7.4 Python

Python is a high-level, general-purpose programming language that is known for its simplicity, readability and versatility. It was invented by Guido van Roussum in 1991. It is typically developers first coding language because it is easy to learn and use. Python uses English-like syntax and indentation for code blocks, making it more accessible to beginners. It is also an interpreted language, meaning that Python is executed line by line, making it easier to debug and test. Developing in Python is also super efficient due to the fact that Python doesn’t need explicit type declarations. Like Java, Python is also an object-oriented language and supports object-oriented principles as well. Python is also a cross platform language that runs on various operating systems with an extensive standard library that has a comprehensive set of modules and functions that can be used for web development, AI, data science, software development, etc. Since its release, Python has a large and very active community that is constantly growing and finding new ways to utilize and improve. Overall, Python is a very powerful language that would allow beginners and experienced programmers alike to create strong, robust applications in the fields of data science, web development, and artificial intelligence.

3.1.7.5 GitHub

GitHub is a cloud-based platform that revolutionizes software development collaboration and version control. Founded in 2008 by Tom Preston-Werner, Chris Wanstrath, P.J Hyett, Scott Chacon and later acquired by Microsoft in 2018, GitHub has become the world’s largest source code host, with over 100 million developers. A GitHub repository can either be private, public or open-source, making it super accessible to anyone in the development community. GitHub primarily works using a version control concept. Meaning, that a person can “clone” a repository to make changes to it either on the “main” branch or their own development branch. Once they are done with making changes, they can then upload those changes and “merge” with the existing repository to push those changes and test. This process of merging and creating new versions makes collaboration almost effortless because it allows developers to edit as a group without stepping all over each other's changes.

The GitHub platform uses Git to help maintain versions of repositories. Git was invented in 2005 by Linus Torvalds. It was developed to address the needs of managing the Linux kernel source code, which required a system that could handle large-scale distribution of software. Git helps keep track of changes to files over time by tracking changes as “Commits”. Commits are recorded snapshots of the project at a specific point in time. This is extremely useful because if the project somehow becomes corrupt or the code gets messed up somehow, you can actually go back to a previous commit to revert the changes that messed up the project without having to start all over. Some of the benefits of using Git include but are not limited to speed, data integrity, staging capability and flexibility. Git allows users to organize and stage their changes so that developers can review them before sending them off to merge with the rest of the project. Developers can do this efficiently with the commands that Git comes with as well. To ensure data integrity and safety, Git uses SHA-1 hashes to ensure that data doesn't become lost or corrupted. SHA-1 hash is a cryptographic function that creates a 160-bit hash value from a single input. It was designed by the U.S. National Security Agency in 1995 and has since become the standard in data security. Overall, using Github is not only secure, it is also efficient and perfect for all group projects due to its versatility, user-friendliness, and collaborative potential.

3.1.7.6 Bitbucket

Bitbucket is a cloud-based Git repository system designed by Jesper Nøhr as an independent startup company in 2008 and officially launched in 2010 when it was acquired by Atlassian. Bitbucket is very similar to GitHub, where it allows a group of developers to actively work on a software project together. Bitbucket also uses version control to help control data inside of repositories. The main difference between GitHub and Bitbucket is that Bitbucket has other softwares like Trello and Jira built into it that helps developers work more efficiently. Jira helps developers detect bugs easily and provides suggested fixes to the code in order to make the debugging process more efficient. Trello makes cards with tasks for the developer that get added to a calendar that helps tell the group what needs to get done each day. Even though it would make sense with more features to gravitate towards Bitbucket, it does have a cost of use which turns users away from it. GitHub is free to use and is mainly used by the public community to share code and projects with each other while Bitbucket, has been adopted by many corporations and private developers to help them stay on top of their tasks on a corporate level. As of 2025, Bitbucket continues to evolve, offering features like native security tools, premium platform support, and flexible planning tools.

3.1.7.7 Our Selection: C/C++, Swift/SwiftUI, Git/GitHub

Technology	**Pros**	**Cons**
C/C++	- High performance and low-level control - Widely used in embedded systems - Portable across platforms	- Steep learning curve - Manual memory management - Error-prone and verbose
Swift/SwiftUI	- Modern and safe language - Great for iOS/macOS development - SwiftUI enables fast UI design	- Limited to Apple ecosystems - Smaller community compared to others
Java	- Strong object-oriented support - Cross-platform via JVM	- Verbose syntax - Slower than C/C++ in some use cases

	- Large ecosystem and support	
Python	- Easy to learn and use - Rapid development and prototyping - Vast library support	- Slower performance - Limited for low-level hardware interaction
Git/GitHub	- Popular and well-documented - Great collaboration tools - GitHub Actions for CI/CD	- Public by default (without paid plan) - Can be overwhelming for beginners
Bitbucket	- Free private repositories - Integration with Jira and Trello - Supports Git and Mercurial	- Smaller user community - Fewer integrations compared to GitHub

Table 3.1.7.7.1 Pros and Cons of Development Technologies

When it came down to our development environment, the thing that was most important for our group was familiarity. We wanted to keep this project as simple as possible with the resources and technologies that we already knew. The whole purpose of this project was to put together the knowledge that we have already learned throughout our college engineering careers. Essentially, we didn't want to have to learn a whole new programming language or a new repository system when we could have just used one that we all have used before. With this being said, we decided to use GitHub as our main repository system so that way we can all collaborate on this project together. Everyone in our group has used GitHub at least once before, so this will allow an easy transition for this project.

The Github community has an abundance of open source code that will become useful in development for our ESP32. Having GitHub also makes it super easy to transfer files to one another while collaborating, which is what we loved so much about it. As far as planning softwares go, GitHub does not have any of those, but Trello or Jira can always be used separately for helping us plan our project milestones.

For our programming languages, we decided to go with C/C++ and Swift/SwiftUI. For our ESP32, C/C++ will work best and it is also what we are most familiar with, so we can just polish our skills on this project. Everyone has also worked with microcontrollers before using C/C++, so this will make it so much easier to develop a working prototype. For our application, Swift/SwiftUI was an easy option considering that Matthew has worked with them before developing iOS applications. Since SwiftUI is super user friendly with a real-time preview, it'll make developing an application super efficient and easy. SwiftUI also has plugins for allowing bluetooth connections to external devices, which will make integrating the application with our device a breeze. We can also test our application on our own devices since we all have iPhones. This will make the development process more streamlined rather than using an android development software.

3.1.8 Computer Vision

To enhance driver awareness and ensure real-time responsiveness, computer vision plays a vital role in the SafeSight system. We explored software frameworks such as OpenCV and TensorFlow/TensorFlow Lite to evaluate their capabilities in supporting image processing and machine learning on embedded devices. These tools were considered for their ability to process visual input from an onboard camera and perform key tasks such as detecting traffic lights, recognizing road elements, and monitoring driver attention. The following section outlines different CV softwares and models that we explored along with their benefits and disadvantages from each other.

3.1.8.1 OpenCV

Computer Vision is a field of study with a goal that enables machines to gain an understanding of visual information. OpenCV (Open Source Computer Vision Library) is an open-source computer vision library for machine learning that is used worldwide by hobbyists, researchers, and developers. OpenCV’s library includes image and video processing, object detection and tracking, facial recognition, and machine learning integration. Computer Vision and libraries such as OpenCV, require loads of data and training to learn and classify images. Classifications made by humans everyday can be replicated and even surpassed in their accuracy/speed with the help of intensive AI training algorithms in computer vision.

3.1.8.2 Tensorflow and TensorflowLite

Tensorflow is another open-source computer vision library developed by Google that supports a wide range of technologies. Examples of technologies that Tensorflow uses are as follows: neural networks, dataflow graphs, tensor processing units (TPUs), Eager execution, Auto differentiation, distributed computing, and high level APIs. Neural network technologies are applied to tasks like image recognition and natural language processing and are employed by tensorflow’s data flow graphs to represent computations. Nodes in these graphs represent mathematical operations, while edges represent multidimensional data arrays (tensors). This flexible architecture allows for efficient execution and processing across GPUs, CPUs, and TPUs. This allows for universal application across various platforms ranging from desktop computers to high-end servers.

A decade ago, researchers at NVIDIA found that GPUs are useful at matrix operations and can be utilized as a supercharger for compute-intensive tasks. This is made possible because of GPUs massive parallel core architecture, allowing for thousands of efficient cores to be launched in parallel threads. As a result, tensorflow runs 50% faster on the latest NVIDIA GPU. In summary, TensorFlow integrates cutting-edge AI technologies such as neural networks, TPUs, distributed computing, and high-level APIs to enable scalable machine learning solutions across various domains. Its flexibility makes it a cornerstone tool for developing state-of-the-art AI applications.

3.1.8.3 Keras

Keras provides tools for creating neural networks using simple, modular components such as layers and models. Keras supports multiple backends, however it is tightly integrated with tensorflow, making it especially powerful for scalable learning machine workflows. Having easy integration with all TensorFlow projects, Keras can be installed easily for implementation with a simple pip command. Acting as a high-level API within TensorFlow, Keras simplifies tasks such as model definition, training, evaluation, and deployment. An API stands for Application Programming Interface and functions as a set of rules or specifications that allows different software applications to communicate with one another, sharing functionality. Keras supports various data formats such as NumPy arrays, and Pandas DataFrames, integrating seamlessly with TensorFlow datasets. In summary, Keras serves as a bridge between high-level model development and efficient execution through TensorFlow. Its integration into platforms like Teachable Machine demonstrates its versatility for both beginners and advanced users in machine learning workflows.

3.1.8.4 YOLO

YOLO stands for "You Only Look Once" and is a real-time object detection algorithm that processes an entire image or frame with a single pass through a neural network. This means that YOLO treats object detection as a regression problem, predicting both the bounding boxes and classes of objects simultaneously. The algorithm works as such, an image is taken or received, divided into a grid of cells, each cell's bounding box coordinates and prediction is made, overlapping predictions are filtered to maintain most confident predictions, and finally the objects are returned with their most confident bounding boxes and confidence scores. This single-stage object detection method makes YOLO an algorithm applicable to real-time processing speed scenarios. Strengths of YOLO include processing images at around 150 frames per second, single-pass architecture proves higher efficiency than other algorithms, and integrates with frameworks like PyTorch and TensorFlow. On the other hand, YOLO's single-pass architecture shaped for efficiency and speed has its weaknesses. YOLO's grid based approach can struggle to detect small or multiple objects, sacrificing accuracy for speed. However, YOLO remains one of the most widely used object detection algorithms due to its unmatched speed and versatility in real-world applications where rapid decision-making is critical.

3.1.8.5 Scikit-image

Scikit-Image is an open-source Python library for image processing and computer vision. It is part of the broader scientific Python ecosystem and is built on top of foundational libraries like NumPy and SciPy. Scikit-Image provides a wide range of tools for manipulating, analyzing, and enhancing digital images, making it a popular choice for researchers, engineers, and developers working on image-related projects. The library emphasizes accessibility, offering a user-friendly API that integrates seamlessly with other scientific Python tools like Matplotlib and Scikit-Learn. It supports tasks such as filtering, segmentation, feature extraction, morphological operations, and geometric transformations. Scikit-Image is widely used in fields like medical imaging, astronomy, robotics, and more.

Table 3.1.8.5.1 Computer Vision Comparison Table

Framework	Capabilities	Ease of Use	Speed	Accuracy	Best Use Cases
OpenCV	Comprehensive library for image/video processing, object detection, tracking, facial recognition, and machine learning integration	High (simple APIs)	Fast	High	Real-time applications involving color/shape labeling
TensorFlow/ TensorFlow Lite	Advanced deep learning framework supporting neural networks, TPUs, dataflow graphs, and distributed computing. TensorFlow Lite enables deployment on mobile/edge devices	Moderate	Moderate	Very High	Deep-learning based object detection, facial sentiment analysis
Keras	High-level API for building neural networks with TensorFlow backend, simplifies model creation, training, and deployment. Supports integration with datasets like NumPy arrays and Pandas DataFrames.	Moderate	Moderate	Very High	Custom object detection tasks that require high precision
YOLO	Real-time object detection algorithm that processes images in a single pass through a neural network. Optimized for speed, but struggles with small/multiple objects due to grid-based architecture.	Moderate	Very Fast	High	Real-time application in surveillance, human posture detection, and self-driving cars
Scikit-Image	Filtering, segmentation, feature extraction, morphological	High	Moderate	Moderate	Simple image processing tasks including basic object/face

	operations, and geometric transformations.				detection

4. Standards and Design Constraints

In engineering and technology development, a standard refers to an established set of guidelines, specifications, or practices designed to ensure quality, safety, interoperability, and reliability across systems and components. Adhering to relevant standards is critical when designing systems like SafeSight, which directly interact with users in real-world environments such as roadways and vehicles.

Alongside standards, design constraints, such as hardware limitations, power consumption, cost, real-time performance, and environmental factors also play a crucial role in shaping system architecture and functionality. In this section, we examine the specific standards relevant to embedded systems, wireless communication, and safety protocols, as well as the constraints that influenced our design decisions throughout the development of SafeSight.

4.1 Industrial Standards

Industrial standards are formalized guidelines and specifications developed by recognized organizations to ensure that products and systems are safe, reliable, and compatible across various industries. These standards are created by organizations such as the International Organization for Standardization (ISO) and the Institute of Electrical and Electronics Engineers (IEEE), and serve to unify technical practices across industries. These standards are especially important in sectors such as automotive, electronics, and communication, where information, safety, and performance are critical.

In the context of SafeSight, aligning with industrial standards helps ensure that the system operates safely alongside existing automotive technologies, communicates effectively with peripheral devices, and meets expectations for long-term reliability and regulatory compliance. By referencing these standards, we were able to design a system that aligns with industry best practices and prepares the project for potential future scalability and integration. This section outlines the relevant industrial standards we considered, including those related to embedded hardware, sensor communication, and automotive safety systems, and discusses how they influenced our design and fabrication.

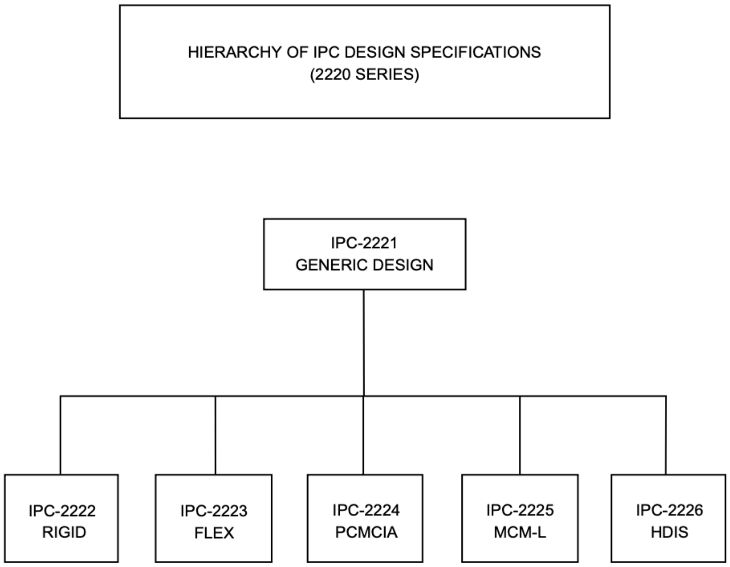
4.1.1 PCB Design Standards

Printed circuit boards (PCBs) are everything in the electronics world. They support everything from TVs to wearable smart watches. While PCBs are essential for everyday life, how can we ensure that our devices and machines work as expected? Standards. The Institute for Printed Circuits (IPC) was developed to support electronic consistency and safety in manufacturing PCBs. They have developed a set of standards that have become known as the IPC standards that ensure manufacturers create safe and consistent products. The IPC has over 300 standards that cover the entire PCB lifecycle, not just the manufacturing processes.

For this project, our PCB manufacturer of choice is going to be JLC PCB, so their standards are going to be used. Their standards include maximum and minimum thickness, clearness, required diameters and required export file formats. Our manufacturer has a wide range of capabilities for this project's Rigid PCB design. JLC PCB allows anywhere between 1-32 layers of copper with a choice of four materials, FR-4, Aluminum-Core, Copper-Core and RF PCB. The dimensions can range from 3 mm x 3 mm - 670 mm x 600 mm. Essentially, you can make it as big, or as small as you want since the dimensions that they allow are such a huge range. Depending on the material and layer count, you can range from 0.8 mm - 4.5 mm of thickness in your PCB. They offer a variety of colors for the solder mask such as green, purple, red, yellow, blue, white, and black as well to suit any project. When it comes down to the drilling of the PCB, JLC PCB can range from 0.3 - 0.63 mm for one layer, 0.15 - 0.63 mm for two layers, and 0.15 - 0.63 mm for 2+ layers. The via hole-to-hole spacing is 0.2 mm with a pad spacing of 0.45 mm. For more experienced engineers, you can make your traces as small as 0.1 mm for one layer, and 0.16 mm for 2 layers. The minimum distance from track to the edge of the board is 0.3 mm.

IPC-2221 guidelines are for the design of PCBs. This standard involves a wide range of aspects related to PCB design to ensure reliability, feasibility, and performance of all PCBs.

Figure 4.1.1.1 Hierarchy of IPC Design Specifications



IPC-2221 Generic PCB Design Specifications addresses many different guidelines to ensure that quality, safe, and reliable PCBs are designed and manufactured. Some of the key points that IPC-2221 addresses are:

- **Design Requirements:** IPC-2221 establishes fundamental design principles for various types of PCBs, including rigid, flex, and hybrid boards. These principles and guidelines are essential for achieving proper layer stack-up, trace routing, component placement, and power management.

- **Material Considerations:** The IPC-2221 provides guidance on selecting PCB base materials, including laminates, substrates, and surface finishes. It considers properties like dielectric constant, thermal conductivity, and moisture absorption to provide the best recommendations for material selection to meet the performance requirements for the electronics under different conditions.

- **Electrical Performance:** IPC-2221 covers specifications such as signal integrity, impedance control, and electromagnetic compatibility (EMC). It also defines standards for trace width, spacing, and controlled impedance. It ensures that there are no stubs and sharp angles in traces to ensure signal integrity. To achieve high-speed PCBs, IPC-2221 uses differential pair routing to transfer high-speed signals via different platforms like USB, HDMI, and Ethernet in order to achieve a clear return path for signals over continuous ground planes. This is a critical area in the IPC-2221 standards to ensure reliable, high-speed PCB functionality.

- **Mechanical Considerations:** IPC-2221 defines standards for PCB manufacturing. It creates standards for PCB board thickness, hole size, and aspect ratios. Standard board thickness has been defined as 1.57 mm, but you can use other thicknesses based on number of layers, copper weight and the expected stress of the application on the PCB. The IPC-2221 defines minimum and maximum diameters for holes in order to ensure reliable plating and structural integrity. It also covers mechanical constraints such as warpage, bow, and flexural strength. It sets limits on the acceptable warpage to ensure the PCB remains as reliable and as optimal without any warpage. Under mechanical considerations, it also covers topics for cutouts and slots, PCB board edge clearances, and guides for mounting holes. This is essential for determining that our PCB will be physically durable and manufacturable.

- **Thermal Management:** Heat and temperature of PCBs are essential to make sure boards don't overheat and that our components dissipate that heat as best as possible. IPC-2221 offers recommendations for heat dissipation, thermal vias, and component placement based on different conditions. It also addresses design considerations for thermal expansion and contraction which will help not cause damage to components when they are under stress. Thermal management is essential to ensure reliability in everyday devices.

- **Manufacturing and Fabrication Guidelines:** IPC-2221 covers design rules for manufacturability (DFM) to ensure cost-effective production. It talks about how easy the fabrication, assembly and testing can be when the rules are followed. It defines hole sizes, pad geometries, and drill tolerances for various PCB classes to reduce the likelihood of manufacturing problems and ensures efficiency of the overall production process. It has become one of the most critical concepts for PCB design to this day. The DFM in the IPC-2221 gives engineers tips and guides them in order to ensure their fabrication process goes as smoothly as possible, without any errors or setbacks.

- **Plating and Finishing:** The IPC-2221 details requirements for plating thickness depending on the material (copper, tin, gold, etc.). It also has rules in order to prevent oxidation of certain materials and improve the solderability of your PCB to increase its overall lifespan. Based on the material, it covers surface finishes such as HASL, ENIG, and immersion silver to ensure electrical performance and enabling long term corrosion resistance.

- **Reliability and Testing:** The IPC-2221 gives engineers recommendations on design practices that support long-term reliability. It establishes criteria for electrical testing, thermal cycling, and mechanical stress tests. It outlines environmental considerations for optimal testing such as humidity, temperature extremes, and vibration. This will help make sure the PCB will endure its intended operating environment. This section talks about different reliability classes ranging from 1-3. 1 being general electronics, 2 being electronics for industry and 3 being high-reliability electronics for the medical, aerospace and the military. Each reliability class has different standards that the electronics need to meet in order to remain reliable to its intended use. When it comes to testing, there are different categories of testing, ranging from electrical testing, to chemical and material reliability. The IPC-22221 have standards to run tests until complete technological failure. This is to ensure that these products are ready for the everyday environment and to take information to improve the next generation of products.

- **Component and Soldering Considerations:** The IPC-2221 provides engineers with guidelines for land patterns, annular rings, and pad design for through-hole and surface-mount components for PCBs. It helps ensure compatibility with soldering processes like wave soldering and reflow soldering.

- **Design for Assembly (DFA) and Design for Test (DFT):** The IPC-2221 recommends best practices for component orientation, spacing, and accessibility. This helps manufacturers with the fabrication process to ensure all components fit properly and there are no issues with installing the components. It also specifies test point placements for in-circuit testing (ICT) and boundary scanning to ensure PCBs are designed for real-world application testing and not for just simulation. This will assist in faster assembly, lower production cost, troubleshooting, etc.

Overall, the IPC-2221 serves as a complete guide for PCB design, providing a key framework for creating reliable, efficient and durable electronic systems. These standards will be utilized in this project as a guide for us to send a PDB design to be fabricated at minimal cost and receive a properly functioning, and reliable PCB.

