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Final Report

Emergency Alert Recognition System

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1. Abstract:

This project presents the design, development, and validation of a compact, audio-based emergency alert system intended to improve driver awareness of nearby emergency vehicles. The system utilizes a digital MEMS microphone (INMP441) to detect external auditory signals such as sirens and vehicle horns. Once a relevant sound is identified, the signal is processed through an embedded microcontroller, and corresponding visual indicators are activated using color-coded LEDs. Each light is paired with intuitive pictograms to represent several types of emergency vehicles, such as police, ambulance, and fire services.

The device is designed to be mounted inside a vehicle and provides a visual alternative for drivers who may not clearly hear external alerts due to noise isolation, hearing impairments, or environmental conditions. A functional prototype was successfully developed and evaluated through structural, thermal, and performance testing. The system demonstrated reliable detection of emergency-related sounds and achieved the required performance thresholds defined in the design specifications.

Emphasis is placed on low-cost implementation, ease of installation, and real-time response. The system aims to enhance road safety by reducing reaction time and increasing situational awareness in critical scenarios.

2. Introduction:

2.1 Background:

Emergency vehicles such as ambulances, police vehicles, and fire trucks rely heavily on auditory warning systems to alert nearby drivers and pedestrians of their presence. Similarly, vehicle horns are commonly used to warn drivers of potential hazards or dangerous situations on the road. These auditory signals play a key role in maintaining traffic safety and ensuring rapid emergency response.

2.2 Problem Statement:

For deaf or hearing-impaired drivers, detecting emergency sirens and warning horns can become difficult or impossible while operating a motor vehicle. Since traditional warning systems depend primarily on sound, these drivers may experience delayed awareness of nearby emergency vehicles or hazardous situations. This limitation creates a safety concern that may affect driver response time and overall road safety.

2.3 Proposed Solution:

To address this issue, this project focuses on the development of an Emergency Alert Recognition System (EARS) for Deaf Drivers capable of detecting emergency-related sounds and converting them into visual alerts. The proposed system combines a sound detection module, an embedded processing system, and a visual LED-based alert system to provide immediate visual notifications without relying on auditory feedback.

2.4 Objectives:

The primary objective of this project is to design and develop a functional prototype capable of assisting deaf or hearing-impaired drivers by improving awareness of emergency-related sounds. Throughout the semester, the project followed a structured engineering design process involving product design specification (PDS) development, concept generation and selection, prototype manufacturing, testing, and documentation.

2.5 Gantt Chart:

The project schedule and major milestones were organized using the Gantt chart shown in Figure 1. Project activities were assigned among team members based on their respective responsibilities in hardware development, software development, testing, manufacturing, and documentation. The schedule established critical milestones, including project initiation (February 13) in where the Product Design Specification (PDS) was developed, completion of idea generation and concept selection (February 27), preliminary design completion (March 6), design formalization (March 20), prototype generation (April 10), completion of manufacturing documentation and user manuals (April 24), and final product presentation (May 1). Color coding was used to distinguish project phases, with purple representing Initiation, pink representing Planning and Idea Generation, green representing Design activities, and yellow representing Final Product development, documentation, and presentation tasks.