4.1.2 UART Communication Method Standards

The Universal Asynchronous Receiver/Transmitter (UART) is an asynchronous serial communication interface that is found in nearly every embedded system, MCU, and peripheral device. Unlike other complex protocols such as USB or Ethernet, UART does not define a rigid protocol stack. Instead, it defines a method for sending and receiving serial data, with the electrical characteristics and standards of the industry. Over the years, several standards have become well established within the industry. Standards such as RS-232, RS-422, and RS-485, that define both the electrical and mechanical properties of UART-based systems.

For starters, UART communication is based on a simple data structure that includes one start bit, five to nine data bits, an optional bit for error detection, and one to two stop bits (Refer to *Figure 3.1.6.1.2)*. This allows for asynchronous communication between two devices without requiring a single, shared clock signal. For UART to work, both the transmitting and receiving devices must be configured with identical communication parameters (baud rate, data length, parity and stop bits) for successful transmission. In UART, the start bit signals the beginning of a data frame, followed by the payload, then the error detection bit, then the stop bits to indicate the end of the data transmission. This framework structure allows UART to be extremely reliable in a multitude of systems ranging from slow, low-speed debugging consoles to fast, high-speed GPS and Bluetooth devices.

While UART defines the actual communication format, the actual physical and electrical signaling is handled by other external standards. The most common among these standards is the RS-232, which deals with voltage levels and different connector types for serial communication. UART signals need to be converted to RS-232 voltage levels using line drivers and receivers. RS-232 transmits a logic ‘1’ as a voltage indicator anywhere between -3V and -15V and a logic ‘0’ for voltages anywhere between +3V and +15V. This goes to show that RS-232 effectively uses negative logic compared to typical digital logic levels. RS-232 is specifically designed for point-to-point connections for distances up to 15 meters with baud rates up to 115.2 Kbps or higher. RS-232 has been widely adopted for PC serial ports and remains useful for major industrial and government equipment.

Sometimes, data needs to be sent over long distances. To solve this, UART often uses RS-422 or RS-485 standards. The RS-422 standard only supports one transmitter with multiple receivers, while the RS-485 standard supports multiple transmitters with multiple receivers on the same differential pair of lines, allowing for multipoint communication. These standards use differential signaling, which is beneficial for reducing noise and increasing distance. These signals support higher data rates than single ended standards like RS-232. RS-485 is often found in automation, control systems, and other environments where long distance communication is crucial.

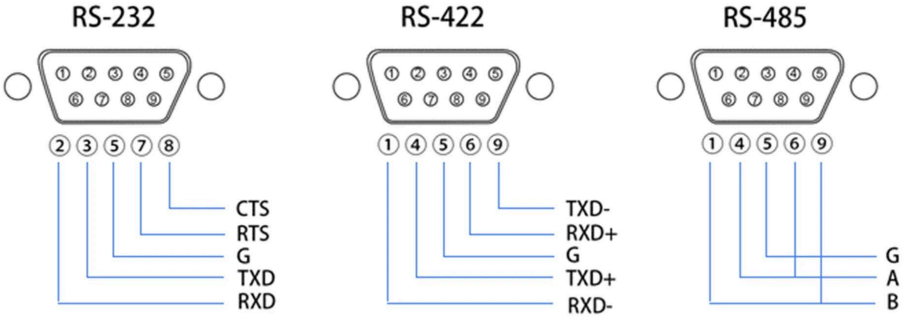


Figure 4.1.2.1 Comparison of UART Standards

In today’s modern embedded systems, UART is used in the logic-level form or TTL UART, where communication occurs directly between integrated circuits that are using standard logic voltage levels such as 5V, 3.3V or 1.8V. This type of UART, often used between a MCU and its peripherals, does not conform to the RS-232 voltage levels and can’t be directly connected to RS-232 ports without performing some kind of level shifting. TTL UART is simple, efficient, and effective, but careful action must be taken to match the voltage levels between devices in order not to damage them.

Since UART has no control mechanism built in, systems will often implement flow control in order to prevent data loss during high-speed or buffered communication scenarios. For hardware, control flow used additional lines such as RTS (Request to Send) and CTS (Clear to Send) in order to manage data transmission. These lines are typically a part of the RS-232 specification. On the other hand, software flow control uses control characters such as XON/XOFF, which are embedded into the data stream to pause and resume data transmission. Flow control is especially important in systems where one device has a limited buffer capacity or is extremely slower than the other.

There is not a standard baud rate that is defined by UART, but among the community, there has become a set of commonly accepted values for different hardware and operating systems. These include 1200, 2400, 4800, 9600, 19200, 38400, 57600, and 115200 bps. There are even higher baud rates like 230400, 460800, and 921600 which are available on more modern devices. Most peripherals for UART allow for flexible configuration though internal clock division or dedicated baud rate generators.

While UART does not define protocols beyond its framing, higher-level protocols such as AT commands and Modbus RTU are often layered on top of UART links in order to enable structured communication. For more demanding and modern applications, there are additional standards such as IEEE 1149.1 (JTAG) for boundary scan testing or for SoCs (System on Chips) and other modern technology.

In conclusion, while UART isn’t governed by a single protocol or standard, its operation is shaped by widely accepted conventions and physical layer standards such as RS-232, RS-422, and RS-485. These standards help define voltage levels, cable requirements and signal types. This will ensure that UART communication is as robust and versatile as possible. By understanding these widely accepted conventions, along with the best practices for testing, framing, flow control, and signal integrity, designers can effectively implement UART in both simple and complex systems.

4.1.3 I2C Protocol Standards

As mentioned in Chapter 3, the I2C protocol, is a widely adopted, synchronous, multi-master, multi-slave, serial communication protocol developed by Philips Semiconductor in the 1980’s. It was designed for integrated circuits to communicate on the same PCB, making it essential for slow, short distance communication within the same embedded system.

I2C operates over two bidirectional open lines: the Serial Data Line (SDA) and the Serial Clock Line (SCL). These lines are connected to a common supply voltage (typically 3.3 V or 5 V) and are pulled up. The devices on the bus can pull the line down, but they can’t drive it high. This will ensure that the communication between multiple devices is safe and there are no serial conflicts. This protocol supports multiple masters and multiple slaves, meaning that any master device can communicate and transfer data to any slave within the system.

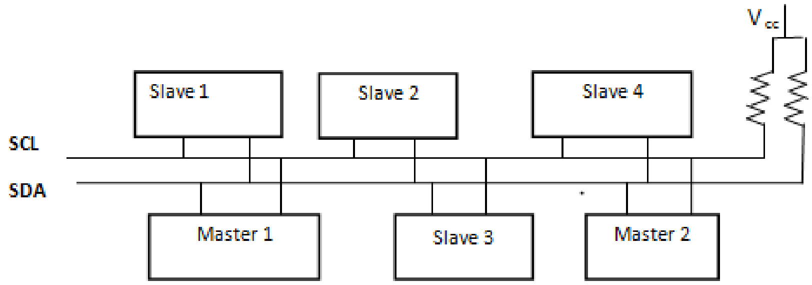


Figure 4.1.3.1 I2C Multi-Master Multi-Slave Communication

Since I2C communication is synchronous, each data transfer begins with a start condition (high-to-low transition on SDA while SCL is high) and ends with a stop condition (a low-to-high transition on SDA while SCL is high). Data is transferred in packets of 8 bits (1 byte) followed by a 1 bit acknowledgment (ACK/NACK). A 7 bit address field has become the most common format because it allows up to 127 different slave devices on a single bus. For larger systems, an extended 10 bit addressing mode is supported (Refer to Figure 3.1.6.3.2).

The I2C protocol has developed a standard for several bus speeds:

- **Standard Mode:** Up to 100 Kbps
- **Fast Mode:** Up to 400 Kbps
- **Fast Mode Plus (FM+):** Up to 1 Mbps
- **High-Speed Mode (HS-Mode):** Up to 3.4 Mbps

What's great about I2C devices is that the devices that support different speed modes can coexist on the same bus. This is of course if the master initiates communication at the appropriate speeds depending on the device. However, all devices must support the lowest common speed if switching mechanisms are not used.

Electrical characteristics and timing requirements for I2C are defined and maintained by NXP Semiconductors in the I2C-bus specification. This specification outlines detailed constraints on rise/fall times, bus capacitance, pull up resistor values, and certain voltage thresholds. For example, the total bus capacitance should never exceed 400 pF because it limits the cable length and number of devices that can be added. Choosing pull-up resistor values (typically between 1 KΩ and 10 KΩ) is crucial for maintaining reliability and signal integrity.

In the end, the I2C protocol is set by a well-defined standard that allows for reliable, low-cost, two-wire communication among chips on the same board. I2Cs use of multiple addressable slave and master devices, along with its simple hardware interface makes it highly versatile. Whether in small networks or in complex systems, I2C remains a fundamental tool for embedded systems development.

4.2 Design Constraints

Throughout the development of SafeSight, a number of design constraints helped shape a handful of our engineering decisions. These constraints define the boundaries within which the system must be developed and deployed, often balancing performance, cost, safety, and feasibility.

Key constraints we considered include time limitations due to project deadlines, economic factors related to component affordability and scalability, and compliance with federal regulations governing vehicle safety and electronics. In addition, we prioritized health and safety considerations to ensure the system does not distract or endanger the driver, and manufacturability to support the potential for real-world production and deployment down the road. The following section details how each of these constraints impacted our design process and the decisions made to meet both technical and practical requirements.

4.2.1 Time

For this project, one of the main constraints is time. Since this project is a Senior Design only project, it gives us only a certain amount of time to complete it by fabricating our idea and design to bring our vision to life. Due to this, there are some decisions that must be made with time in mind that will help us meet deadlines rather than taking longer to build a better project but possibly not completing the project.

One crucial issue was the time constraint because we were limited to one academic calendar year to make a fully functional, flawless prototype. Meaning, there are no extensions on the timeframe, giving us hard deadlines that we need to meet in order to pass the class and move on to graduation. Lucky for us, we already had our group planned out from a semester in advance and we had a general idea about what we wanted to do. We started doing research and making sure our idea was feasible in this time frame beforehand in order to get ahead of everyone else.

Since software is involved in our project, we will run into another issue with time due to all of the debugging and testing that will need to be done. When it comes to software and programming, you never know how long a problem is going to take to get solved. This will cause multiple setbacks that must be fixed within this short time frame that we are given. Meaning, these unforeseen errors will pose a massive threat to our deadline and we will need to work efficiently to take care of these errors as fast as possible.

An added issue that may affect this project is ordering and shipping of parts. Especially from JLC PCB, where the shipping can take anywhere from 4-6 weeks. We will need to test and debug using breadboards in the mean-time so that we know our software works and when the PCB comes in, we can then put all of the components on it and just simply upload the working code. If we don’t test and debug during the shipping of the PCB, it can lead to massive problems with time management, especially with a hard deadline.

3D printing has become common among Senior Design projects. Since we are planning on 3D printing the housing for our device, we need to take into account the fabrication time and account for printing errors, especially since no one in our group has prior 3D printing experience. This can lead to us wasting valuable time printing and designing when we can be debugging or soldering components on the PCB.

The result of all of these time constraints can lead to rushing a project. Rushing can cause us to cut corners and not give the expected results that we want. Time management, accountability and communication need to be on point for all group members so that way we can meet the goals that we have outlined for each other and this project as a whole. If you say “I will do it” then you better do it by the expected deadline so that way the group doesn’t fall behind. We need to hold each other accountable for our work. By not doing these things, it can lead us down the path of failure by not meeting the hard deadlines that have been set for us.

4.2.2 Economic

For SafeSight, one of the most challenging constraints was the economic constraint. Since we are all college kids, and don’t have the funds to build the most expensive, best performing products, it made it difficult because we had to decide if we wanted a cost-effective product or a better performing product. Specifically, for the radar sensor, there were many different options that involved varying ranges for detection. There was a hard tradeoff between range and cost in order to make sure that we don’t break the bank.

Another economic constraint was that we needed to take into account if any of our parts break, we need to buy a new component. We may not take that into account with our budget, so we need to alot time and money in case we run into that roadblock. By doing this, it allows us to not go over both time and money.

When researching parts, we came across another economic constraint, the Raspberry Pi. We ran through many different subsystems for the computer vision aspect of this project. Our first idea was to use a NVIDIA Jetson Nano Super which runs about $249.00. This was obviously way out of our budget range and we decided to go with something a little more budget friendly, the Raspberry Pi V5. The difference between the two is that the Jetson Nano excels in AI and computer vision tasks due to its NVIDIA GPU, while the Raspberry Pi V5 is more for general use with a focus on speed and versatility. The Raspberry Pi V5 runs about 90 dollars and depending on the peripherals that we need, it may end up costing us around $130-$150, which is much more affordable than the Jetson Nano, and could still do everything that we need it to do to handle our computer vision for this project. With the Pi’s versatility, it will allow us to add many different peripherals without having to worry about if the device is compatible or not. This will cause us to save time and money in the long run.

Just like the Raspberry Pi V5, another piece from the parts selection that we needed to consider was the microcontroller unit of our project. The first option that came to mind when making this selection was to use an Arduino microcontroller that has built-in Wi-Fi to connect to the phone for our application use. However, there were very limited options when it came to those requirements that would fit our budget. We decided to find a microcontroller with both Wi-Fi and Bluetooth interface so that way we SafeSight can communicate with our application with ease to view pictures and files from Bluetooth rather than Wi-Fi. We stumbled across the ESP-32 and realized that it would be perfect for our project since it had Wi-Fi and Bluetooth with a fast enough CPU to get the job done. Buying an Arduino MCU, specifically the ATMega328p, would’ve just been a waste of money since it did not have the specifications that we were looking for. The ESP-32 costs about $12 for a three pack while the ATMega328p costs around $9 for one. This benefits us because in case we break an ESP-32, we don't have to waste both time and money buying a new MCU. Therefore, because of this economic constraint, we decided to pick the ESP-32 since it more accurately matched our needs.

In conclusion, the economic constraint poses a massive threat to our project because it causes us to pick products that are more budget friendly rather than favoring performance. This means that there needs to be a lot of research that needs to be done so that we don't run into challenges along the way. We could also help with the economic problem by throwing in a little extra money along the way to help increase our budget to help overcome any financial problems that we may encounter.

4.2.3 Federal Regulation Constraints

Developing driver safety technology to be mounted on a windshield involved adhering to several federal regulations and standards to ensure safety, functionality, and compliance. The Federal Motor Vehicle Safety Standards (FMVSS) dictates some requirements in regards to the windshield mounting aspect of this system. Firstly, there are retention standards that include the windshield remains retained on the car in any aspect of a collision or sudden change of force applied to the windshield. This directly correlates to the device as it must not intrude on 50% of the windshield periphery, given the vehicle has passive restraints on the windshield and 75% periphery for vehicles without passive restraints. The device must also not obstruct the area swept by windshield wipers, as this can compromise visibility during adverse weather conditions. Under section 108(a)(2)(A) of the FMVSS regulation text it states : *"manufacturers, distributors, or repair businesses are prohibited from rendering any safety feature inoperative*." Meaning that our device cannot interfere with windshield functionality or any other safety systems like airbags or lane assistance in more up to date vehicles.

Federal Motor Carrier Safety Administration (FMCSA) regulations also add onto the federal regulations expected in this system. One regulation is the placement of the device in the vehicle. FMCSA regulations define specific areas where devices can be mounted on windshields, these areas are restricted to no more than 8.5 inches below the upper edge of the windshield wiping area and no more than 7 inches above the lower edge of the area swept by windshield wipers. The bright side of the FMCSA regulations is that they do allow mounting devices on the windshield as long as they are explicitly designated "vehicle safety technology" which includes systems like lane departure warnings, braking assist systems, driver cameras, GPS units, traffic sign recognition, lidar, radars, and sensors. The system being designed meets these specifications.

National Highway Traffic Safety Administration (NHTSA) guidance tells requirements for the device being developed to acquire correct certification. The manufacturers, in this case being the team developing the product, must comply with all applicable FMVSS before being sold or installed in vehicles. This includes the devices not hindering existing safety standards like crash resistance or visibility. Given that the device will be installed after the vehicle is purchased from a car dealership, the installation process must not compromise compliance with FMVSS standards for new vehicles or equipment. Some examples include not interfering with windshield integrity or other factory installed safety features. As windshields also have their own regulations such as coloring, obstruction prohibitions, and decals or stickers, mounted devices must not violate these specifications as well.

Additionally, there must be testing conducted to ensure that the method of keeping the device in place is effective in a collision scenario. Given a collision, the device cannot result in a projectile, must withhold dynamic shock and vibrations as well. The device must minimize distractions by ensuring the drivers do not look away from the road for more than 2 seconds as this will undoubtedly cause the system to function inversely from its purpose.

4.2.4 Remaining Constraints

4.2.4.1 Health and Safety

Another constraint that must be factored in when developing and testing this project is health and safety. Since this project is going to go inside people's cars, we need to make sure that the product is reliable. The safety of people while driving is our top concern and the last thing we want is a device that doesn't work properly or is slow. For example, we don't want the device to pick up a green light by mistake, alert the driver, the driver go into the intersection, and then crash because it wasn't a green light. As a group, we need to make sure our device is reliable and accurate so that way it isn't giving false results to the driver.

We had to also take into account how we were going to be powering the device. The last thing we wanted is to power it via batteries, and under intense heat, have the batteries explode and cause a fire in the car. The safety of the drivers was taken into account after we realized that most people keep their cars outside. As we all know, keeping a battery in direct sunlight is no good. That is why we decided to power it via the 12V cigarette lighter in the car. That way, there is no potential for a battery related fire, keeping the drivers safe at all times.

4.2.4.2 Manufacturability

The final constraint that is probably the most important for this project is manufacturability. Our group is limited to the lab equipment that is provided to us for Senior Design students only. This limits the amount and type of manufacturing that we can do severely. This means that we need to keep our design simple enough to be fabricated in the lab.

Since we are allowed to buy components online, that means that we are not fabricating any MCUs by hand. This means that we can just simply put the components that were purchased online together and make them communicate. The only thing that needs to be truly fabricated is the PCB and that gets sent out to JLC PCB to get done over there. However, once we get it back, we need to solder all the components onto the PCB, which will factor into the manufacturability and feasibility constraint for this project.

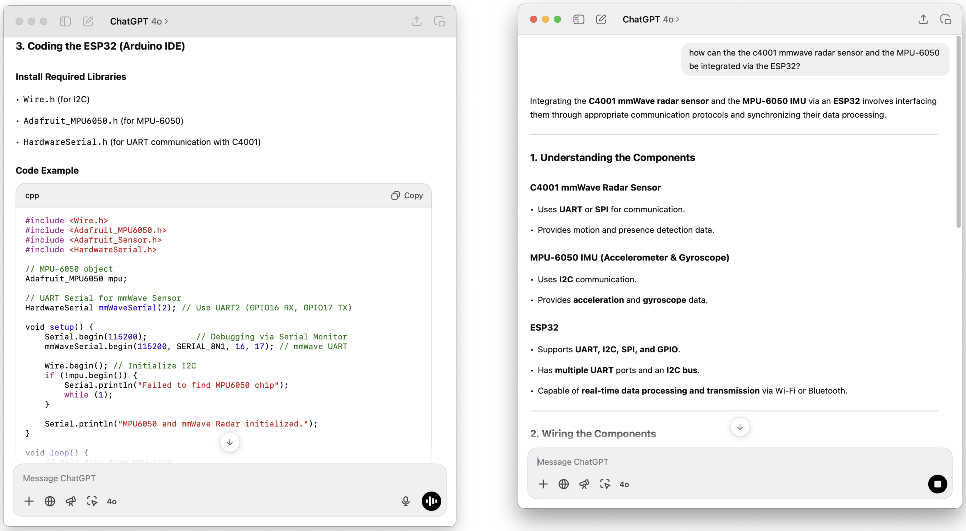
5. Artificial Intelligence Comparison

As part of our research methodology, we compared the performance and usefulness of two modern AI platforms, ChatGPT and Perplexity AI. We are going to use these two in order to support our development process. These tools represent the forefront of natural language processing and are commonly used for gathering information, generating code, and clarifying complex concepts. We chose to evaluate both platforms to understand their differences in functionality, depth of responses, and practical value during different phases of the SafeSight project.

Our comparison considered several factors, including the accuracy and clarity of responses, the ability to handle technical queries, the sources of information provided, and the overall user experience. ChatGPT offered detailed, conversational explanations and code support, while Perplexity emphasized citation backed answers and concise summaries. By analyzing these tools through practical use cases, we gained insight into how each platform can aid in research and development. The following section presents our findings, comparing the strengths and limitations of each AI assistant in the context of our project.

5.1 ChatGPT

ChatGPT has become known as one of the worlds best tools in regards to conversing, creativity, and problem solving. This human-like conversationalist is amazing as a sidekick where we as humans can ask it problems pertaining to detailed examples we come across and it can work with us to solve issues like debugging code, explaining concepts, making images, and much more. Throughout the progress of the project, ChatGPT was used to refer to spec sheets that gave us hardware pinouts, example code in order to flash the hardware correctly, and ideas on how to approach certain wiring and applications to make the system work as intended. For example, in regards to conducting research on this system we are designing, chatGPT offered valuable insight on what to research in regards to limitations, compatibility, and functionality of all components. Alongside the brainstorming capabilities of ChatGPT, there were also uses for this LLM in regards to integrating hardware at the testing bench. ChatGPT offered valuable insight on how to program the ESP32 through the Arduino IDE for example, which gave us the rundown of required files, example code, and synchronizing processing data into the ESP32 board.



3. Coding the ESP32 (Arduino IDE)

Install Required Libraries

- Wire.h (for I2C)
- Adafruit_MPU6050.h (for MPU-6050)
- HardwareSerial.h (for UART communication with C4001)

Code Example

```cpp
#include <Wire.h>
#include <Adafruit_MPU6050.h>
#include <Adafruit_Sensor.h>
#include <HardwareSerial.h>

// MPU-6050 object
Adafruit_MPU6050 mpu;

// UART Serial for mmWave Sensor
HardwareSerial mmWaveSerial(2); // Use UART2 (GPIO16 RX, GPIO17 TX)

void setup() {
    Serial.begin(115200);          // Debugging via Serial Monitor
    mmWaveSerial.begin(115200, SERIAL_8N1, 16, 17); // mmWave UART

    Wire.begin(); // Initialize I2C
    if (!mpu.begin()) {
        Serial.println("Failed to find MPU6050 chip");
        while (1);
    }

    Serial.println("MPU6050 and mmWave Radar initialized.");
}

void loop() {
    // Read data from MPU-6050
```

how can the the c4001 mmwave radar sensor and the MPU-6050 be integrated via the ESP32?

Integrating the **C4001 mmWave radar sensor** and the **MPU-6050 IMU** via an **ESP32** involves interfacing them through appropriate communication protocols and synchronizing their data processing.

1. Understanding the Components

C4001 mmWave Radar Sensor

- Uses **UART** or **SPI** for communication.
- Provides motion and presence detection data.

MPU-6050 IMU (Accelerometer & Gyroscope)

- Uses **I2C** communication.
- Provides **acceleration** and **gyroscope** data.

ESP32

- Supports **UART, I2C, SPI, and GPIO**.
- Has **multiple UART** ports and an **I2C bus**.
- Capable of **real-time data processing and transmission** via Wi-Fi or Bluetooth.

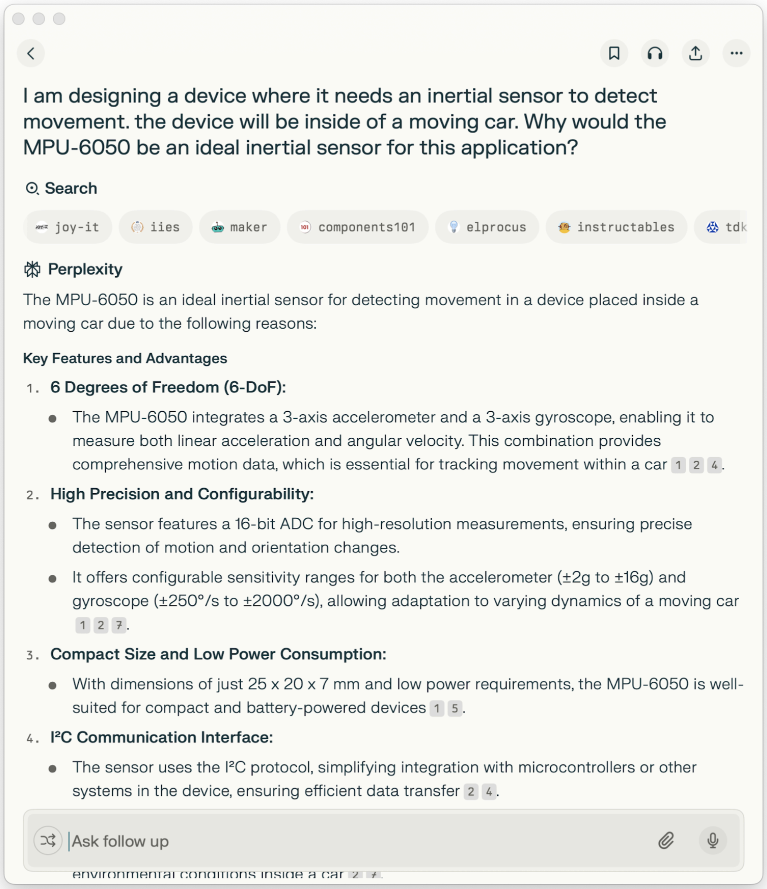
2. Wiring the Components

Figure 5.1.1 ChatGPT Usage Example

From the ideas that ChatGPT gave insight on, another LLM used was Perplexity. Perplexity is an AI powered search engine that gives us real time information that then provides sources. These sources were often educational texts, hardware manufacturing firms, and engineering specific websites that often encountered experiences with these components.

5.2 Perplexity

For the majority of research conducted on compatibility, meeting constraints, identifying what components were going to function according to the specifications of the system, etc. Perplexity offered a very good platform to identify all of these requirements with research backed to prove its answer. Much like searching on the web through engines like Google, Perplexity was able to search and find direct, reputable sources for the information it provided in accordance with the prompt. This engine also offers features to expand knowledge in which it provided follow up questions to provoke thought and thus led to more questions being answered simply from the AI's recommendation.



I am designing a device where it needs an inertial sensor to detect movement. the device will be inside of a moving car. Why would the MPU-6050 be an ideal inertial sensor for this application?

The MPU-6050 is an ideal inertial sensor for detecting movement in a device placed inside a moving car due to the following reasons:

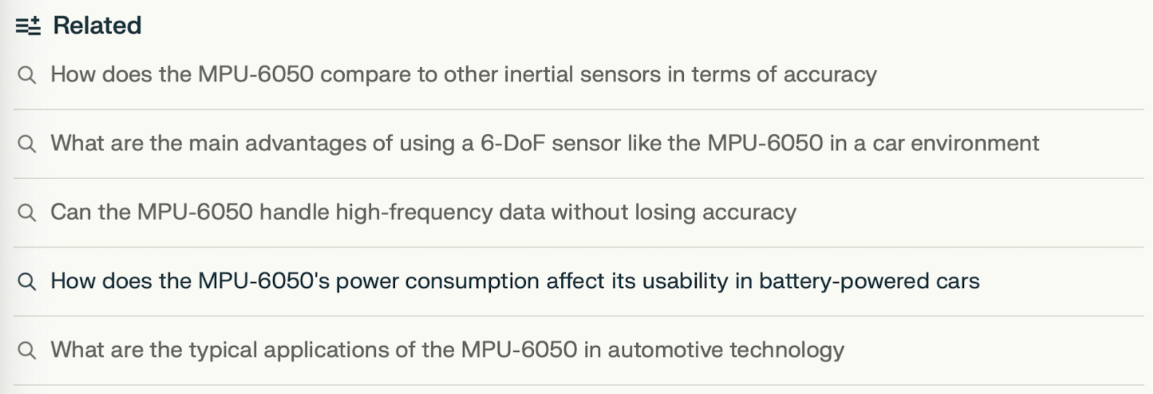
Key Features and Advantages

1. **6 Degrees of Freedom (6-DoF):**
   - The MPU-6050 integrates a 3-axis accelerometer and a 3-axis gyroscope, enabling it to measure both linear acceleration and angular velocity. This combination provides comprehensive motion data, which is essential for tracking movement within a car [1] [2] [4].
2. **High Precision and Configurability:**
   - The sensor features a 16-bit ADC for high-resolution measurements, ensuring precise detection of motion and orientation changes.
   - It offers configurable sensitivity ranges for both the accelerometer (±2g to ±16g) and gyroscope (±250°/s to ±2000°/s), allowing adaptation to varying dynamics of a moving car [1] [2] [7].
3. **Compact Size and Low Power Consumption:**
   - With dimensions of just 25 x 20 x 7 mm and low power requirements, the MPU-6050 is well-suited for compact and battery-powered devices [1] [5].
4. **I²C Communication Interface:**
   - The sensor uses the I²C protocol, simplifying integration with microcontrollers or other systems in the device, ensuring efficient data transfer [2] [4].

environmental conditions inside a car [2] [7].

Figure 5.1.2 Perplexity Ai Usage Example

Here we asked the question on a hardware piece we already decided on. This engine then gave a cohesive list of functional advantages for the inertial sensor. Bringing real information from sources cited at the end of the information provided in the numbered grey boxes.



Related

- How does the MPU-6050 compare to other inertial sensors in terms of accuracy
- What are the main advantages of using a 6-DoF sensor like the MPU-6050 in a car environment
- Can the MPU-6050 handle high-frequency data without losing accuracy
- How does the MPU-6050's power consumption affect its usability in battery-powered cars
- What are the typical applications of the MPU-6050 in automotive technology

These questions are what the AI would “guess” you want to know more on, provided added information on topics we may not have thought to cover in the expenditure of our research. This LLM was very useful and proved to be a helpful research assistant where the user, us, was able to pick and choose what information was valuable, similar to the process of using a search engine the traditional way. Except, this LLM allowed for quicker navigation, source identification and summaries of the information you can expect to find in the sources.

5.3 Benefits of Using AI

AI can be incredibly useful during the design phase of a project like SafeSight by helping us analyze large amounts of data quickly and identify patterns that might not be obvious through manual testing. For example, when evaluating sensor data or camera feeds, AI tools can highlight inconsistencies, detect anomalies, or simulate various environmental conditions. This makes it easier to tweak the design early on and avoid problems down the line. It’s especially helpful when trying to optimize hardware placement or test how different inputs affect system behavior.

During testing, AI can speed up the process by automating repetitive tasks and simulating edge cases that would be time consuming to recreate manually. It can evaluate system responses to a wide range of conditions. For example, low lighting, fast moving objects, or noisy signals. This will cause the system to flag any unexpected behavior. This not only saves time but also helps ensure that SafeSight performs well in real world scenarios. With AI, we can gather deeper insights into system performance and make more informed decisions about adjustments or improvements.

Overall, using AI as a tool during design and testing allows us to work more efficiently and with greater confidence. It helps reduce trial-and-error cycles and supports data driven decision making, which is critical for building a reliable, safe, and user friendly system. For a project like SafeSight, where safety and precision are top priorities, having AI assist in the background can make a big difference in the quality of the final product.

6. Hardware Design

In regards to the whole system there is a list of physical constraints we need to fulfill in order to make sure the system is operable within the environment of a moving vehicle. First, we must make the system fit behind the rear view mirror of a car without obstructing the view of the driver. In order for this to be done we went ahead and referred to the guidelines by the Federal Motor Carrier Safety Administration (FMCSA) which dictated that a device in vertical position must not exceed up to 8.5 inches below the upper edge and up to 7 inches above the lower edge of the area swept by the windshield wipers. The device must also remain outside of the driver's sight lines to the road, highway signs, and signals. The device cannot be placed in areas swept by the windshield wipers unless they are explicitly defined as "Vehicle Safety Technology". Fortunately for the system, the device is defined as such.

The FMCSA has broadened its definition of "vehicle safety technology" to include systems such as Camera, Lidars, Radars, Senors, and video systems for collision mitigation, lane departure warnings, GPS, and traffic sign recognition. The reason these regulations exist is to balance technological advancements in vehicle safety systems with driver visibility and road safety. Mounting devices outside of these prescribed areas or obstructing sight lines can lead to violations and increased risk of distracted driving, which in turn would counteract the purpose of this device we are developing.

Secondly, the device must be durable and robust enough to handle environmental resistance. In the environment of traffic, there are multiple factors that can affect the device. When you turn the car on, its engine begins to provide vibrations throughout the whole vehicle (unless electric). When the car comes to a sudden stop, the rapid change in velocity makes the device prone to heavy change where the force moving forward will overcome the force moving against it. Given the change in seasons we experience on earth, the device must also withstand heavy temperature readings from the sun during warm months and also colder temperatures sometimes below 0 degrees fahrenheit. In order for these conditions to not affect the system being developed, it is imperative for the components in the hardware design to all have ideal temperature ranges, shock withstanding, and proper solidified connections so that the system does not come apart in the rapidly changing environment that automobile traffic can provide. These considerations bring about another aspect of the mounting mechanism needed for such a system to properly withhold the environment. The mounting system should be secure yet easy to install and remove without damaging the windshield. It should resist the said vibrations and movement while maintaining proper alignment with the design of the system.

In regards to the hardware itself, designing the PCB will also require these considerations. When designing a PCB for use in an automobile, it is crucial to select materials capable of withstanding the shocks, vibrations and harsh environmental conditions to this dynamic environment. Commonly used PCB materials include the FR-4. Since the FR-4 has both standard and high-tg variants, it gives us a range which will be constricted by budget in order to make this system rest on a robust board. These boards are printed on a fiberglass-reinforced epoxy laminate material which is widely used in PCBs. This reinforcement provides high mechanical strength and rigidity, high temperature variants (high tg) can withstand temperature ranges up to 150 deg. C (302 deg. F), and it is cost effective for the budget. The one limitation for this is that the vibration resistance is moderate, in order to work around this we would need to encapsu the board in a case, as we planned to do so already. The hardware being implemented on this board will also meet all the shock and temperature robustness described. The recordings of those specifications are provided in the sections pertaining to those IC's as it is a reason for the decision process on the components.

There are multiple mounting systems that can be implemented in order to withstand these environmental conditions. First and foremost, the most ideal would be a velcro mounting system. This system offers heavy duty velcro straps that are used to attach devices securely to mounting surfaces, in this case the windshield. These advantages are that it is flexible and adjustable, allowing for repositioning and removal without the need of extra tools. This system has proven resilient against vibrations and shocks in dynamic environments and also it is extremely strong and durable, capable of holding significant weight (2 square inches of velcro can hold up to 175 pounds). The rearview mirror replacement mounts that attach to the windshield are using the same mounting button as a rearview mirror. This system utilizes an existing mounting point, avoiding adhesives and drilling, while providing a stable attachment point for devices. Since the rearview mounting system is commonly used for backup cameras, monitors, and other devices, it would be ideal for the system to be mounted as such, combined with the velcro in order to ensure shock prevention and even handle scenarios where the device remains secure in a crash or accident.

Third, it is imperative for the design of this system to be appropriate for human-machine interaction (HMI). The interface should be intuitive and easy to understand all while minimizing driver distraction. This includes clear visual and audio indicators for warnings on collisions and distractions. Avoiding the use of extra peripheral devices for use, avoiding complex menus and prolongs attention interactions. As this system will be communicating to the driver on various conditions to be alert on, it is also important for the information to be conveyed in a concise and relevant manner to avoid cognitive overload. This would then bring us to follow the National Highway Traffic Safety Administration's (NHTSA) guideline for in-vehicle electronic devices. These include but are not limited to avoiding the driver looking away from the road for more than 2 seconds at a time, and minimize manual inputs during operation. As this system will function without the need for a driver to input anything after installation, this requirement is met. As Well as the system's implementation to be a simple audio signal from a piezoelectric buzzer, the system will ensure the driver's attention will remain on the road with no distractions being met. Alongside these design features, the method of powering and communicating data with the driver will also be minimal to reduce the space of hardware in the car, removing the concern of the system interfering with the driver's use of the vehicle. Since the car's 12V cigarette lighter port will be used to power the device, it is simply a matter of cable management that can be routed to avoid any interference with the shifting gear and the buttons accessible to the driver. The ESP32's functionality of bluetooth will transmit data from the device to the user's application seamlessly without additional hardware as well. This will be ideal in keeping the system from interfering with the driver's focus on the road.

6.1 Power Supply Design - Regulators

The device with its power demands exceed the probability of having a wireless approach that involves operating on a rechargeable battery. The Raspberry Pi 5 running computer vision tasks in parallel with the ESP 32 consumes an average of 7.2 Watts an hour, making it so that the battery small enough for a space conscious design would be depleted every week (5-7 hours of use). Thus, a wired design for power that taps into the battery of a vehicle using the cigarette lighter port is the most power conscious and efficient design to power the Safe Sight device.

In addition, keeping our source of main power in mind (12 V car battery), we must also consider the operational power requirements of our ESP 32 (3.3V) and Raspberry Pi (5V). These constraints require us to design regulators that convert and drop down the main 12V source to 5V and 3.3V to properly power the individual operational processing components and sensors in our device. First, we must design the first regulator to step down the 12V voltage of a standard cigarette lighter port in a vehicle to 5V and then make a decision to either have the second regulator tap from the 5V power and convert it to 3.3V or straight from the 12V source (12V to 3.3V regulator).

6.1.1 ESP 32 Power Supply Regulator - TPS564252

The TPS56425x is a line of regulators that take 3V-17V inputs and can convert them to a range of low voltage outputs 0.6V - 10V at a 2-A continuous current. The TPS564252 supplies a steady 3.3V output with a great operational efficiency at a 12V input, making this model in the TPS line of regulators meet the specifications of our ESP 32 perfectly.

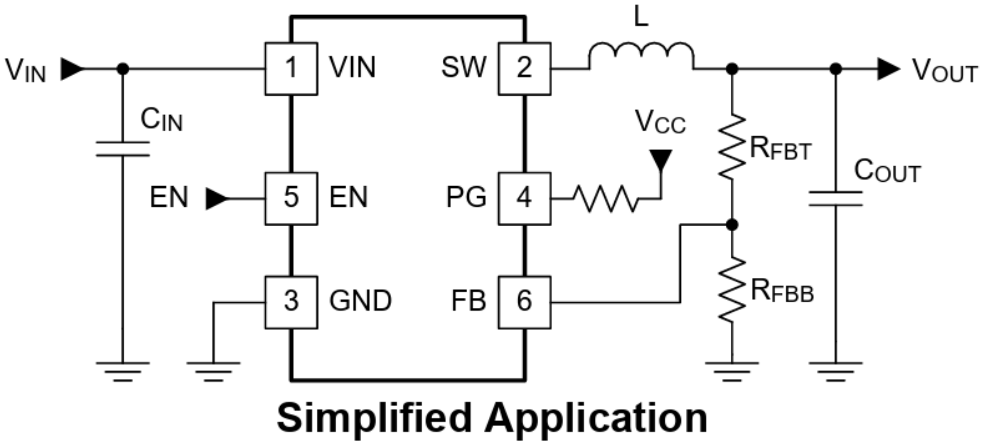


Figure 6.1.1.1 Power Supply Regulator Schematic

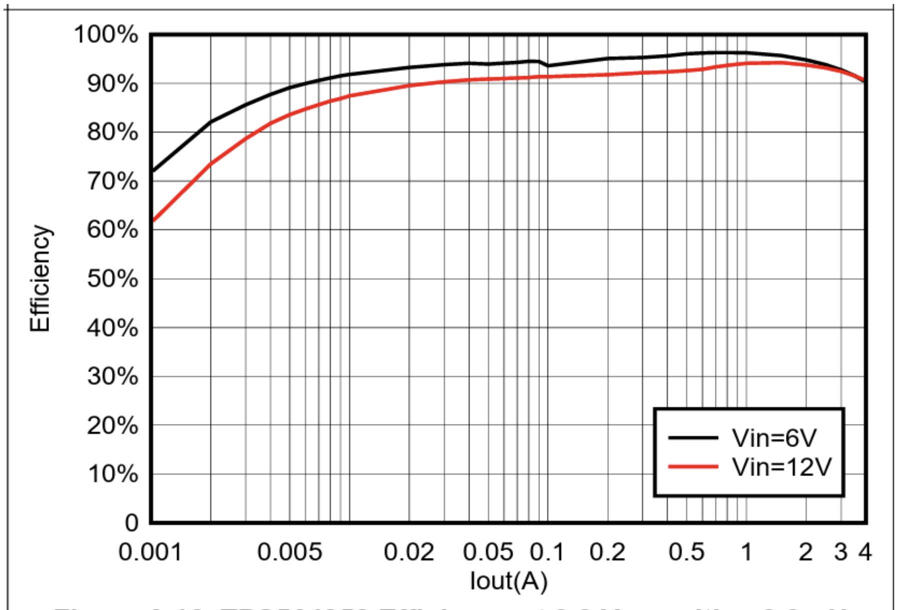


Figure 6-16. TPS564252 Efficiency at 3.3 V_{OUT} with a 3.3-µH Inductor

Figure 6.1.1.2 Power Supply Efficiency Graph

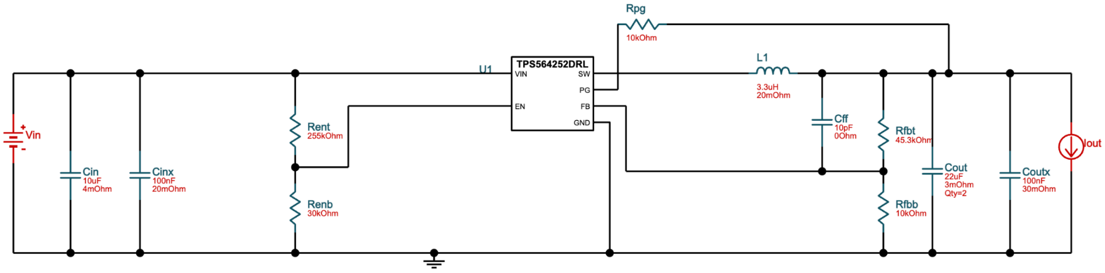


Figure 6.1.1.3 Total Power Supply Schematic

Using TI WEBENCH power designer we customized this TPS564252 voltage regulator circuit to meet our power specifications for the ESP 32. The simulated outcome and estimated BOM are as follows:

1. **Vout Actual:** 3.32 V
2. **Vout Tolerance:** 2.67%
3. **Total BOM:** $0.72
4. **BOM Count:** 13
5. **Vout:** 3.3 V
6. **Duty Cycle:** 28.29%
7. **Efficiency:** 94.2%
8. **Frequency:** 620.82 kHz
9. **Pout:** 6.6 W
10. **Mode:** CCM
11. **Vout Peak-to-Peak:** 8.31 mV
12. **Vin Peak-to-Peak:** 368.66 mV

13. Iout: 2A

In conclusion, the TPS564252 proves itself to be a cost effective and efficient choice as a voltage regulator for the ESP 32, performing with an efficiency rate over 90% when given a steady input voltage of around 12V (Figure 6.1.2).

6.1.2 Raspberry Pi Power Supply Regulator - TPS566242

The TPS56624x is a line of regulators that take 3V-16V inputs and can convert them to a range of low voltage outputs 0.6V - 7V at a 6-A continuous current. The TPS566242 supplies a steady 5V output with a great operational efficiency at a 12V input, making this model in the TPS line of regulators meet the specifications of our Raspberry Pi perfectly.