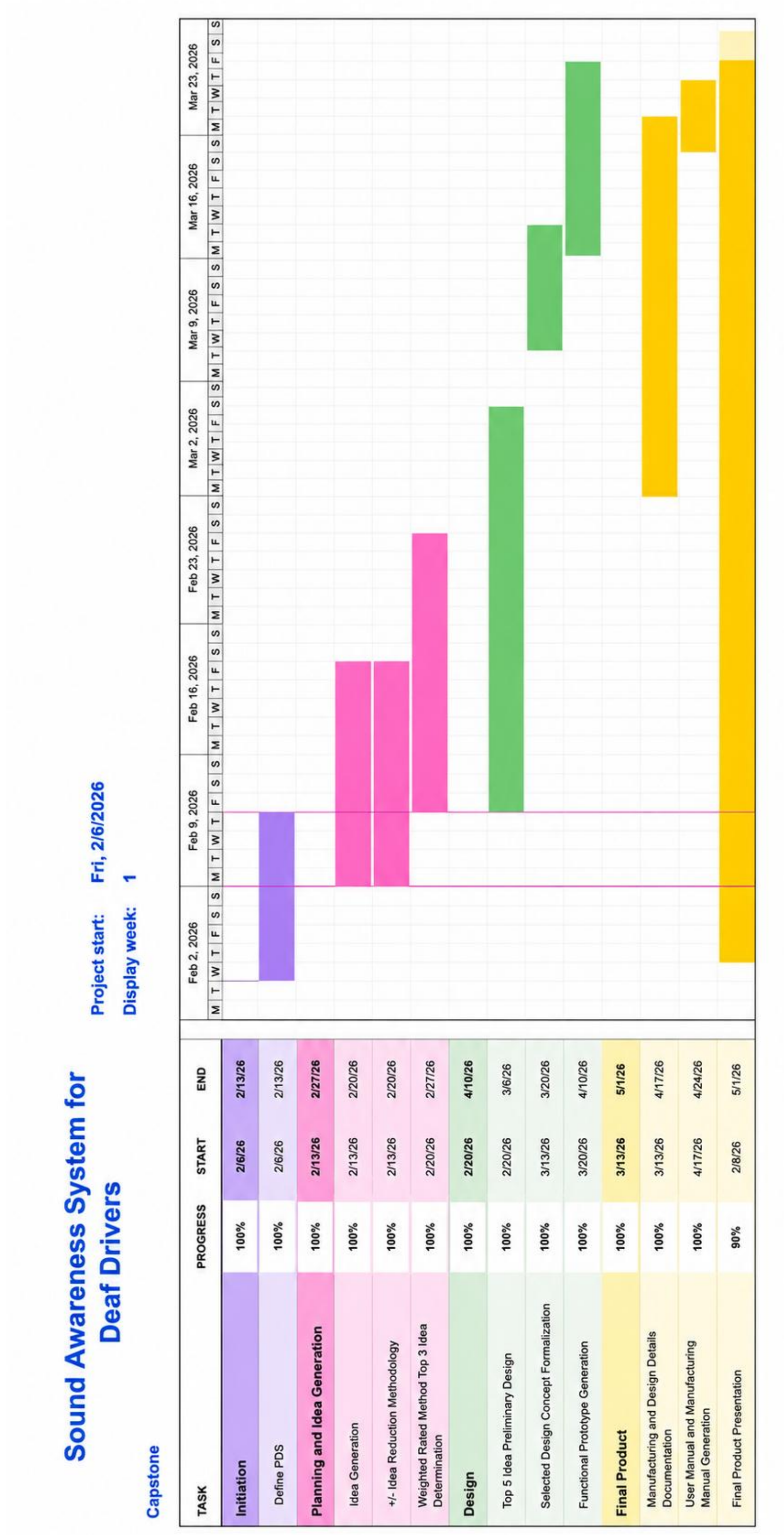


Figure 1. Gantt chart

2.6 Three Main Phases:

To provide a clear understanding of the development process of this project, the remainder of this report is structured into three main phases: the ideas phase, the design phase, and the testing phase.

The **idea generation phase** focuses on the initial decision-making process that shaped the direction of the project. This includes the identification of the problem, the generation of multiple design concepts, defining Product Design Specification (PDS) with its metrics and priorities, and the selection of the most suitable preliminary solution. Throughout this phase, iterative feedback played a key role in refining and improving the proposed ideas before moving forward.

The **design phase** involves the detailed development of the selected concept into a fully defined system. During this stage, design parameters are refined and finalized, and technical documentation is produced. This includes CAD models, electronic schematics, and detailed measurements necessary for fabrication. Additionally, the manufacturing process is initiated, and formal documentation is continuously updated to reflect design decisions.

Finally, the **testing phase** focuses on evaluating the completed prototype or system. In this stage, the project is evaluated under expected operating conditions to determine whether it meets the required specifications and user needs. Performance is analyzed, and any necessary adjustments are identified to improve functionality, reliability, and overall effectiveness.

3. Product design specification (PDS):

The Product Design Specification (PDS) was developed to formally translate the needs of the target users into measurable engineering requirements for the system. Given that the intended users are individuals with hearing impairments or reduced auditory perception, the primary objective of the project is to design an emergency sound detection system capable of identifying critical road sounds, such as sirens from ambulances, police vehicles, fire trucks, and car horns, and converting them into reliable user alerts.