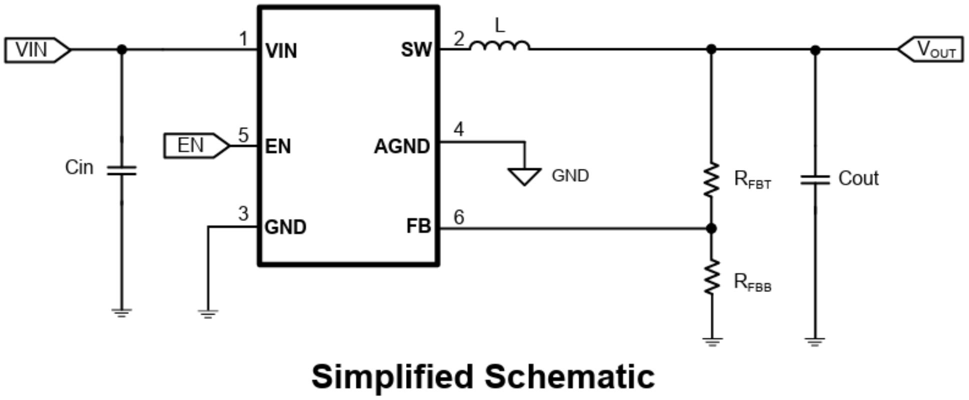


Figure 6.1.2.1 Pi Regulator Schematic

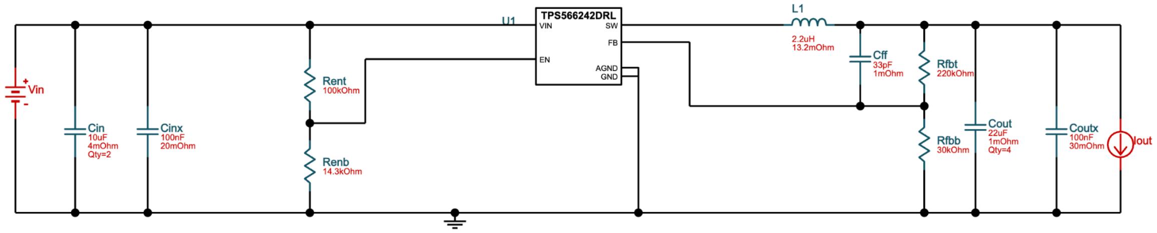


Figure 6.1.2.2 Pi Full Power Supply Schematic

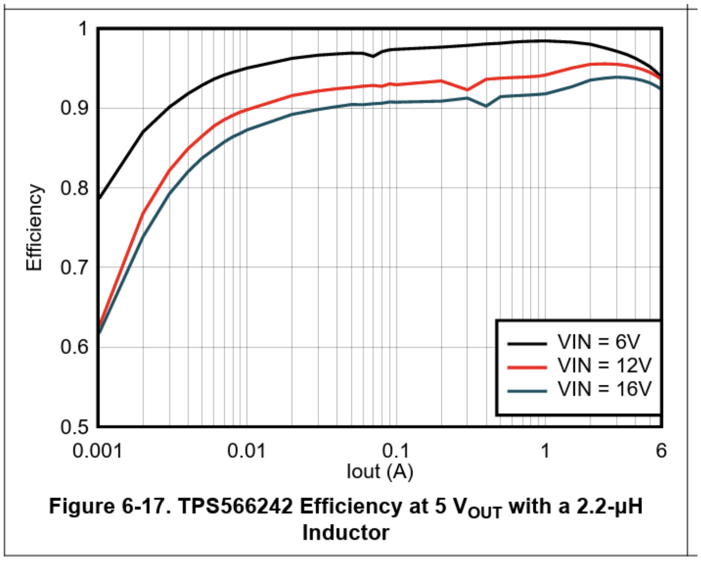


Figure 6-17. TPS566242 Efficiency at 5 V_{OUT} with a 2.2-μH Inductor

Figure 6.1.2.3 TPS566242 Efficiency Graph

Using TI WEBENCH power designer we customized this TPS566242 voltage regulator circuit to meet our power specifications for the Raspberry Pi 5. The simulated outcome and estimated BOM are as follows:

14. **Vout Actual:** 5 V
15. **Vout Tolerance:** 3.64%
16. **Total BOM:** $1.35
17. **BOM Count:** 15
18. **Vout:** 5 V
19. **Duty Cycle:** 42.8%
20. **Efficiency:** 94%
21. **Frequency:** 570.11 kHz
22. **Pout:** 25 W
23. **Mode:** CCM
24. **Vout Peak-to-Peak:** 11.6 mV
25. **Vin Peak-to-Peak:** 600.86 mV
26. **Iout:** 5A

In conclusion, the TPS566242 proves itself to be a cost effective and efficient choice as a voltage regulator for the Raspberry Pi 5, performing with an efficiency rate over 90% when given a steady input voltage of around 12V (Figure 6.1.2.2).

6.2 Development Board - ESP32

We will be utilizing the ESP32 MCU in this project. However, we must create our own development environment on our custom PCB design to interact and access the ESP32 MCU. This includes creating a schematic and PCB development board that is able to communicate via serial to upload and debug the ESP32 MCU, connect our MCU to all peripheral components, and power our MCU appropriately. In this section, we will showcase our selections for USB-Serial converters, MCU footprint, and switch configurations.

6.2.1 Micro USB - UART Conversion Schematic

On our development board, we selected a micro USB converter circuit to allow for improved accessibility to debugging our MCU in the future. This conversion circuit will then lead to an integrated circuit (CP2102) to communicate via serial communication to our ESP32 MCU.

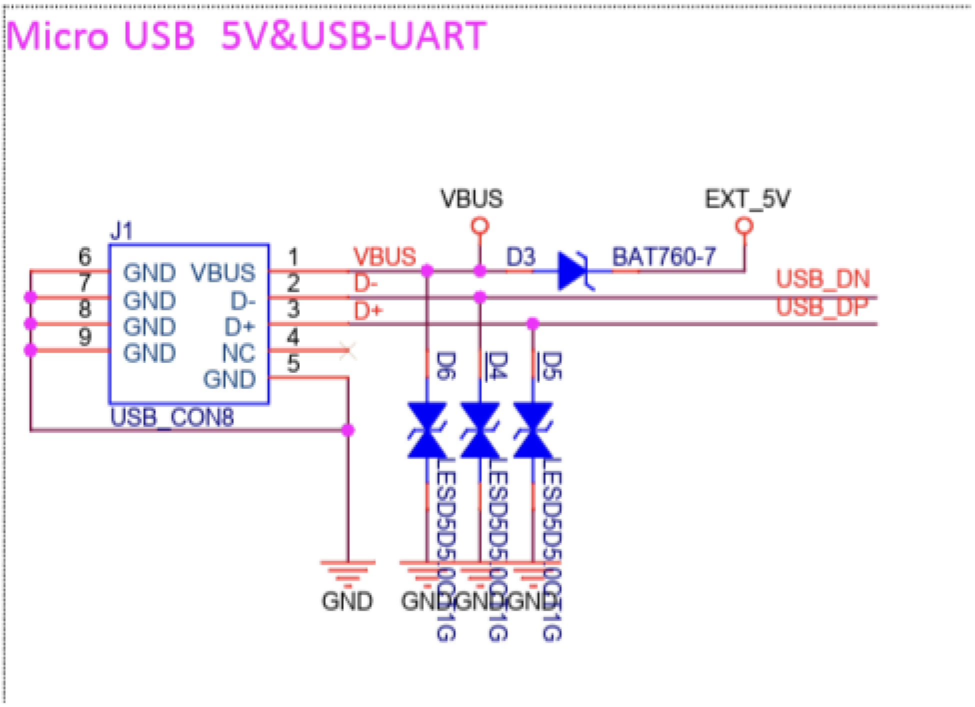


Figure 6.2.1.1 Micro USB Conversion Schematic

6.2.2 IC CP2102 - UART Conversion Schematic

The integrated circuit CP2102 is a standard used by most Espressif ESP32 development boards. Therefore, for its efficiency, compatibility, and compact size, we chose it to serve as our USB-Serial converter to communicate with the ESP32 processor. The CP2102 and the micro USB-UART adapter are vital in our PCB/Schematic design to provide a viable and quick way to upload and debug via serial communication.

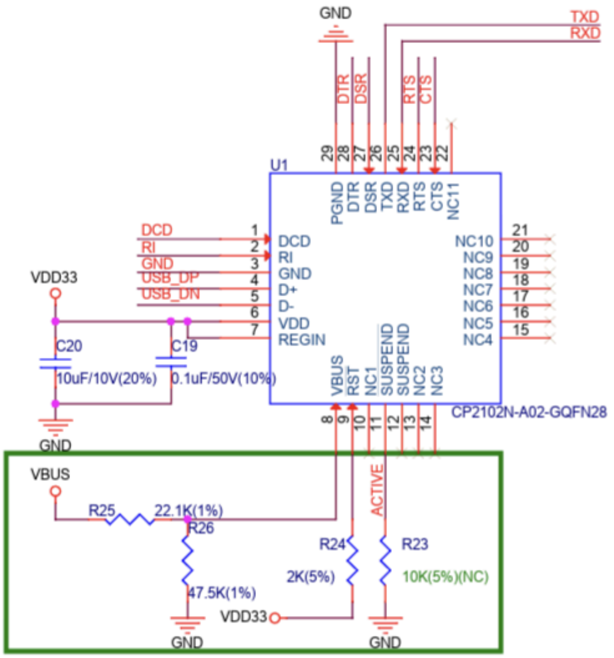


Figure 6.2.2.1 UART Conversion Schematic

6.2.3 AMS1117 - USB 5V - 3.3V Power Supply Converter

The AMS1117 power supply will convert 5V DC from the micro USB to 3.3V so that the ESP32 can be powered by the same source at which it will be receiving serial data when uploading/debugging (Micro USB). This way we can ensure that the ESP32 will be receiving power delivery and serial data consistent from the same source. We will be moving the LED in this schematic to the 3.3V header as a way to make sure that the power supply is supplying power properly

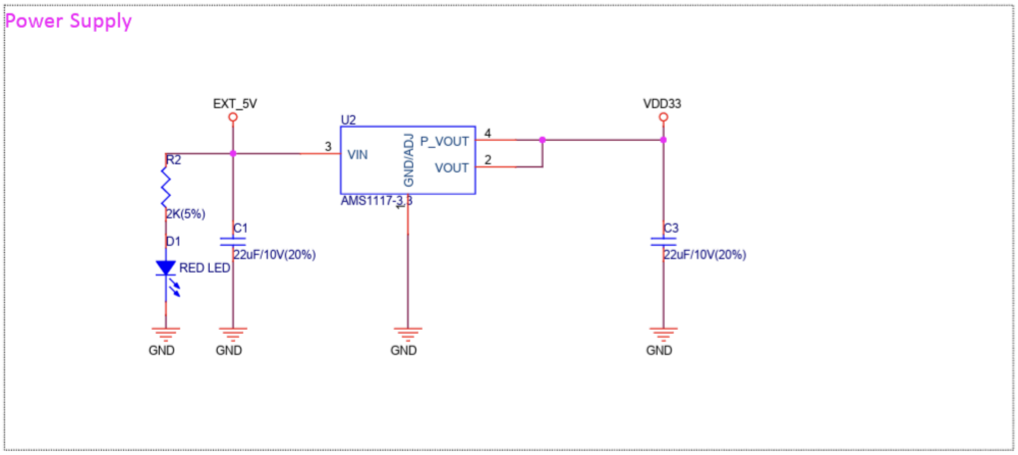


Figure 6.2.3.1 USB 3.3V PWC Schematic

6.3 Custom Footprints - Schematic to PCB

After creating a development board schematic layout for our ESP 32, we must now create custom footprints for our sensors to be housed on our PCB. The C4001 Radar sensor and MPU-6050 Accelerometer's dimensions will be taken from their respective datasheets and a custom footprint will be made to house them accordingly on our PCB. The custom footprints will be linked to pin headers on our overall schematic.

6.3.1 C4001 Radar Sensor - Custom Footprint

In order to obtain the exact physical dimensions and locations of pin headers on the development board of the DFRobot C4001 Radar Sensor, we must first reference its datasheet. Once the diagram and appropriate dimensions have been referenced from the datasheet, we can begin to create a custom footprint to associate with pin headers on the schematic. This will make sure our PCB design houses all its components properly and keeps its dimensions within measurable standards. Below is a 5-pin header that will serve as a placeholder in the schematic design, to then be associated with our custom C4001 Radar sensor footprint in our PCB design.

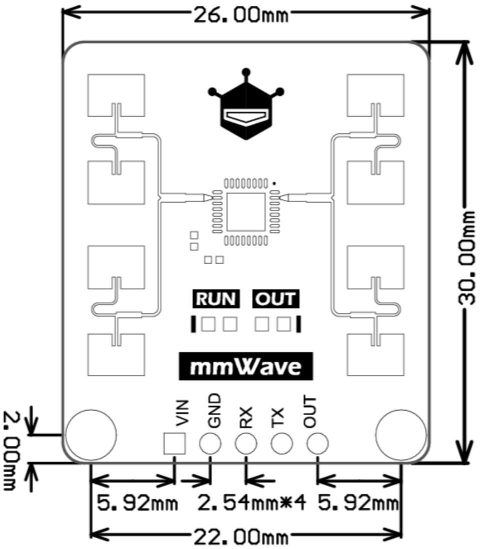
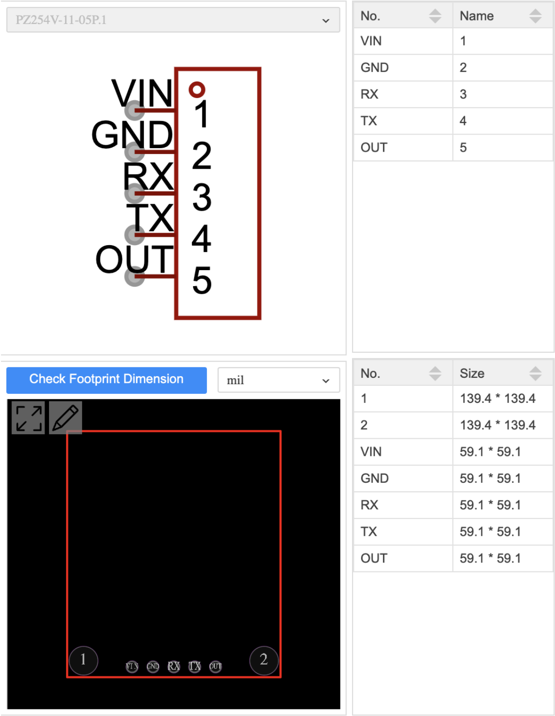


Figure 6.3.1.1 C4001 Radar Sensor Layout



No.	Name
VIN	1
GND	2
RX	3
TX	4
OUT	5

No.	Size
1	139.4 * 139.4
2	139.4 * 139.4
VIN	59.1 * 59.1
GND	59.1 * 59.1
RX	59.1 * 59.1
TX	59.1 * 59.1
OUT	59.1 * 59.1

Figure 6.3.1.2 C4001 Custom Footprint

6.3.2 MPU-6050 Accelerometer - Custom Footprint

In order to obtain the exact physical dimensions and locations of pin headers on the development board of the DFRobot C4001 Radar Sensor, we must first reference its datasheet. Once the diagram and appropriate dimensions have been referenced from the datasheet, we can begin to create a custom footprint to associate with pin headers on the schematic. This will make sure our PCB design houses all its components properly and keeps its dimensions within measurable standards. Below is a 5-pin header that will serve as a placeholder in the schematic design, to then be associated with our custom C4001 Radar sensor footprint in our PCB design.

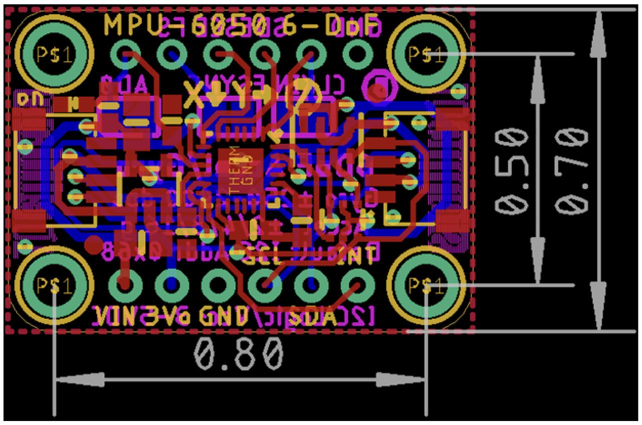
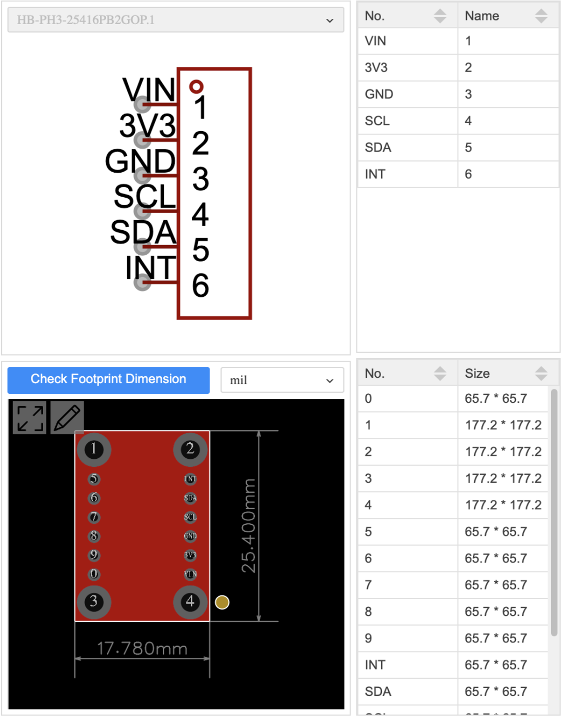


Figure 6.3.2.1 MPU-6050 Layout



No.	Name
VIN	1
3V3	2
GND	3
SCL	4
SDA	5
INT	6

No.	Size
0	65.7 * 65.7
1	177.2 * 177.2
2	177.2 * 177.2
3	177.2 * 177.2
4	177.2 * 177.2
5	65.7 * 65.7
6	65.7 * 65.7
7	65.7 * 65.7
8	65.7 * 65.7
9	65.7 * 65.7
INT	65.7 * 65.7
SDA	65.7 * 65.7

Figure 6.3.2.2 MPU-6050 Custom Footprint

Since there is no documentation available online for the respective footprints of the devboards that come with the radar and accelerometer sensors, we were led to create our own custom footprints for our PCB design. This allows for the most optimal design and generates simplicity in the final assembly of the PCB. The tradeoff of creating a custom footprint for such components is that you lose time in the design stage but gain it once it comes down to the assembly. It is a better practice to dedicate more time to the PCB schematic and footprints in the design stage so that less problems can arise in the assembly stage, where going back to the drawing board to tweak designs might not be an option in a time sensitive setting.

6.4 Final Schematic - All Components Included

The final schematic brings all of the previous reference schematics and connects them together as one. It will serve as the main documentation for reference when assembly and PCB layout begin. This comprehensive draft ensures that every subsystem is properly integrated and that all signal paths and power requirements are clearly defined. By consolidating the individual modules into a single, cohesive diagram, the final schematic helps identify potential conflicts or design issues before fabrication. This document is essential for both the design team and manufacturers, providing a clear blueprint to guide the entire build process and future troubleshooting.

The final schematic consists of two pages on the EasyEDA schematic and PCB design software. The first page consists of the ESP32 MCU, its respective micro USB, power, and communication circuits, MPU-6050 Accelerometer, C4001 Radar, and respective pin outputs. The second page includes the power supply/converter for the 12V input that will be seen by the cigarette lighter charger port which is standard in every vehicle. While modern vehicles do not include the cigarette lighter anymore, all still have a 12V access port. The final schematic and its two pages are depicted below.

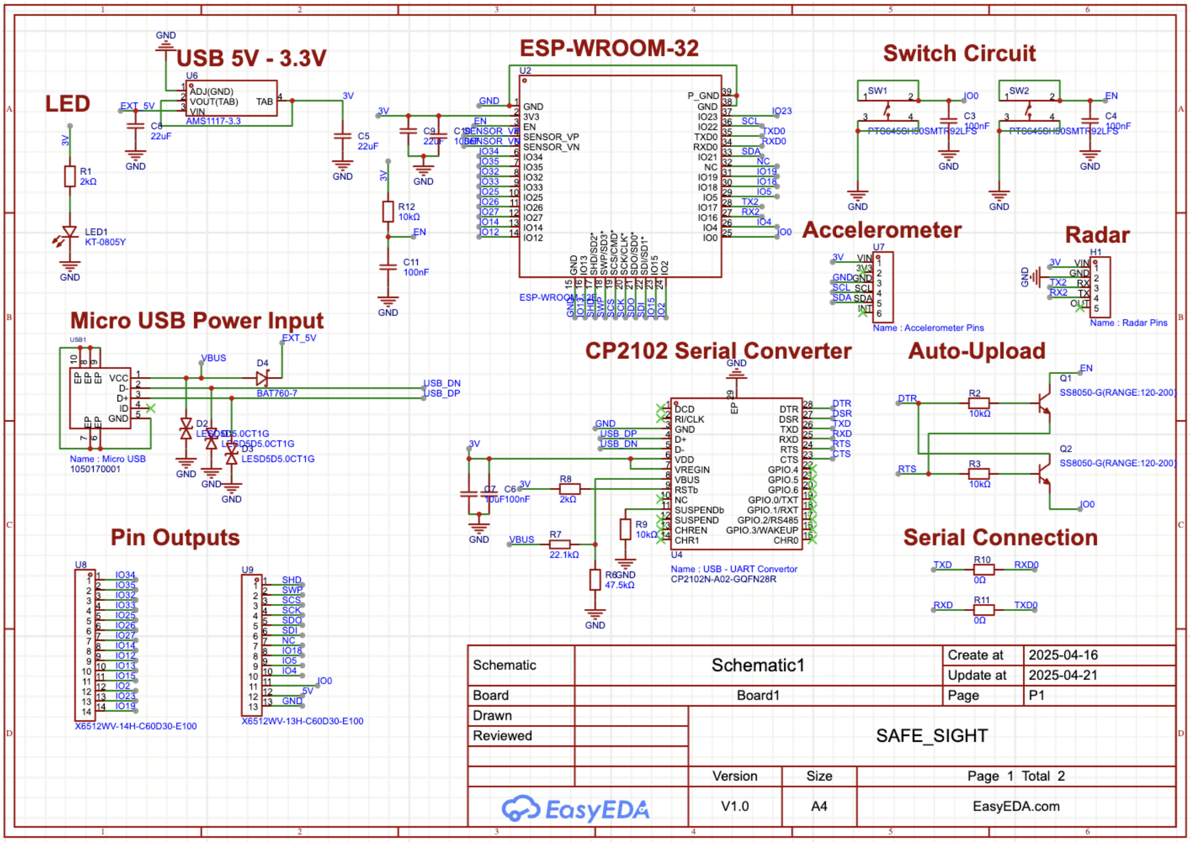


Figure 6.4.1 Final Schematic - All Components

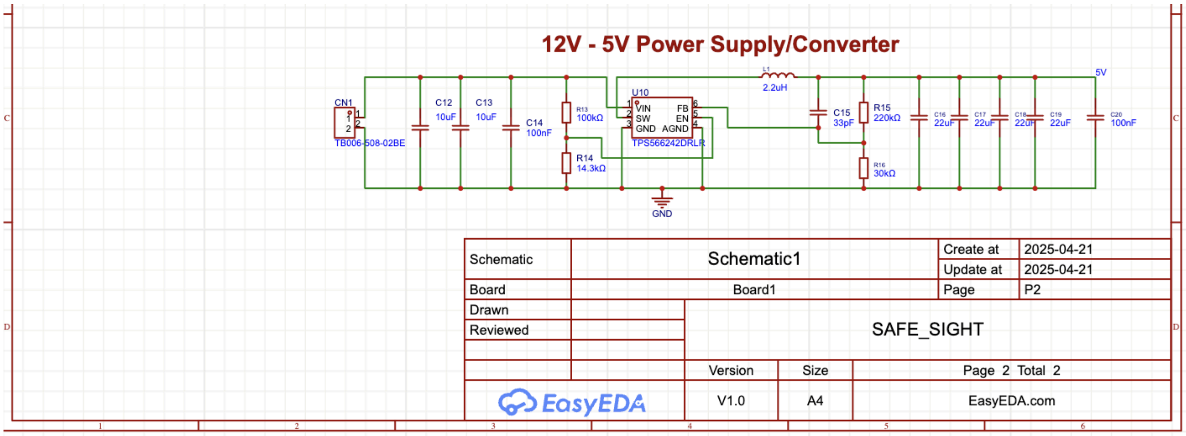


Figure 6.4.2 Final Schematic - All Components Pt 2

7. Software Design

The software design of SafeSight is crucial for its ability to interpret sensor data, make decisions in real time, and deliver accurate feedback to the user. Our design process involved mapping out various logic-based scenarios that the system might encounter in real-world driving environments. These scenarios informed the development of control algorithms, response mechanisms, and safety checks.

The system architecture is built around modular logic blocks, each responsible for a specific function, such as traffic light detection, driver attention monitoring, and alert triggering. Logic decisions are made based on sensor inputs processed through conditional statements, thresholds, and decision trees. To clearly visualize how the system behaves under different conditions, we created a series of flowcharts that outline specific inputs, expected outputs, and system states.

7.1 Software Logic Introduction - Scenarios

Before an approach to coding any implementation of software design, we must first consider the various scenarios our Safe Sight product will encounter on the roadways, then create ideas of software implemented logic, and finally execute and implement software to our design. This process requires careful anticipation of change and modularity to ensure the system remains adaptable and scalable as new challenges arise. Additionally, abstraction plays a critical role in isolating essential behaviors from implementation details, allowing us to focus on high-level problem-solving without being bogged down by unnecessary complexities.

7.1.1 Red-Light Scenario

The first scenario, the scenario that inspired our product, is the red-light scenario. The red light scenario consists of the operator's vehicle stopped at a red light. Having two outcomes, the driver of the vehicle housing our safe sight device will either react accordingly in a timely manner to the switching of the traffic light from red to green, or fail to react accordingly due to their attention being absent to the roadway. Now, if the driver remains attentive in the scenario, our safe sight product will do nothing, for the driver did not commit an attention infraction. However, if the driver fails to react to the changing traffic signal, Safe Sight will activate an alarming tone and take a picture of the driver, documenting the attention infraction’s date, time, and record media of the incident. A logic flow graph is pictured below to demonstrate this scenario.

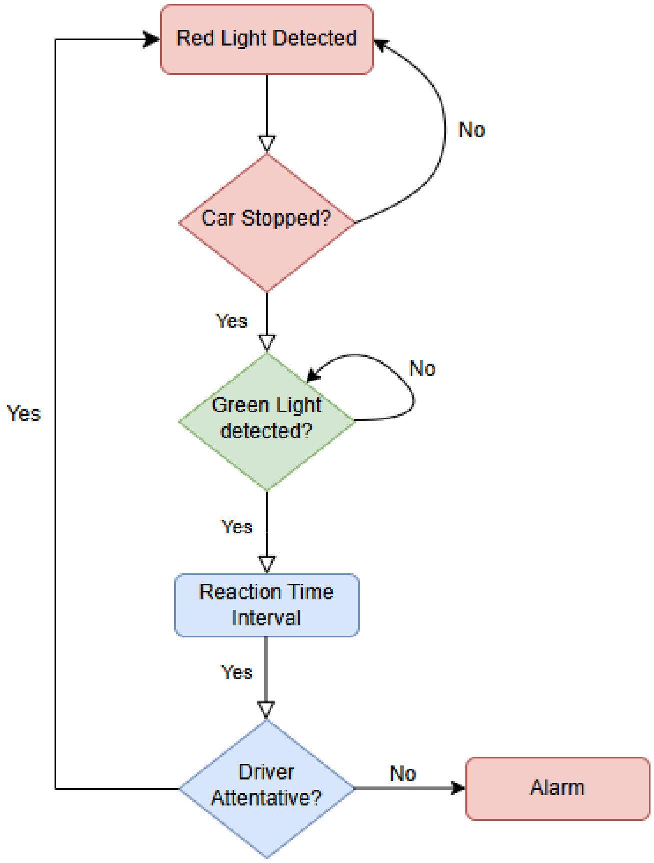


Figure 7.1.1.1 Red Light Scenario Flowchart

7.1.2 Driver Distracted While Driving Scenario

Furthermore, another scenario where Safe Sight will be implemented is in the event of a driver who is distracted while their vehicle is in motion. The driver's attention to the roadway will be assessed based on their overall head posture. If the driver is looking down, for example, texting and driving or changing the song on their stereo, they will be flagged as committing an attention infraction, and Safe Sight will alarm the driver and document the offense. This can be structured as software logic by using real-time data from cameras and sensors to track head movements and compare them against predefined thresholds for safe driving behavior. For instance, if the system detects a downward gaze lasting longer than a set duration, it triggers an alert and logs the incident in a database for future reference. However, if the driver maintains their attention to the road with minimal and normal shifts in their overall posture, Safe Sight will do nothing and remain silent. By employing machine learning algorithms, the software can also adapt over time to recognize patterns of natural head movements versus distracted behaviors, ensuring greater accuracy and fewer false positives. A logic flow graph is pictured below to demonstrate this scenario.

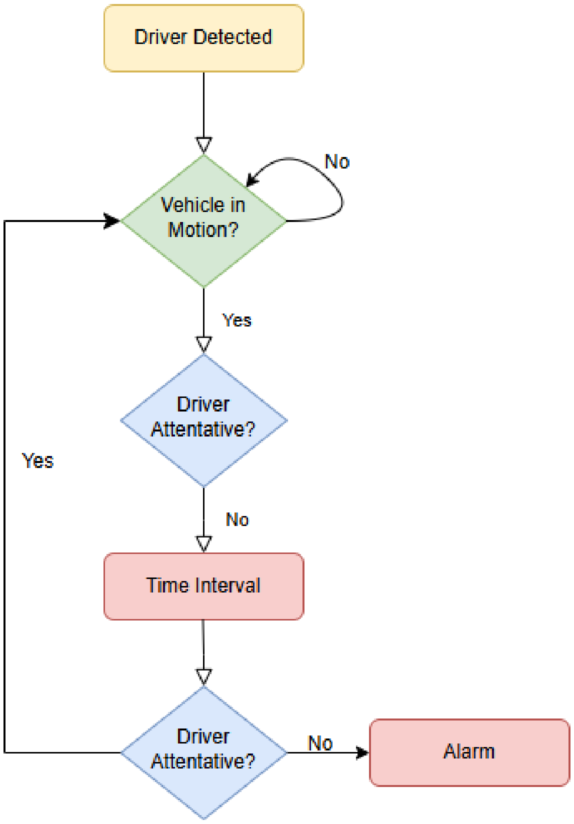


Figure 7.1.2.1 Driver Distracted While Driving Scenario

7.2 Application Design

When it came down to actually designing our application that is going to be used with SafeSight. There were a lot of things that needed to be considered. We took into consideration how we were going to connect to SafeSight in order to view photos that are being stored on the Raspberry Pi. We also took into consideration how the UI of the app is going to look. We wanted an app that would represent our hard work on this project. In this section, we are going to discuss how we designed our application, what features it is going to entail, along with what our expectations are for the future with this app and SafeSight as a whole.

7.2.1 Initial Design and Thought Process

Initially, we wanted an application to simply connect to SafeSight using the ESP32s or the Pi's bluetooth. This will allow the user to access their photos that the Pi has taken of them when they were distracted. Along with this, we wanted an overall driver report, live camera feed, profile page and bluetooth device search. Initially, we wanted the user to be able to log in with a username and password to access their SafeSight device.

However, we thought about what we wanted this app to encompass and decided that we did not want to go that route due to the complexity of databases. We wanted to make something super user-friendly. Almost like how other cameras like the Insta360 camera or the GoPros have it where all you have to do is either connect to their network or bluetooth, and you can view and edit everything that is on the camera. Since everyone will have their own, unique device, there is no need to create a user database for the app. This will allow us to focus on each tab of the app individually rather than focusing more on databases, which is irrelevant for this project. Below, you will see the breakdown of each screen and tab in the app with their designated functions.

7.2.2 The Start Screen

Below is the UI for the login screen, as stated before, my original idea was to make this a login page with a sign in for google, apple, and a .edu sign in. However, we soon realized that this was not necessary due to the uniqueness of the device. With your very own bluetooth signal, your device is unique to you, making it secure with no need for a username and password authentication. Using SwiftUI, we created this wonderful, user-friendly start screen with a button that says "Connect Your Device". This was created using SwiftUI's 'Z-Stack' and 'V-Stack' view blocks which allow for us to stack images and buttons either in front or behind each other in a nice vertical column. When you push that button in the middle, the app will then take you to another screen where it searches for bluetooth devices using your phone's bluetooth antenna. This will allow the user to connect to their device and have a welcoming experience when they go to view the content on their SafeSight module.

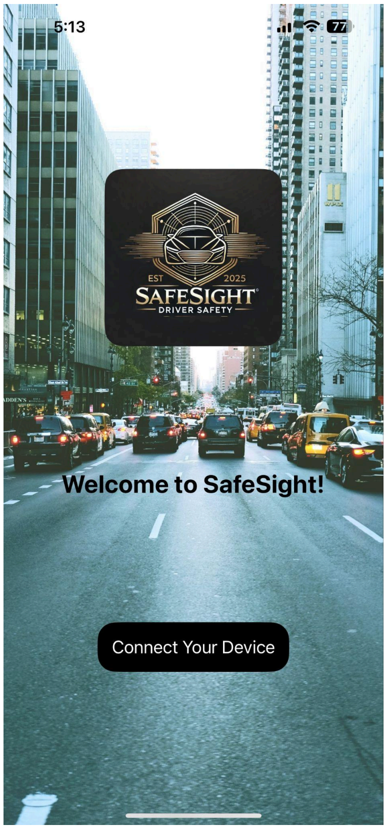
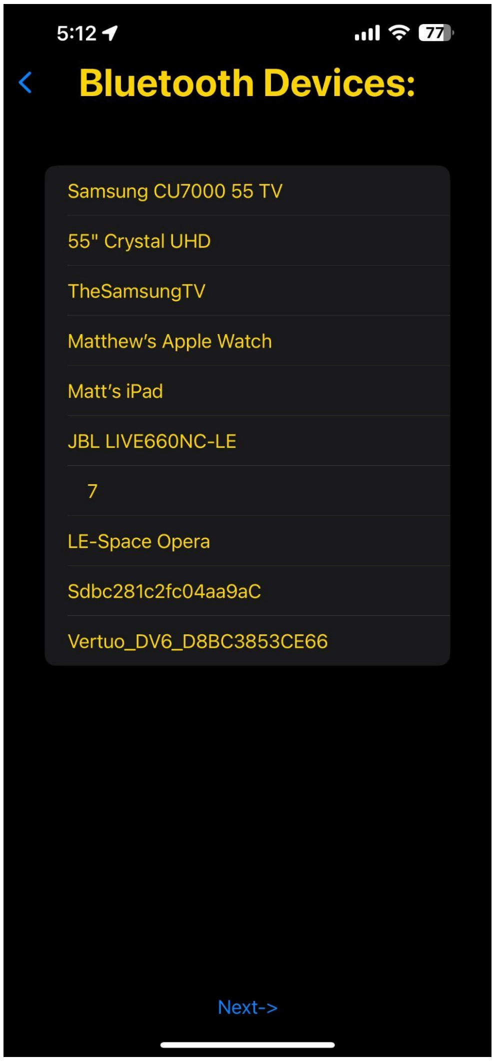


Figure 7.2.2.1 Application Start Screen

7.2.3 Bluetooth Device Selection

After the initial welcome screen, users are guided to the Bluetooth Device Selection screen, where they can connect to their SafeSight device. This view is built using SwiftUI and powered by CoreBluetooth, Apple's Bluetooth Low Energy framework. When the view loads, a CBCentralManager is initialized to manage Bluetooth operations. Once Bluetooth is confirmed to be powered on, the app begins scanning for nearby peripherals that are broadcasting BLE signals. As devices are discovered through the centralManager(_:didDiscover:advertisementData:rssi:) delegate method, they are collected into a list and displayed to the user using SwiftUI's reactive List view. Each device appears with its name (or a placeholder if unnamed), and the user can tap their SafeSight device to initiate a connection using connect(_:options:). Once the connection is established and confirmed through the centralManager(_:didConnect:) delegate, the app seamlessly navigates to the Home view, where the main SafeSight functionalities become accessible. Below, you will see the UI that we have created for selecting and viewing our Bluetooth devices.



Bluetooth Devices:

- Samsung CU7000 55 TV
- 55" Crystal UHD
- TheSamsungTV
- Matthew's Apple Watch
- Matt's iPad
- JBL LIVE660NC-LE
- 7
- LE-Space Opera
- Sdbc281c2fc04aa9aC
- Vertuo_DV6_D8BC3853CE66

Figure 7.2.3.1 Bluetooth Device Selection Screen

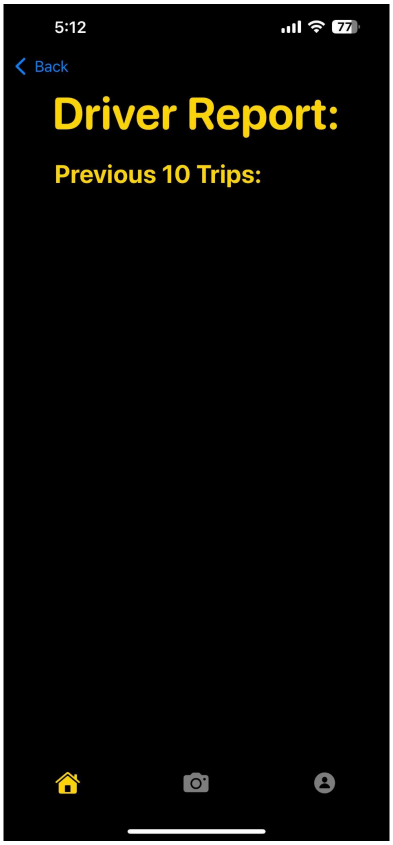
7.2.4 The Home Screen

Once the user has selected their SafeSight device, they will be guided to the Home Screen. From there, you will see three tabs: Driver Report, Live Camera Feed, and Profile. This view will allow the user to see all of the data that their SafeSight Device has collected throughout their previous 10 Trips. Since these views are not complete yet, you will see what they currently look like, along with descriptions on what changes are to come in the near future.

7.2.4.1 The Home Screen: Driver Report

In this tab, the user will be able to see the statistics from their past 10 trips. It will give a list consisting of the number of distractions per trip, along with an average number of distractions for the user. This will allow the user to be mindful of how often they are getting distracted while driving, along with individual reports on each and every trip.

In the future of this project, we will add a table with the distractions per trip that will allow the user to click on each and every trip to see the breakdown of that particular trip. We will also possibly add a nice pie chart that will show the overall time they are paying attention vs the amount of time they are distracted while driving. These future updates can be done by using built-in SwiftUI components such as List (for the table), Navigation Link (to make the table reactive), and SwiftUICharts (to make a pie chart). Below, is what currently exists in the UI development for this tab view.



Driver Report:

Previous 10 Trips:

Figure 7.2.4.1.1 Driver Report Tab View Current State

7.2.4.2 The Home Screen: Live Camera Feed & Photo Gallery

For this tab, we plan on integrating a live camera feed of the driver along with a collection of photos that the device has taken of the user being distracted. This is going to be one of the main tabs of the application because it is going to probably be the most amount of work due to the sending and receiving of image files from the Pi to the phone. However, this is the main purpose of SafeSight, to show the world how distracted everyone is while driving.

In future updates, there will be a window on top of a Z and V Stack, that will allow the user to view the camera feed that is being transmitted from the Raspberry Pi, along with the driver view camera feed. Right below that, will be all of the photos taken by the Raspberry Pi camera. From there, the user will be able to select, view, and even share the photo with friends or family. If the owner of the vehicle was Uber for example, they could even keep track when their drivers get distracted by giving them an attention score. This would let users of Uber know if the driver that is picking them up is a good driver. So far, it looks like the photos will be transferred via raw data from the Pi to your iPhone. The image will be encoded as small chunks of raw data (using CoreBluetooth) and then the iPhone will reconstruct the image to properly display it. With that being said, below, is the current state of the Live Camera Feed & Photo Gallery tab. Feel free to use your imagination to see what the final product will look like.

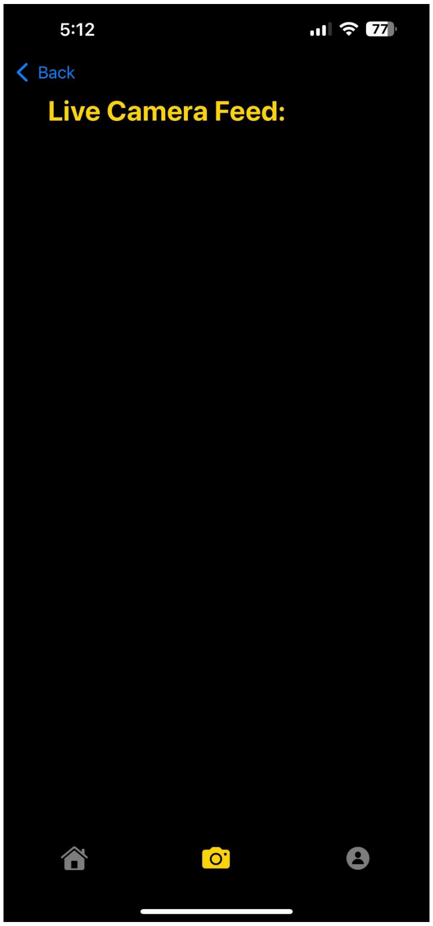


Figure 7.2.4.2.1 Live Camera Feed & Photo Gallery Tab View Current State

7.2.4.3 The Home Screen: Profile Page

Once the user has viewed all of the information from the Raspberry Pi, they will be led to the Profile Page tab. In this tab, the user will be able to disconnect or reconnect to their SafeSight Device along with being able to access a couple of other options that we have not thought of yet. In future updates, there will be a list of options displayed with SwiftUIs List view that will allow the user to do a multitude of things. The most important one will be a “disconnect from device” button. Below, you will see the current state of this Profile Page tab view.

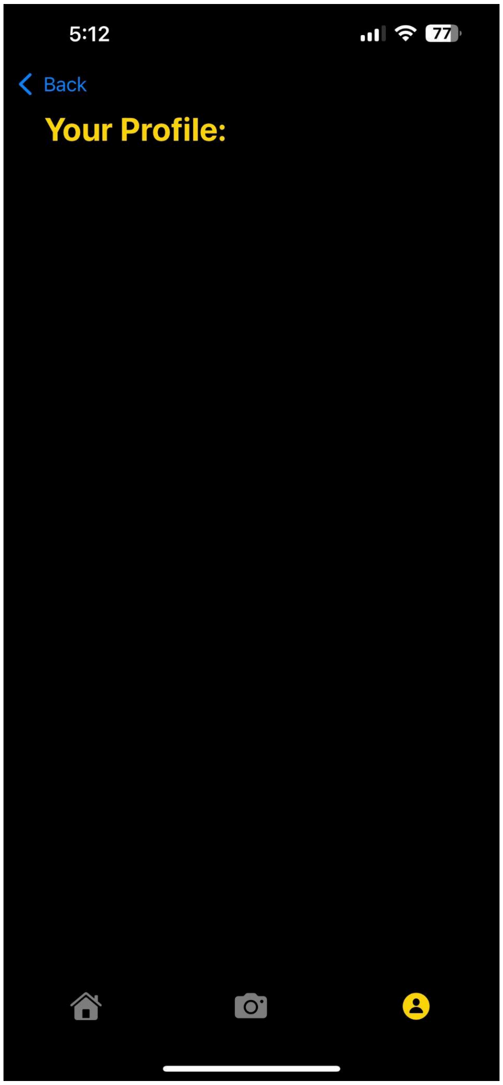


Figure 7.2.4.3.1 Profile Page Tab View Current State

8. System Fabrication/ Prototype Construction

This section is where we will be showcasing the system fabrication into a PCB. PCB is short for printed circuit board and it is vital when creating a robust and size conscious system to house all necessary electronics. PCBs are the cornerstone of all commercial electronics products. They are seen in technology ranging from your remote control race car to supercomputers that run extensive computations. Just as there are many ways to apply a PCB in electronics, there are just as many methods in designing a PCB. Printed circuit board software that many college students are exposed to are CAD softwares and they include Fusion 360, Autodesk EAGLE, KCAD, and EasyEDA. The software that will be implemented in our SafeSight project is EasyEDA for its accessibility and compatibility by allowing design collaboration, LSCS library access, and access to designing through a browser window. There are many steps in the design process to get a simple schematic to a finished PCB layout, and choosing the appropriate software will provide the appropriate foundation for flawless execution.