3.1 Customer Needs:

To ensure that the system adequately addresses user needs, a structured requirements analysis was conducted during the early stages of the project. User needs were identified through:

1. Background research on challenges faced by deaf and hard-of-hearing drivers.
2. Reviews of existing assistive technologies.
3. Discussions within the project team regarding practical vehicle safety concerns.

This process resulted in a comprehensive list of twenty-eight user-centered requirements derived from the functional, safety, and usability expectations of the target population. These requirements define the essential characteristics the system must satisfy to be considered effective.

Each requirement was classified as either a Demand (D) or a Wish (W). Demands represent mandatory requirements that are critical to the successful operation and safety of the system, whereas Wishes represent desirable features that enhance performance or user experience but are not strictly necessary for basic functionality. For example, Accurate Emergency Sound Recognition was classified as a Demand because the system must reliably detect emergency sirens to fulfill its primary purpose. In contrast, Upgradeable Software was classified as a Wish because future software updates would improve long-term usability but are not required for the device to perform its core function.

Table 1. User Needs

#	Requirement	Description / Measure of Success	D / W
1	Accurate Emergency Sound Recognition	The system shall detect sirens and vehicle horns with minimal missed detections.	D
2	Low False Positives	Must distinguish emergency sounds from background noise in urban environments.	D
3	Sound Classification	Different alert types (siren vs. honk) should be distinguishable to the user.	W
4	Real-Time Alerting	Time from detection to user alert must be fast enough for safe driver reaction.	D
5	Immediate & Intuitive Feedback	Alerts must be instantly understandable without training while driving.	D
6	Visual Power Confirmation	Device must indicate when powered on (important for deaf users).	D
7	Adjustable Alert Intensity	Visual brightness and detection sensitivity shall be user adjustable.	W
8	Non-Obstructive Placement	Device must not block driver vision or interfere with vehicle controls.	D
9	Compact System	Must occupy minimal cabin space and allow flexible placement.	W
10	Non-Invasive Installation	Installation must not permanently modify the vehicle.	D
11	Tool-Free / Simple Mounting	It should be installable without professional assistance.	W
12	Secure Attachment Under Vibration	Mount must remain stable under vehicle vibration conditions.	D
13	Road Shock Resistance	Device shall withstand potholes and continuous automotive vibration.	D
14	Privacy	Device should not save/upload personal recordings.	D
15	Drop Survival	Device must survive accidental drop of ~3 ft without failure.	D
16	Weather & Temperature Protection	Must operate under automotive heat, humidity, and weather exposure.	W
17	Loud Environment Functionality	Must perform reliably despite traffic and city noise.	D
18	Works Across Vehicles	Must function independent of vehicle model or type.	D
19	Vehicle-Powered Operation	Should draw power from the car with minimal energy consumption.	W
20	Low Power Consumption	Must not significantly load the vehicle battery.	D
21	Operate at Driving Speeds	Should function correctly up to typical highway speeds (~50–100 mph target).	W
22	Minimal Maintenance	Designed for exceptionally low upkeep (simple periodic check).	D
23	Easy to Maintain	Maintenance should require minimal tools and labor.	W
24	Long Service Life	System should achieve extended operational lifetime before failure.	W

25	Time to First Critical Failure	Must maintain functionality for a defined durability period.	W
26	Affordability	Total device cost must remain low for wide adoption.	D
27	Non-Startling Alerts	Alerts must inform you without causing panic or distraction.	D
28	Upgradable Software	The system should allow future algorithm improvements.	W

3.2 Engineering Metric and Requirements:

Following the need analysis, the requirements were systematically converted into engineering metrics to establish measurable design targets (Table 2). This process ensured that abstract user needs were translated into quantifiable parameters that can be evaluated during testing and development.