Beyond the selection of design software, the journey from concept to a finished PCB involves a structured, multi-step process that transforms an idea into a tangible, manufacturable product. The process typically begins with the creation of a schematic, which serves as the electrical blueprint for the board's functionality. This schematic is then translated into a physical layout using CAD tools, where component placement, trace routing, and design rules are meticulously defined to ensure optimal performance and manufacturability. Additional steps include designing the board's stackup for signal integrity, inserting drill holes for component leads and vias, and adding labels or reference designators for assembly. Once the layout is finalized, manufacturing files such as Gerbers are generated, which are then used to fabricate the actual PCB. Throughout this process, close collaboration with manufacturers and adherence to industry standards are essential to avoid costly revisions and ensure the final product meets all functional and reliability requirements.

8.1 PCB Design - Organization

Once a schematic is finalized in the software of choice, the next step is to convert your finalized schematic into a PCB design. In EasyEDA, once we first convert our schematic to PCB design, the orientation of components may show themselves as quite confusing. However, the first order of business is to lay out the circuit boards' dimension parameters and then organize all the components within this space. Every design will differ, however there are principles to follow. For example, in our SafeSight design, we will be using micro USB ports, buttons, and a wire terminal and will naturally place these components on the edge or corners of the PCB away from surface mounted components to allow for easy access and isolation from potential shorts. The organization step is vital and must be executed at the beginning of the PCB design because any changes in location once the routes are made will result in rigorous problem solving in order to accommodate any changes in component placement. Below is an example of our layout before and after routing is done. We reorganized the radar footprint before routing so that it could be isolated away from components and be seated next to the accelerometer on the PCB.

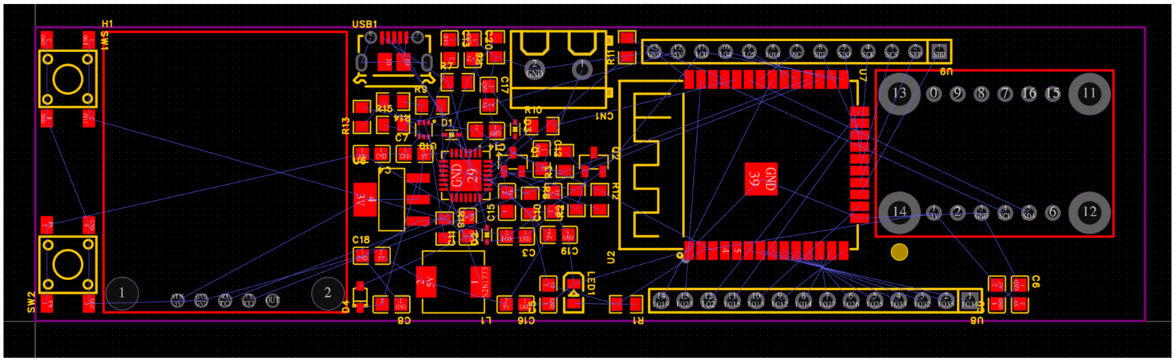


Figure 8.1.1 PCB Organization

8.2 PCB Design - Routing

After our components are laid out on our PCB in an appropriate order for the project application, we must move on to the next stage of PCB design: routing. Routing on a PCB consists of running wires along the top and bottom layers of the board to their respective pads. No routes can intersect with one another, so we use Vias as a method to transfer surface running routes to bottom running routes. This is the main method of preventing overlap or intersection of routes which will result in improper performance when electronic testing is made. The red routes represent the surface layer of the PCB in this picture below, and the blue routes represent connections running along the bottom surface of the PCB.

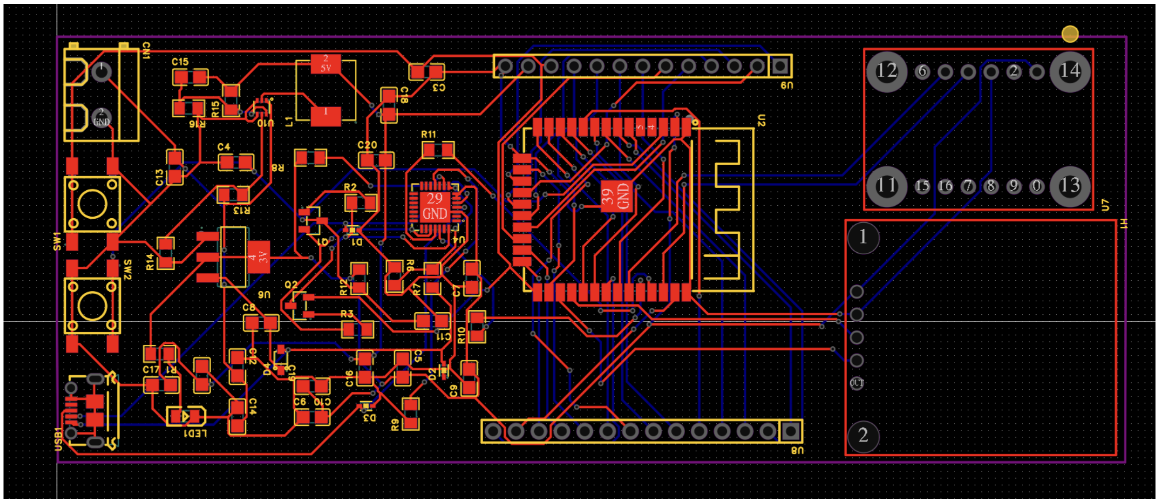


Figure 8.2.1 PCB Trace Routing

The last and equally important stage for running routes is the distance between parallel running connection routes on the PCB. If a pair of routes is running too close to one another in a parallel orientation, they run the risk of parasitic capacitance. Parasitic capacitance, also known as stray capacitance, refers to the unintended and unavoidable capacitance that arises between conductive elements in an electronic circuit or component due to their proximity. In PCB design, parasitic capacitance manifests between adjacent traces, layers, or components, often causing crosstalk, signal integrity issues, or unintended resonant circuits. While impossible to eliminate entirely, its effects can be mitigated through careful layout practices like avoiding parallel routing and optimizing trace spacing.

8.3 PCB Design - DRC and 3D/2D Verification

Once our components are organized on our PCB, the dimensions of the board are set to their respective parameters, and all the routing is done between pads, we must complete the last step which is to do a DRC check and verify that the 3D and 2D CAD models fit our standards for the final product. The DRC check stands for Design Rule Check and verifies all electronic routing connections, making sure they are spaced from one another properly and that all connections are just. If the DRC flags any suspecting connections it will notify the user of the Design software and advise a fix before file export for PCB fabrication. Below is the verified DRC check of our SafeSight design and the respective 3D and 2D models. Our design is verified in the DRC and no potential problems with routing or component placement have been flagged by the software.

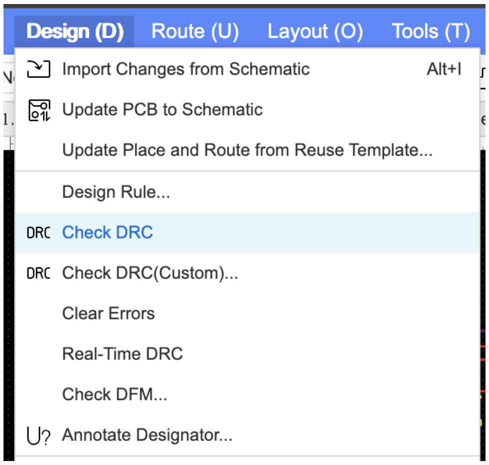


Figure 8.2.1 Check DRC Option

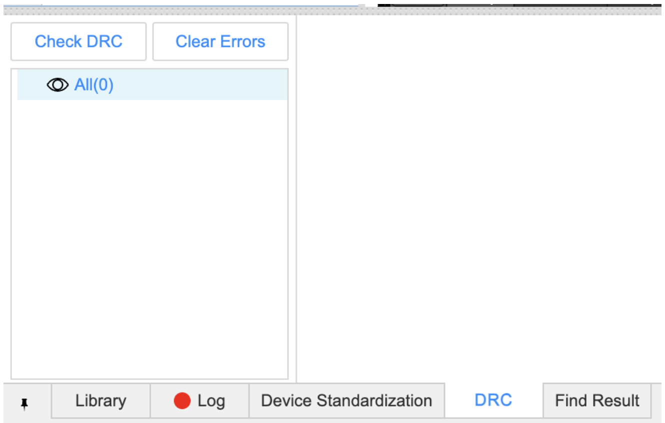


Figure 8.2.2 DRC Completion

After completing the DRC check, the final verification stage integrates both electrical and mechanical validation to ensure the design meets functional and physical requirements.

Modern PCB CAD tools like Altium Designer, KiCad, and EasyEDA enable simultaneous 3D/2D validation, allowing designers to inspect component clearances, enclosure fit, and thermal performance through automated collision detection and layer stackup analysis. For example, 3D visualization can reveal hidden issues like protruding components interfering with mounting points or inadequate airflow around heat-sensitive parts.

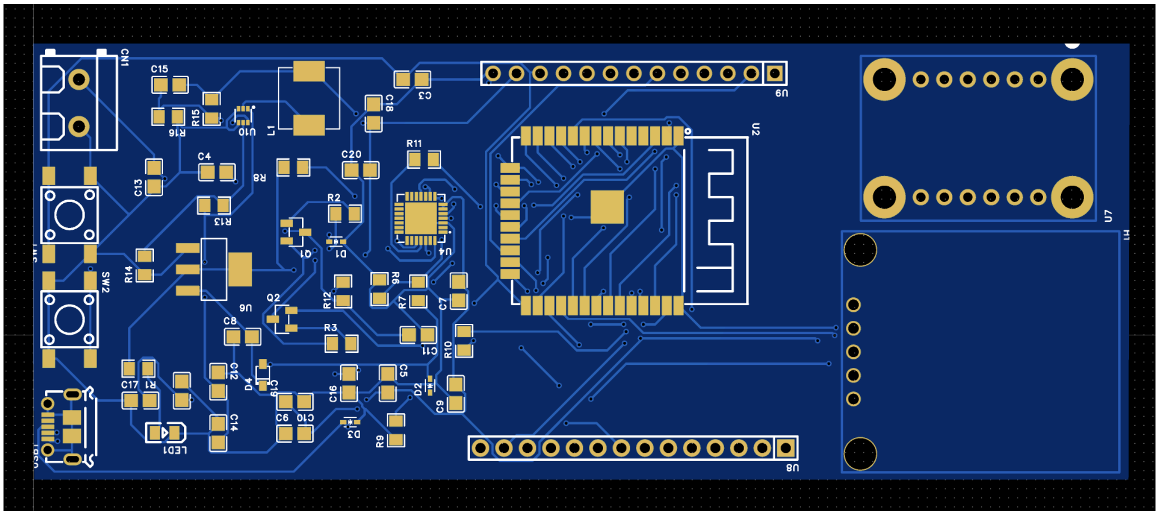


Figure 8.2.3 Modern PCB Cad Layout

Due to the fact that we connected pin headers in the schematic to custom footprints for our sensor development boards, the software associated 3D versions of pin headers in the place of the 3D representation of the sensor development boards. This will not be an issue when it comes to PCB assembly and is only a simple model in the 3D diagram. The final PCB after assembly will not contain those two extra rows of pin headers at the end, instead the development boards for the sensors will take their place. Below is the 3D model for our finalized PCB design in EasyEDA.

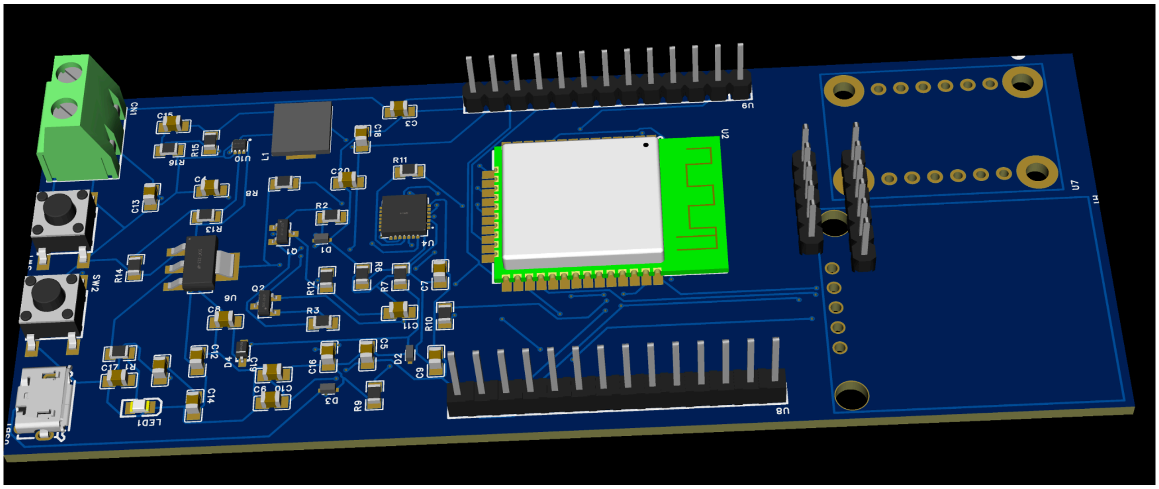


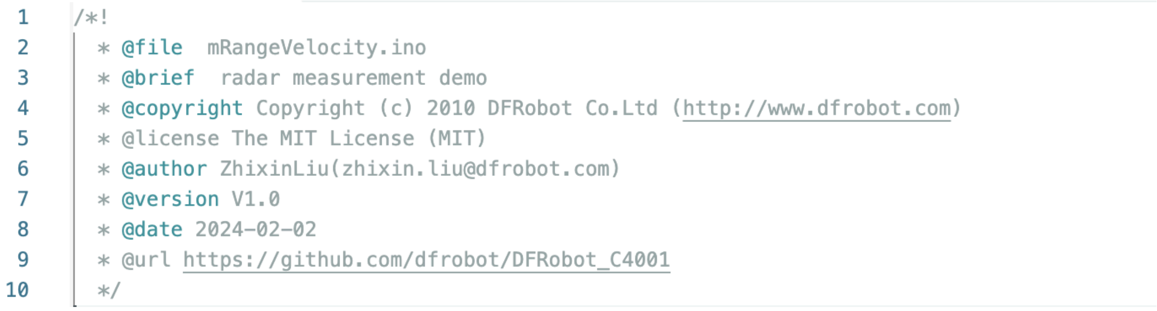
Figure 8.2.4 3D PCB View

9. System Testing and Evaluation

Throughout the physical build of the project, we decided to take steps into how the construction of the system will be built by testing individual components one by one prior to finalizing the project in its entirety. With this, we went ahead and ordered the mmWave radar from DF Robot, the MPU-6050 inertial sensor, ESP32 development boards, and the raspberry pi in order to effectively test the components for which we intend to establish a communication protocol between the components in our demonstration.

9.1 Radar Integration

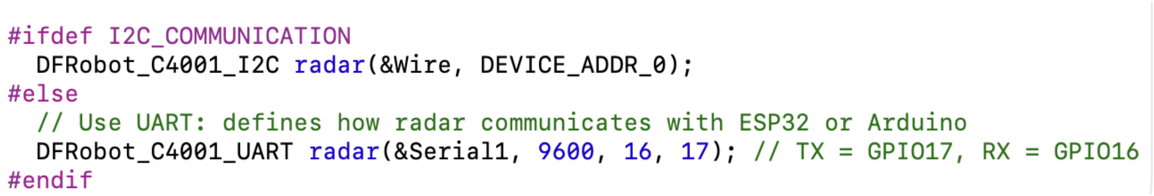
With the development of the project, the hardware components purchased needed to be tested in order for the communication protocol between the individual IC’s to function accordingly with the MCU (ESP32). In order to access the Radar we went ahead and utilized the Arduino IDE to directly communicate with the ESP32 and direct the pins for the R and TX terminals.



```
/*!
  * @file  mRangeVelocity.ino
  * @brief  radar measurement demo
  * @copyright Copyright (c) 2010 DFRobot Co.Ltd (http://www.dfrobot.com)
  * @license The MIT License (MIT)
  * @author ZhixinLiu(zhixin.liu@dfrobot.com)
  * @version V1.0
  * @date 2024-02-02
  * @url https://github.com/dfrobot/DFRobot_C4001
  */
```

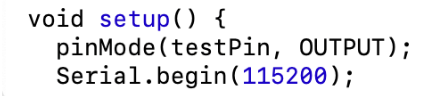
This section of the documentation block at the top of the sketch file specifies the name of the file, in this case “mRangeVelocity.ino” which is an arduino sketch. The “@brief” gives a short description of the sketch, where the radar measurement demo is stored for the DFRobot C4001 mmWave Radar. Giving our credits to the copyright owners in the next line and then the MIT License for the permissive open-source license we used to access the code template for the DFRobot.

In this code we went ahead and used the DFRobot_C4001.h library for communicating correctly with the C4001 radar module.



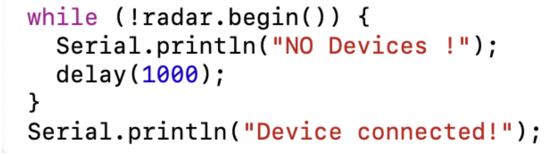
```
#ifdef I2C_COMMUNICATION
  DFRobot_C4001_I2C radar(&Wire, DEVICE_ADDR_0);
#else
  // Use UART: defines how radar communicates with ESP32 or Arduino
  DFRobot_C4001_UART radar(&Serial1, 9600, 16, 17); // TX = GPIO17, RX = GPIO16
#endif
```

In order to communicate with the ESP32 via serial communication, we used the pins 16 and 17 (RX and TX, respectively) to establish the Serial1 connection with the ESP32.



```
void setup() {
  pinMode(testPin, OUTPUT);
  Serial.begin(115200);
```

This section of the code starts the USB serial port for debugging, sets the testPin (GPIO 19) as output in order to trigger the response of the radar throughout the whole system. In this case we used a red LED in order to demonstrate the trigger's effectiveness in this prototype system.



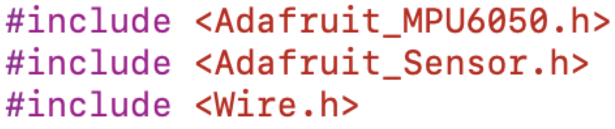
```
while (!radar.begin()) {
  Serial.println("NO Devices !");
  delay(1000);
}
Serial.println("Device connected!");
```

In order to initialize the radar sensor, we have this while loop operating in the code to print out the serial monitor to determine when our radar has been initialized. After several boot-up attempts, the radar typically takes around 20 seconds to initialize within the system on a 3.3V activation voltage.

In the developmental stage of the radar's integration, we went ahead and used the default mode of the radar to be "eSpeedMode" where it detected moving objects along with their speed and range. While this may be useful for walking speed, object approach and security detection, it may deem a bit ineffective for the purposes of our radar use within this system, thus we went ahead and changed the operating mode to be eDistanceMode in order to track distance on both animate and inanimate objects.

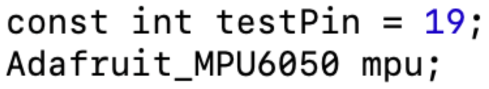
9.2 MCU-6050 Integration

The MCU-6050 is the inertial sensor we decided to use within this system. With the MCU-6050 we decided to go with I2C communication with the **Wire.h** command in the header file. Alongside that command we have other header file inclusions, for example to provide a unified sensor abstraction layer we implemented the **Adafruit_sensor.h** file and to ensure we are utilizing the accelerometer and gyroscope within the module, the **Adafruit_MPU6050.h** file:



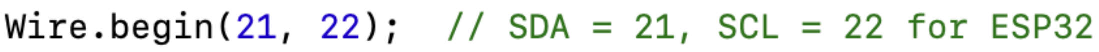
```
#include <Adafruit_MPU6050.h>
#include <Adafruit_Sensor.h>
#include <Wire.h>
```

Again, like we have done in the previous hardware fabrication, we enabled the digital output pin with **testPin** this was used for toggling a signal (possibly for debugging or an external indicator like an LED as we implemented in the demo videos. **Mpu** is what we will use to interface with the MPU6050.



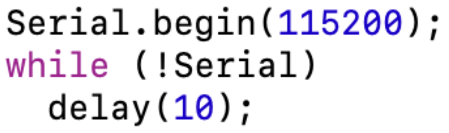
```
const int testPin = 19;
Adafruit_MPU6050 mpu;
```

The next portion of the fabrication process involved the initialization of the sensor. This included the initialization of the I2C bus with custom SDA and SCL pins, which was allowed by the ESP32 alongside the explicit definition of what pins we were intending to use with this bus.



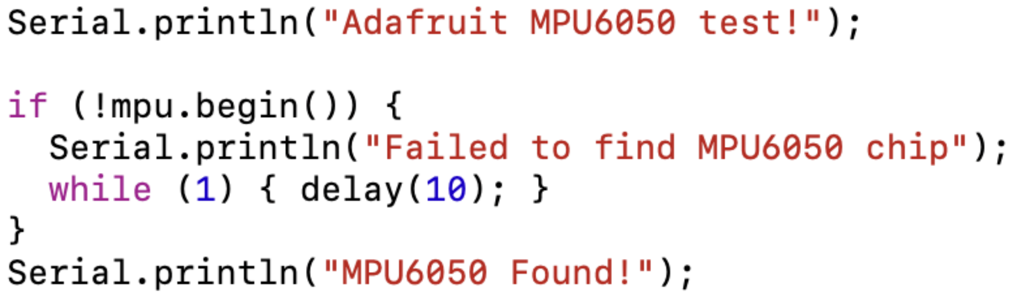
```
Wire.begin(21, 22);  // SDA = 21, SCL = 22 for ESP32
```

Then, we configured the **testPin** as an output and set it high initially. This began the serial monitor at 115200 baud and waited for it to be ready. This was not strictly necessary for the ESP32 but it was a safe measure in order to ensure we knew exactly what to expect with the components.



```
Serial.begin(115200);
while (!Serial)
  delay(10);
```

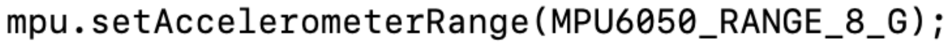
The next block of code was focused on initializing the MPU6050 and if this were to fail, the loop lasts forever, printing an error message to the user in order to fix any connections on the hardware side if needed.



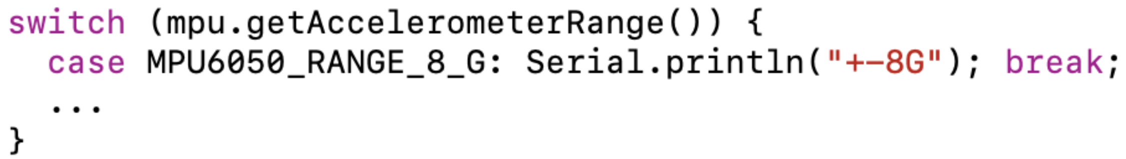
```
Serial.println("Adafruit MPU6050 test!");

if (!mpu.begin()) {
  Serial.println("Failed to find MPU6050 chip");
  while (1) { delay(10); }
}
Serial.println("MPU6050 Found!");
```

The next section of this code is to configure the sensor in order for us to extract accurate and precise data from the sensor. First and foremost, we set the accelerometer range to +/- 8g (gravitational units). The 8g gravitational unit setting is a good start to the fabrication process as the more range we add, the less sensitivity we get. With the ambition of this sensor being in the automotive space, it is good for us to fine tune this value when presenting in a more applicable case scenario.

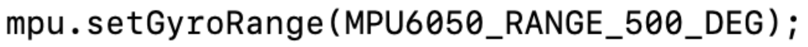


```
mpu.setAccelerometerRange(MPU6050_RANGE_8_G);
```



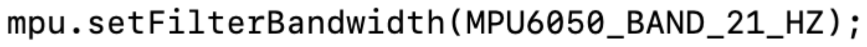
```
switch (mpu.getAccelerometerRange()) {
  case MPU6050_RANGE_8_G: Serial.println("+-8G"); break;
  ...
}
```

Next, we went ahead and defined the gyroscope range to be +/-500 degrees per second.



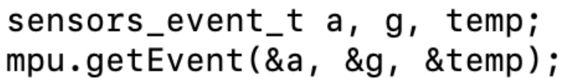
```
mpu.setGyroRange(MPU6050_RANGE_500_DEG);
```

In order to reduce high-frequency noise associated with the environment around the sensor initially in the fabrication process, a digital filter was introduced with a bandwidth of 21 Hz.



```
mpu.setFilterBandwidth(MPU6050_BAND_21_HZ);
```

Acquiring this data is crucial in this process, to make sure we are getting accurate readings and that this sensor will be applicable to the intended use we have. Thus, reading the information is a big part of this process.

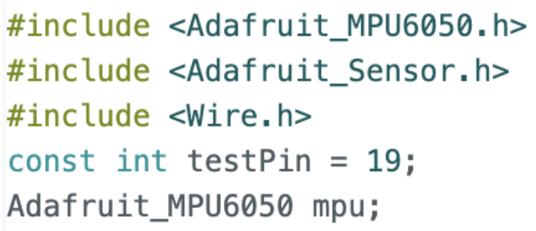


```
sensors_event_t a, g, temp;
mpu.getEvent(&a, &g, &temp);
```

The data acquired here is the accelerometer data, the gyroscope data, and the temperature data (a, g, temp). Finally in this short drafted code, we toggled the pin 19 for HIGH of 10ms and LOW for 10ms, creating a 20ms cycle (50Hz pulse). This was used for debugging, triggering, syncing with another sensor and device, and testing the responsiveness of the output. The ESP32 MCU communicated with the Adafruit MPU6050 sensor over the I2c interface as we described above through pins GPIO21 and GPIO22. The firmware initializes the sensor, sets up the desired sensitivity ranges for the accelerometer and gyroscope, and applies a digital low-pass filter at 21 Hz to minimize noise. Sensor data is acquired using the getEvent() function from the Adafruit Sensor API and output via the serial monitor at 115200 baud. Our test pin (GPIO19) is toggled at regular intervals to provide a visual or logic-level signal, confirming the program's execution and synchronizing with external devices.

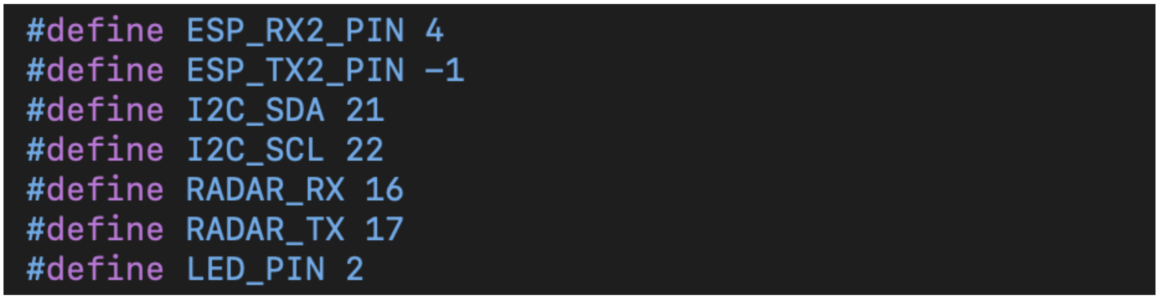
9.3 Radar, Accelerometer, and Raspberry Pi integration

The final integration for these arduino sketches was to integrate both components: the MPU6050 accelerometer and the DFRobot C4001 mmWave radar sensor with an ESP32 microcontroller using both the I2C and UART interfaces. This combination will transmit data centered around distance and motion, communicating with another device via UART2 for external signaling such as the LED and piezoelectric buzzer.



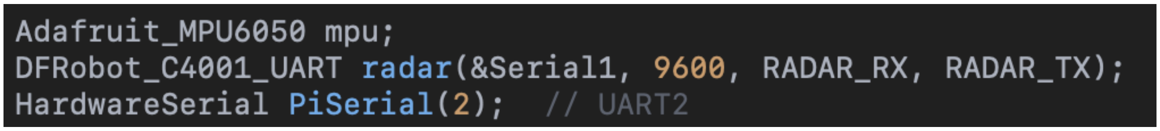
```
#include <Adafruit_MPU6050.h>
#include <Adafruit_Sensor.h>
#include <Wire.h>
const int testPin = 19;
Adafruit_MPU6050 mpu;
```

In this block of code we are providing the functions to communicate over I2C (wire.h), interface with the MPU6050 sensor from the Adafruit, and to interface with the DFRobot C4001 radar sensor via UART. In order for the circuit build to be functional on a breadboard / development board, we defined the connection ports within the code:



```
#define ESP_RX2_PIN 4
#define ESP_TX2_PIN -1
#define I2C_SDA 21
#define I2C_SCL 22
#define RADAR_RX 16
#define RADAR_TX 17
#define LED_PIN 2
```

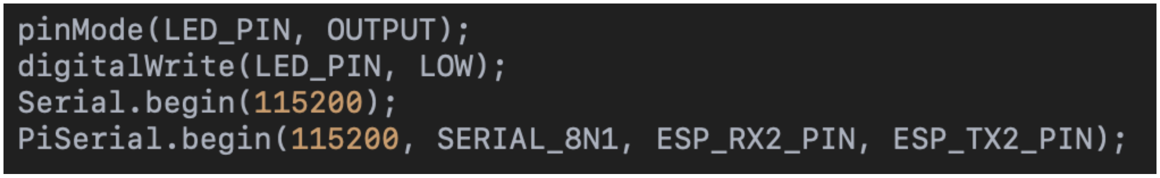
These configurations include the UART2 on GPIO4, Radar sensor on GPIO16 (RX) and GPIO17 (TX), I2C on GPIO21 (SDA) and GPIO22 (SCL) with the built-in LED on GPIO2. The object instantiations include the MPU, which handles MPU6050 sensor operations, Radar, which manages C$))! Radar communication on Serial1, and PiSerial which opens an extra serial channel on UART2 for external communication.



```
Adafruit_MPU6050 mpu;
DFRobot_C4001_UART radar(&Serial1, 9600, RADAR_RX, RADAR_TX);
HardwareSerial PiSerial(2);  // UART2
```

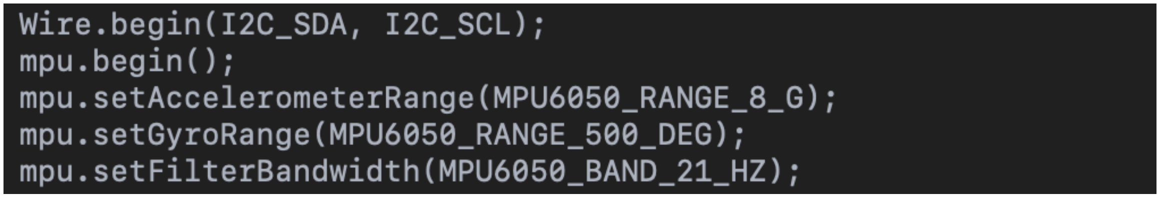
To effectively transmit data to our natural senses alongside the external IC of the Raspberry Pi,the setup prior to the body of the code is imperative. Here we set up the

LED pin as output to turn it off, we initialize the Serial (USB) for logging and set up the UART2 (PiSerial) to listen on GPIO4.



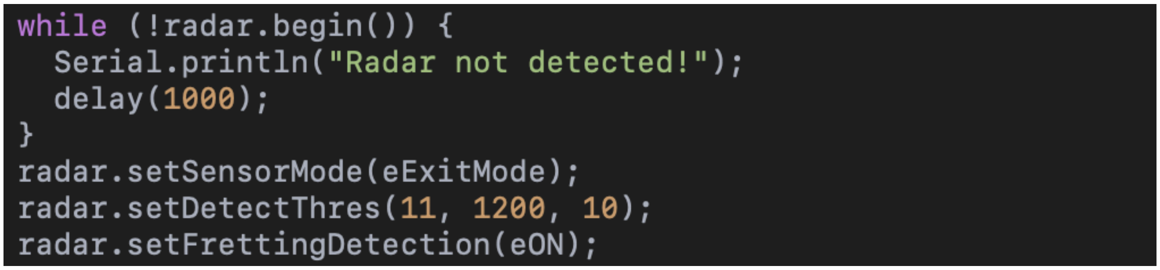
```
pinMode(LED_PIN, OUTPUT);
digitalWrite(LED_PIN, LOW);
Serial.begin(115200);
PiSerial.begin(115200, SERIAL_8N1, ESP_RX2_PIN, ESP_TX2_PIN);
```

The I2C and MPU6050 Initialization begins with the I2C communication with defined pins. This ensured the MPU6050 initializes with +/- 8G accelerometer range, +/- 500 deg/s gyroscope range, and 21Hz digital filter to reduce high-frequency noise.



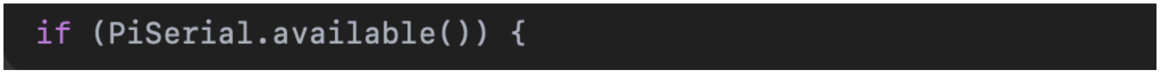
```
Wire.begin(I2C_SDA, I2C_SCL);
mpu.begin();
mpu.setAccelerometerRange(MPU6050_RANGE_8_G);
mpu.setGyroRange(MPU6050_RANGE_500_DEG);
mpu.setFilterBandwidth(MPU6050_BAND_21_HZ);
```

The C4001 radar initialization waits for the radar sensor to full initialize, then configures the radar detection mode and thresholds. This sets the sensor to exit mode, defines detection threshold values, and enables fretting detection which is needed to be sensitive to small movements.



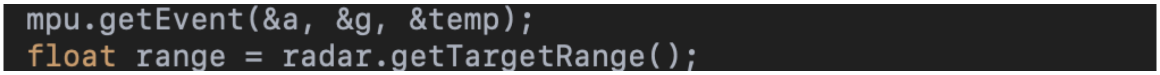
```
while (!radar.begin()) {
  Serial.println("Radar not detected!");
  delay(1000);
}
radar.setSensorMode(eExitMode);
radar.setDetectThres(11, 1200, 10);
radar.setFrettingDetection(eON);
```

From here we check to see if the data is available on UART2 from the raspberry pi with an if statement which will give us continuous execution while the device is running.



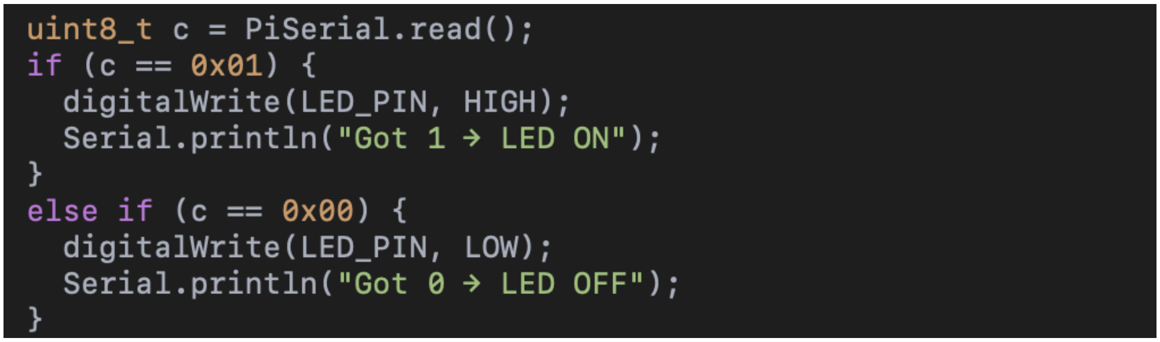
```
 if (PiSerial.available()) {
```

Grabbing the sensor readings includes the data on the accelerometer, gyroscope, and temperature data from the MPU6050. This target range from the radar sensor (in cm or mm depending on configurations) will be good data to reference when fine tuning is done prior to the final fabrication of the device on a PCB.



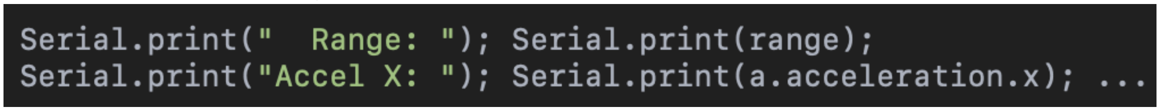
```
 mpu.getEvent(&a, &g, &temp);
 float range = radar.getTargetRange();
```

The LED control and serial logging is then defined in order for us to see that the communication between devices is behaving as we expect. If 0x01 is received over UART2, then the LED will turn on, if 0x00 is received, the LED will turn off. This lets an external system control the ESP32’s onboard indicator. In this case, the external system is the Raspberry Pi.



```
uint8_t c = PiSerial.read();
if (c == 0x01) {
  digitalWrite(LED_PIN, HIGH);
  Serial.println("Got 1 → LED ON");
}
else if (c == 0x00) {
  digitalWrite(LED_PIN, LOW);
  Serial.println("Got 0 → LED OFF");
}
```

Finally, before executing the code and witnessing the sensor values, we need to ensure that we are receiving real-time sensor readings from the ESP32 to the serial monitor. This is useful for us as we are debugging or logging physical activity and distance within this system. To ensure the fine tuning process is as prepared as possible for ideal system performance in Senior Design 2, it is imperative for these values to be communicated effectively.



```
Serial.print("  Range: "); Serial.print(range);
Serial.print("Accel X: "); Serial.print(a.acceleration.x); ...
```

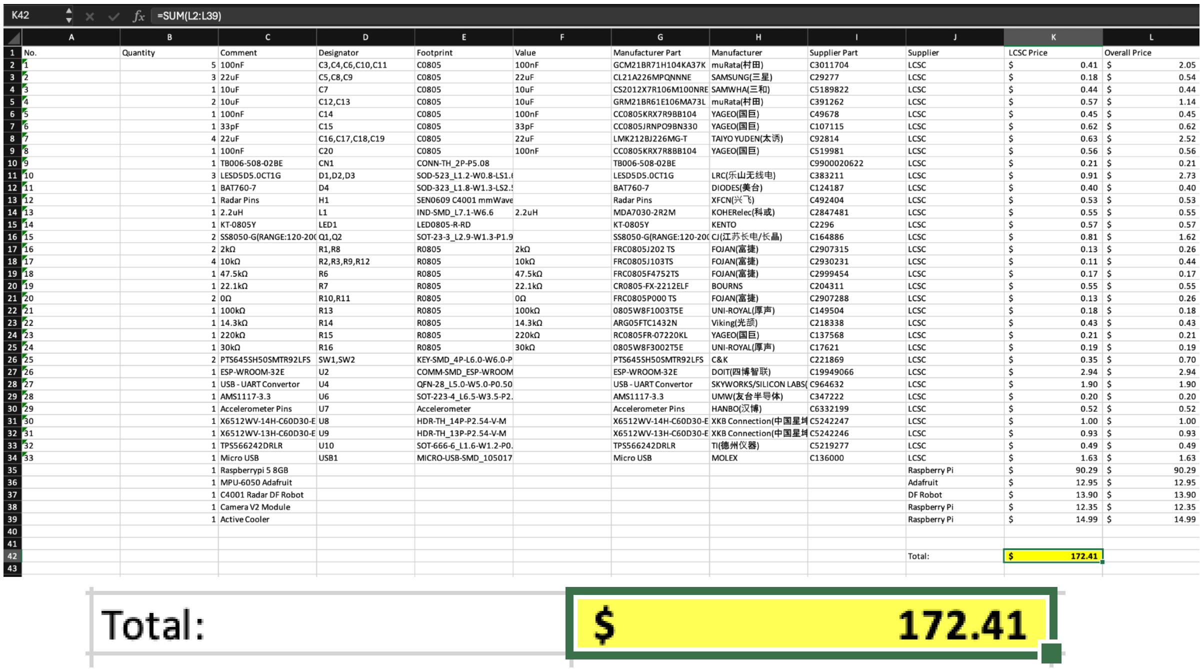
This code demonstrates a multi-sensor integration on an ESP32 platform using I2C and UART simultaneously. With the MPU6050 accelerometer/ gyroscope capturing motion data, the C4001 mmWave radar detecting distance and movement, and a PiSerial interface allowing the Raspberry Pi to control onboard functions like LED and trigger readings. All the data is then logged to the serial monitor, enabling both real-time feedback and analysis.

10. Administrative Content

In this chapter, we will go over planning our budget, milestones for senior design 1 and 2, and we will show the work distribution on who is primarily doing what in this project. We will go over the reasoning for all of these choices, along with plans for the future to help make sure we are moving forward efficiently to complete this project.

10.1 Budget and Financing

As stated in Chapter 4, one of the biggest challenges for this project is the funding generated from senior year students not working in the industry. With that being said, initially we began with a maximum budget with the initial BOM being under $300 which would evenly distribute the cost per member of this team to be $100. But after some requirements to meet constraints of regulations, functionality, adjustments to the hardware, and performance benchmarks, some of the costs ended up exceeding the initial proposal of ideas. For instance, during testing we needed more ESP32 boards in order to test different subsystems in the project. This led to the cost of a microcontroller unit to be multiplied by 3 in order to rely on other microcontrollers for simultaneously testing subsystems at the same time. The cost for PCB boards will also be more than anticipated as we will adjust the sizing and the components accordingly.



K42 =SUM(L2:L39)

	A	B	C	D	E	F	G	H	I	J	K	L
1	No.	Quantity	Comment	Designator	Footprint	Value	Manufacturer Part	Manufacturer	Supplier Part	Supplier	LCSC Price	Overall Price
2	1	5	100nF	C3,C4,C6,C10,C11	C0805	100nF	GCM21BR71H104KA37K	muRata(村田)	C3011704	LCSC	$ 0.41	$ 2.05
3	2	3	22uF	C5,C8,C9	C0805	22uF	CL21A226MPQNNNE	SAMSUNG(三星)	C29277	LCSC	$ 0.18	$ 0.54
4	3	1	10uF	C7	C0805	10uF	CS2012X7R106M100NRE	SAMWHA(三和)	C5189822	LCSC	$ 0.44	$ 0.44
5	4	2	10uF	C12,C13	C0805	10uF	GRM21BR61E106MA73L	muRata(村田)	C391262	LCSC	$ 0.57	$ 1.14
6	5	1	100nF	C14	C0805	100nF	CC0805KRX7R9BB104	YAGEO(国巨)	C49678	LCSC	$ 0.45	$ 0.45
7	6	1	33pF	C15	C0805	33pF	CC0805JRNPO9BN330	YAGEO(国巨)	C107115	LCSC	$ 0.62	$ 0.62
8	7	4	22uF	C16,C17,C18,C19	C0805	22uF	LMK212BJ226MG-T	TAIYO YUDEN(太诱)	C92814	LCSC	$ 0.63	$ 2.52
9	8	1	100nF	C20	C0805	100nF	CC0805KRX7R8BB104	YAGEO(国巨)	C519981	LCSC	$ 0.56	$ 0.56
10	9	1	TB006-508-02BE	CN1	CONN-TH_2P-P5.08		TB006-508-02BE		C9900020622	LCSC	$ 0.21	$ 0.21
11	10	3	LESD5D5.0CT1G	D1,D2,D3	SOD-523_L1.2-W0.8-LS1.(		LESD5D5.0CT1G	LRC(乐山无线电)	C383211	LCSC	$ 0.91	$ 2.73
12	11	1	BAT760-7	D4	SOD-323_L1.8-W1.3-LS2.!		BAT760-7	DIODES(美台)	C124187	LCSC	$ 0.40	$ 0.40
13	12	1	Radar Pins	H1	SEN0609 C4001 mmWave		Radar Pins	XFCN(兴飞)	C492404	LCSC	$ 0.53	$ 0.53
14	13	1	2.2uH	L1	IND-SMD_L7.1-W6.6	2.2uH	MDA7030-2R2M	KOHERelec(科或)	C2847481	LCSC	$ 0.55	$ 0.55
15	14	1	KT-0805Y	LED1	LED0805-R-RD		KT-0805Y	KENTO	C2296	LCSC	$ 0.57	$ 0.57
16	15	2	SS8050-G(RANGE:120-20(	Q1,Q2	SOT-23-3_L2.9-W1.3-P1.9		SS8050-G(RANGE:120-20(	CJ(江苏长电/长晶)	C164886	LCSC	$ 0.81	$ 1.62
17	16	2	2kΩ	R1,R8	R0805	2kΩ	FRC0805J202 TS	FOJAN(富捷)	C2907315	LCSC	$ 0.13	$ 0.26
18	17	4	10kΩ	R2,R3,R9,R12	R0805	10kΩ	FRC0805J103TS	FOJAN(富捷)	C2930231	LCSC	$ 0.11	$ 0.44
19	18	1	47.5kΩ	R6	R0805	47.5kΩ	FRC0805F4752TS	FOJAN(富捷)	C2999454	LCSC	$ 0.17	$ 0.17
20	19	1	22.1kΩ	R7	R0805	22.1kΩ	CR0805-FX-2212ELF	BOURNS	C204311	LCSC	$ 0.55	$ 0.55
21	20	2	0Ω	R10,R11	R0805	0Ω	FRC0805P000 TS	FOJAN(富捷)	C2907288	LCSC	$ 0.13	$ 0.26
22	21	1	100kΩ	R13	R0805	100kΩ	0805W8F1003T5E	UNI-ROYAL(厚声)	C149504	LCSC	$ 0.18	$ 0.18
23	22	1	14.3kΩ	R14	R0805	14.3kΩ	ARG05FTC1432N	Viking(光颉)	C218338	LCSC	$ 0.43	$ 0.43
24	23	1	220kΩ	R15	R0805	220kΩ	RC0805FR-07220KL	YAGEO(国巨)	C137568	LCSC	$ 0.21	$ 0.21
25	24	1	30kΩ	R16	R0805	30kΩ	0805W8F3002T5E	UNI-ROYAL(厚声)	C17621	LCSC	$ 0.19	$ 0.19
26	25	2	PTS645SH50SMTR92LFS	SW1,SW2	KEY-SMD_4P-L6.0-W6.0-P		PTS645SH50SMTR92LFS	C&K	C221869	LCSC	$ 0.35	$ 0.70
27	26	1	ESP-WROOM-32E	U2	COMM-SMD_ESP-WROOM		ESP-WROOM-32E	DOIT(四博智联)	C19949066	LCSC	$ 2.94	$ 2.94
28	27	1	USB - UART Convertor	U4	QFN-28_L5.0-W5.0-P0.50		USB - UART Convertor	SKYWORKS/SILICON LABS(	C964632	LCSC	$ 1.90	$ 1.90
29	28	1	AMS1117-3.3	U6	SOT-223-4_L6.5-W3.5-P2.		AMS1117-3.3	UMW(友台半导体)	C347222	LCSC	$ 0.20	$ 0.20
30	29	1	Accelerometer Pins	U7	Accelerometer		Accelerometer Pins	HANBO(汉博)	C6332199	LCSC	$ 0.52	$ 0.52
31	30	1	X6512WV-14H-C60D30-E	U8	HDR-TH_14P-P2.54-V-M		X6512WV-14H-C60D30-E	XKB Connection(中国星坤	C5242247	LCSC	$ 1.00	$ 1.00
32	31	1	X6512WV-13H-C60D30-E	U9	HDR-TH_13P-P2.54-V-M		X6512WV-13H-C60D30-E	XKB Connection(中国星坤	C5242246	LCSC	$ 0.93	$ 0.93
33	32	1	TPS566242DRLR	U10	SOT-666-6_L1.6-W1.2-P0.		TPS566242DRLR	TI(德州仪器)	C5219277	LCSC	$ 0.49	$ 0.49
34	33	1	Micro USB	USB1	MICRO-USB-SMD_105017		Micro USB	MOLEX	C136000	LCSC	$ 1.63	$ 1.63
35		1	Raspberrypi 5 8GB							Raspberry Pi	$ 90.29	$ 90.29
36		1	MPU-6050 Adafruit							Adafruit	$ 12.95	$ 12.95
37		1	C4001 Radar DF Robot							DF Robot	$ 13.90	$ 13.90
38		1	Camera V2 Module							Raspberry Pi	$ 12.35	$ 12.35
39		1	Active Cooler							Raspberry Pi	$ 14.99	$ 14.99
40												
41												
42										Total:	$ 172.41	
43												

Total: $ 172.41

Figure 10.1.1 Total Money Spent so Far

10.2 Milestones for the Project

Throughout the semester, it was important for us to approach the project in a manner that will be reasonable and achievable to accomplish within the span of 2 semesters, or roughly 7 months. The first half of this time frame dictated a bunch of research, collaboration, critical thinking, and reason prior to finalizing the idea we wanted to approach for this project. Given that many of the technologies already exist in the world, making a project with a limited budget was achievable as the engineering has already been implemented in the real world. The SafeSight device came to the minds of 3 engineering undergrads as we analyzed a real world problem, reasonable achievements with proper research, and achievable in the time constraints of two semesters.

10.2.1 Senior Design 1

In this semester, we attacked the idea head on with proper ideas for which this project will be able to achieve. In the thought process expressed in the first 2 chapters of this documentation, we established that the SafeSight device will be able to detect when a driver is distracted on the road when commuting from destination A to destination B, notify the driver that it is time to proceed with the flow of traffic, identify proximity ranges when the driver is parking with a “Parking Mode” activated with a switch in the system, have crash avoidance signals to drivers operating the vehicle at high velocities when there is a detected stationary object ahead at a range of about 30 meters. With all of these ambitions it is important to select the right hardware, make the purchases and execute testing to ensure the system will be compatible with the dimension restraints, engineering accuracy, and system robustness. These and many other considerations were kept in our minds as we conducted the research presented in chapter 3 of the report.

Senior Design 1 provided the development of a theoretical software and hardware diagram where the components will be communicating with one another via bluetooth, app development code, and hardware wiring with protocols such as I2C and UART. These diagrams are expected to be done and completed in the coming semester of Senior Design 2.

10.2.2 Senior Design 2

For the upcoming semester and the oncoming objectives for the rest of the project, there are many obstacles to tackle. First and foremost, the PCB layout needs to be finalized in order for us to arrange the components accordingly for the device to fit the physical constraints pointed out throughout the report like size and weight in order to operate in an area where the driver’s visual and auditory senses are not taken away from operating a moving vehicle. Granted that the hardware selected may not prove to be meeting the functionality spec we need it to for the final fabrication of the device, we would need to update the documentation for newer hardware upgrades we seem fit when we test and tune the functionality of the device in order to achieve the appropriate needs of a dynamic traffic environment. This would also bring us to the next milestone where we would solder the components accordingly on the PCB board where we need input headers, the MCU, resistors and capacitors and external IC’s we will be running the CV modules on in order to ensure that the communication remains consistent in the final product developed. Below is a chart with expectations for Senior Design 2 alongside milestones met with Senior Design 1.

Table 10.2.2.1 Senior Design 1 and 2 Milestones

Senior Design 1 Milestones	**Senior Design 2 Milestones**
Conducted research on relevant technologies and real-world feasibility	Finalize the **PCB layout** to meet physical and functional constraints
Collaborated to define a practical, achievable project within a 2-semester time frame	Order and solder components onto the custom PCB (MCU, ICs, headers, passive components)
Identified and defined the **problem statement** (driver distraction and crash avoidance)	Test and validate each component's functionality (especially radar, MPU6050, CV modules)
Finalized project idea: **SafeSight device**	Integrate hardware onto a compact form factor suitable for use inside a vehicle
Outlined device features: distracted driver detection, parking assist, forward collision warning, etc.	Replace or upgrade hardware if it does not meet spec; update documentation accordingly
Selected appropriate hardware based on functionality and budget	Begin testing communication protocols (I2C, UART, Bluetooth) in real hardware configuration
Created initial **hardware and software architecture diagrams**	Implement Computer Vision modules and optimize for real-time execution on selected hardware
Proposed communication protocols: I2C and UART	Ensure seamless communication between subsystems and software modules
Began preliminary app design for mobile interaction with the SafeSight device	Finalize and integrate the app interface with the physical system
Prepared for physical prototyping phase by completing design documentation and diagrams	Conduct full system integration, real-world testing, and performance validation in a driving environment

10.3 Table of Work Distribution

Below is the table of work distributions. Since we have one computer engineer and two electrical engineers on this project, we are dividing the work in each person's strong suit. The computer engineer (Matthew) will take on a majority of the coding and software development, while the two electrical engineers (Mahyar and Albert) will take on a majority of the hardware assembly, as they are more knowledgeable in that sense. This will help make sure that everyone does what they are more knowledgeable in, while helping others to make sure this project gets done efficiently.

Table 10.3.1 Work Distribution Table

	Radar	MPU6050	Raspberry Pi	PCB	App Development	Website Development	Device Intercoms
Primary	Albert Lougedo	Albert Lougedo	Mahyar Mahthabfar	Mahyar Mahtabfar	Matthew Carvajal	Matthew Carvajal	Albert Lougedo, Matthew Carvajal, Mahyar Mahthabf-ar
Secondary	Mahyar Mahtabfar, Matthew Carvajal	Mahyar Mahthabfar. Matthew Carvajal	Matthew Carvajal	Albert Lougedo			

11. Conclusion

The SafeSight project not only represents an innovative response to the growing issue of distracted drivers, but it reflects the knowledge embedded in three engineering undergraduates who spent the last 4 years of their life learning how to develop such a technology. This project is a testament of what thoughtful, well organized undergraduate engineering can accomplish over the course of two semesters. The objective from the very beginning was to create a device that can be portable, help humanity by increasing efficiency through daily commutes, and keeping more people safe when commuting. This project incorporates many different technologies such as a radar sensor, computer vision, accelerometer, LED lighting, piezoelectric buzzers, web development software, wireless connections, PCB designs and many more. Throughout the recent couple of months passed, we have focused on the project ideation, feasibility studies, hardware and software research, and the overall architecture of how this system was to be integrated. Taking into account many constraints and factors to ensure that the vision we had in our first meeting can one day be a reality. At it's core, SafeSight was born from the realization that distracted driving is a growing and fatal concern. The presence of smartphones and other attention-diverting scenarios has fundamentally lost the faith we see in everyday commuting, requiring new safety features in vehicles. This in turn results in more cost to the vehicles being released every year. In recognition of this social shift, the team identified the problem and proposed a fun solution to develop and implement into vehicles. This mission to empower drivers with immediate feedback on unconventional behaviors is to reinforce long-term habits that promote attentive responsibility behind the wheel.

Throughout this semester, we have approached this project, initially, with methods. Starting with the identification of a problem and then leading with hypothetical scenarios, it all began with a drawing board. Whether the driver was an older subject or a new driver, the safesight technology had to hold everyone to the same standard. With this comprehension approach, we needed to understand what the limitations were for us alongside a literature review of current commercial technologies that can solve all of these scenarios. The early phase introduced a new foundation of technical knowledge as the research began after the agreement on the project's functionality. Thus, as the first two weeks took off, the technical knowledge being gathered led to informed decision making on hardware, communication interfaces, sensor compatibility, and computational resources. Each subsystem we decided to use, from the MPU6050 accelerometer to the ESP32 microcontroller, was selected for the specific ability and compatibility it brought to the system idealized from the beginning. With the decision process came the emphasis on modularity, ensuring that each component of the system could be independently tested and verified, in order to track errors when fine tuning the system. This allowed us to develop a system that is maintainable for the time being, and which in any case allot room for improvement if deemed necessary.

In the lens of software, we took significant strides in ensuring that the SafeSight computer vision functionality was working properly. The use of algorithms such as OpenCV for facial orientation detection, object classification and environmental analysis has proved the technical feasibility of our goals. With the computational power of the Raspberry Pi handling computationally intensive CV tasks, the work from the rest of the system can be a bit off-loaded, allowing the system with the designated components to operate effectively alongside the Pi. This dual processor design allows for each unit to operate within an optimal range without the reduction of performance offered from each subsystem.

On the subject of communication protocols (namely UART and I2C), we established these protocols across different hardware components within the prototype development. This intentional selection was to ensure the system compatibility and stability. For instance the ESP32 had many limitations for the amount of pins used to intercommunicate hardware, thus some of the hardware chosen needed to be adaptable, meaning if need be, it can interchange from UART to I2C or SPI within a gametime decision. These obstacles being overcome demonstrated the understanding of the intricacies of embedded systems, overall improving the system robustness before the continuation of a more solidified project.

Taking into account the constraints we faced in the design of tis system, one viewpoint we needed to ensure based on early agreement is logistics. We agreed initially to remain committed to working on the budget that 3 senior students can afford, and being able to develop the system thus far with half the expected budget has been very effective. One thing to point out is that there may be room for improvement on some hardware selections, given the remainder of the system continues to be budget-friendly. Even though the components selected can deliver high functionality for their cost, it is still nice to have improved data readings for better IC architecture available on the market. With the current prototype remaining in the early integration stages, the current hardware selections passed the initial compatibility tests, opening the way for us to charge into the assembly and validation in senior design 2.

Looking ahead, the remaining goals for the next phase include finalizing the specific hardware components after further testing and fine tuning, which will in turn lead to the final PCB layout, full system fabrication, and real-world testing in the dynamic environment of traffic. Knowing fully well that we are to anticipate challenges related to environmental interfacing, the hurdles yet to come will test the robustness of the system with adjustments being made as necessary.

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Appendix B- LLM Prompts

Prompt: What would be the best Raspberry Pi to use for computer vision with an ESP32?

Answer: 🚀 Best Option for Computer Vision + ESP32: Raspberry Pi 5 (4GB or 8GB)
The Raspberry Pi 5 is currently the most powerful Pi available and a perfect match for running modern computer vision tasks while communicating with an ESP32. It has a significantly faster processor than the Pi 4, improved I/O speeds, and better support for intensive applications like OpenCV and TensorFlow Lite.

🔍 Why the Pi 5 is Ideal for SafeSight and Vision Tasks:
CPU: Quad-core 64-bit Cortex-A76 @ 2.4GHz – over 2x faster than Pi 4

RAM Options: 4GB or 8GB LPDDR4X – great for multitasking and model inference

USB 3.0: Faster data transfer with cameras and peripherals

Camera Support: Two CSI camera connectors, perfect for stereo vision or dual-camera setups

PCIe Support: Expandable for NVMe SSDs (if needed for fast storage)

🧠 Use Case Examples:
Real-time image processing (e.g., traffic light detection, face or object recognition)

Running machine learning models for behavior prediction or driver attention detection

Processing data from the ESP32 (e.g., radar or motion sensor) and combining it with visual input

🔌 ESP32 Integration Options:
UART: Ideal for serial communication

I2C/SPI: For sensor data or short-distance comms

Wi-Fi: If both devices are on the same network

Bluetooth: For low-power wireless communication

🧰 Recommended Accessories:
Official Raspberry Pi 5 Power Supply (27W USB-C)

Active Cooling System or Heat Sink/Fan Combo – the Pi 5 runs hot under load

Camera Module 3 (with autofocus and HDR) – works natively and supports ML tasks

32GB+ microSD card or NVMe SSD (for large model files or video storage)

If you're working on real-time driver assistance or environmental awareness like in SafeSight, the Pi 5 gives you enough power to process video streams while handling communication with the ESP32. It's a future-proof choice, especially if you're considering deploying deep learning models locally.

Want help setting up OpenCV or TensorFlow Lite on it next?

Prompt: Why is Tensorflow and OpenCV the best to use?

Answer: Great question — here's a breakdown of why TensorFlow and OpenCV are such a strong combo for a project like SafeSight, especially when running on something like a Raspberry Pi with an ESP32:

🧠 TensorFlow: Best for Machine Learning & AI
TensorFlow is one of the most popular open-source libraries for building and deploying machine learning models, especially when it comes to image recognition, object detection, and real-time decision-making.

Why it's great:
TensorFlow Lite is optimized for edge devices like the Raspberry Pi. It allows you to run pre-trained neural networks efficiently with low memory and processing power.

You can train models on a PC (or use pre-trained ones) and deploy them on the Pi for tasks like:

Traffic light recognition

Distracted driver detection

Hand gesture recognition

Strong documentation and community support means it's easier to troubleshoot or find models for your use case.

📸 OpenCV: Best for Image Processing & Computer Vision
OpenCV (Open Source Computer Vision Library) is the go-to toolkit for handling image and video operations like filtering, object tracking, edge detection, motion analysis, etc.

Why it's great:
It's lightweight and runs well on Raspberry Pi, even with limited resources.

It handles all the image preprocessing that TensorFlow models usually need—like resizing, color correction, cropping, or converting formats.

Excellent for camera integration, live streaming, or analyzing visual data in real time.

Works directly with the Raspberry Pi Camera Module and USB webcams.

🔄 Why They Work Best Together:
OpenCV prepares the image (e.g., crops a traffic light from a frame), and TensorFlow classifies it (e.g., green, yellow, red).

OpenCV can also handle things like drawing bounding boxes or alerts on the screen based on TensorFlow's predictions.

Together, they give you a full pipeline from capturing input → processing → making decisions.

🚗 In the Context of SafeSight:
OpenCV can help detect visual elements (e.g., lane markings, faces, or moving objects).

TensorFlow Lite can take that input and determine what's happening (e.g., is the driver distracted? Is there a stop sign ahead?).

This combo turns the Pi into a smart, on-device assistant without needing cloud processing — perfect for privacy, speed, and reliability in real-world use.

Let me know if you want help choosing a specific model or example script using both!

Prompt: What communication method is best to use between the ESP432 and the Pi?

Answer: Great question — choosing the best communication method between the ESP32 and the Raspberry Pi depends on what you're sending (sensor data, control signals, video, etc.), how often you send it, and your project's environment.

Here's a breakdown of the most common methods, with a clear recommendation at the end:

🔌 1. UART (Serial Communication) – Best Overall Choice
✅ Recommended for most SafeSight use cases

Pros:

Simple and reliable

Easy to implement on both ESP32 and Raspberry Pi (via GPIO)

Low latency

Use Case: Sending sensor readings, commands, or status updates at a steady rate

How: Use GPIO pins on both devices, connect TX ↔ RX and GND ↔ GND

Speed: Good enough for real-time communication up to 1 Mbps or more

✅ Why it's best: It’s stable, doesn’t require a network, and avoids the complexity of protocols like I2C/SPI/Wi-Fi unless needed.

📡 2. Wi-Fi (ESP32 as Client or Server)
Pros:

Wireless

Easy to scale across devices

Cons:

More power-hungry

More setup and error handling required (e.g., disconnects)

Use Case: If you want remote monitoring or multiple devices talking to a single Pi

Common Protocols: HTTP, WebSocket, MQTT

✅ Use this if your devices are mobile or you need communication over a distance.

🔄 3. I2C
Pros:

Can connect multiple devices to one Pi

Cons:

Slower than UART (standard 100–400 kHz)

Limited distance (10–20 cm reliably)

ESP32 must act as a slave, which is tricky to implement stably

Use Case: Only for basic data sharing if UART isn’t possible

⚠️ Not recommended unless you're familiar with the timing issues involved on the ESP32 side.

⚡ 4. SPI
Pros:

Faster than I2C (up to several Mbps)

Cons:

More complex (4 wires: MISO, MOSI, CLK, CS)

Needs custom handling for master/slave roles

Use Case: High-speed data transfer (e.g., camera frames or real-time sensor arrays)

⚠️ Usually overkill unless you're sending high-throughput data at low latency.

🧲 Summary Recommendation:

Method	Best For	Complexity	Reliability	Notes
UART	Most SafeSight applications	⭐ Easy	✅ Very High	Use serial on GPIO
Wi-Fi	Wireless or remote operation	⚠️ Medium	✅ High (with error handling)	Great for mobile or long-range
I2C	Simple, low-speed setups	⚠️ Tricky	⚠️ Medium	Avoid if timing is critical
SPI	High-speed communication	❗ Complex	✅ High	Only if absolutely needed

🔧 TL;DR:
Use UART via GPIO for the most stable, simple, and effective communication between your ESP32 and Raspberry Pi — especially for sending sensor data or control commands in your SafeSight system.

Need help wiring it up or writing the UART code for both sides?

Prompt: What does the MPU-6050 and the MPU Human Detection Sensor entail?

Answer: Great question — let’s break down what the MPU-6050 and MPU-based Human Detection sensors do, how they work, and how they’re used in projects like SafeSight.

🌀 1. MPU-6050 – Accelerometer + Gyroscope Sensor
🔧 What It Is:
A 6-axis motion tracking sensor that combines:

3-axis accelerometer (measures acceleration in X, Y, Z)

3-axis gyroscope (measures rotation rate around X, Y, Z)

📦 Features:
Small, low-power, low-cost

Uses I2C or SPI for communication

Built-in Digital Motion Processor (DMP) for sensor fusion

Can be used to calculate orientation, motion, and tilt

🚗 Use Cases:
In SafeSight: Can detect sudden movements like harsh braking, swerving, or collisions

Used for:

Fall detection

Gesture recognition

Vehicle dynamics

Balance or stability tracking (e.g., robot platforms)

🚶 2. "MPU" Human Detection Sensor (e.g., mmWave / PIR / Radar Sensor)
🔍 Clarification:
“MPU” in this case might be misinterpreted — it usually refers to a Microprocessor Unit, not specifically a human detection sensor. But in projects, you might see:

👁️ Human Detection Sensor Types:
PIR (Passive Infrared):

Detects changes in infrared heat

Cheap, basic, and detects presence but not direction or distance

mmWave Radar (e.g., C4001, IWR6843):

Much more advanced

Detects motion, presence, breathing, direction, and distance

Works through walls or obstructions

Excellent for detecting humans in real time with precise distance and speed data

🧠 If the sensor is labeled something like "MPU-based Human Detection Sensor," it's likely referring to an integrated module with:
A microcontroller (MPU)

A human presence detection sensor (usually radar-based)

Communication interfaces (UART, I2C, etc.)

🧩 Summary: What They Entail

Sensor Type	What It Measures	Ideal For	Notes	
MPU-6050	Motion Acceleration & Rotation	Crash detection, orientation	Needs calibration for accuracy	
Human Detection Sensor	Radar/PIR	Presence, motion, distance	Occupancy sensing, people tracking	mmWave is more reliable than PIR

If you’re building a driver assistance system or in-cabin monitoring setup:

Use the MPU-6050 for motion data (e.g., detecting collisions, turns)

Use a human detection sensor (preferably radar-based) for identifying occupants or monitoring attention and presence

Let me know which sensor model you have, and I can help you interpret its data or set it up!