Table 2. PDS engineering metrics

#	Needs Covered	Metric	Units	Marginal Value	Ideal Value	Importance
1	1,2,3,17	Emergency Sound Detection Accuracy	%	≥80	≥95	14
2	4,5	Detection-to-Alert Latency	ms	≤1000	≤500	10
3	7,17	Maximum Ambient Noise Tolerated	dB	70	85	7
4	5,27	User Alert Recognition Time	s	≤1.5	≤1.0	10
5	26	Device Cost	$	≤120	≤50	9
6	22,23	Time Between Maintenance	months	≥6	≥12	5
7	10,11	Installation Time	hr	1	≤0.25	5
8	9	Device Frontal Area	cm^2	≤80	≤60	4
9	20	Power Consumption	W	≤10	≤5	5
10	16	Operating Surface Temperature Range	°C	25 < T < 60	10 < T < 80	5
11	28	Firmware Upgradability	Binary	Required	Seamless	3
12	14	Privacy Protection	Binary	No storage	Verified	3
13	12,13	Mounting Vibration Resistance	Hz	50	80+	6
14	13,19	Road Shock / Drop Resistance	g / drop	3-ft drop	No failure	4
15	21	Maximum Vehicle Operating Speed	mph	50	100	3
16	24	Device Lifetime	years	≥2	≥8–10	4
17	25	Time to First Critical Failure	years	≥1	≥3	3
18	6,8,15	Human-Interface Adjustability (brightness + sensitivity range)	%	Functional	Wide range	4

Together, these two structured tables form the foundation of the Product Design Specification (PDS). The first table captures the qualitative and functional needs of the end users, while the second translates these needs into measurable engineering metrics. In Table 2, the Needs Covered column identifies which user requirements from Table 1 are addressed by each engineering metric, ensuring direct traceability between customer expectations and technical specifications. The Metric column defines the parameter used to evaluate system performance, while the Units column specifies the measurement units associated with each parameter.

The Marginal Value represents the minimum acceptable performance required for the system to function adequately, whereas the Ideal Value represents the target performance desired for optimal operation. The Importance factor indicates the relative priority of each metric during the design process, with higher values assigned to features considered more critical to user safety and system functionality. These values were estimated using background research, engineering judgment, automotive safety considerations, and analysis of practical operating conditions for deaf drivers.

For example, *Emergency Sound Detection Accuracy* was assigned a high importance value of 14 because accurate siren and horn recognition are essential for the primary safety objective of the device. The system was required to achieve at least 80% detection accuracy (marginal value), with a target performance above 95% (ideal value). Similarly, *Detection-to-Alert Latency* was assigned an importance value of 10 because delayed alerts could reduce driver reaction time during emergency situations. In contrast, metrics such as *Firmware Upgradability* and *Privacy Protection* received lower importance values since they improve long-term usability and reliability but are less critical to the immediate safety function of the prototype.

4. Concept generation and idea development:

4.1 Key Functional Categories:

To ensure a systematic and comprehensive ideation process, the system was decomposed into five key functional subsystem categories: sound detection, signal processing, alert mechanism, power source, and connectivity method. These categories represent the core subsystems required for the operation of the device, from initial sound capture to final user notification.

For each category, multiple design options were proposed based on feasibility, performance, and alignment with the Product Design Specification (PDS) shown in Table 3. This approach allowed for structured variation within each subsystem while maintaining clear design boundaries.

Table 3. Key functional categories

Category	Option Code	Description
Sound detection	D1	Microphone / Sound Sensor
	D2	Vibration Sensor
Processing Method	P1	Embedded Processor
	P2	AI-Based Recognition
Alert Method	A1	LED Pictograms
	A2	Steering Wheel Vibration
	A3	LED + Vibration
Power Source	S1	Car Battery
	S2	Solar
	S3	Portable Battery
Connectivity	C1	Wired
	C2	Wireless

4.2 Combinatorial Idea Generation:

To efficiently expand the solution space, a combinatorial design approach was applied. Using the options presented in Table 3. By systematically combining the available options across all five categories, a total of seventy-two potential system configurations were generated (This was calculated by multiplying the number of options within each category, example: 2 x 2 x 3 x 3 x 2 = 72). This method ensured broad coverage of feasible design alternatives without requiring redundant manual ideation of complete systems.

In accordance with project constraints and PDS requirements, the initial set of configurations was then refined. Specifically, wireless connectivity options were excluded due to increased cost and implementation complexity, which conflicted with the system's affordability and reliability requirements. This reduction resulted in a final set of sixty viable concept combinations, forming the official idea bank used for subsequent evaluation and selection.

Table 4. presented in this section summarizes the category breakdown and the resulting combinations, providing a structured foundation for the concept selection and design refinement phases that follow. For example, idea #1 consists of D1 sound detection (microphone/sound sensor), P1 processing method (embedded processor), A1 alert method (LED pictograms), S1 power source (car battery), C1 connectivity (wired). Similarly, ideas 2 through 60 are described in Table 4.

4.3 Final Bank of Ideas:

Table 4. Final Bank of Ideas

Idea #	Detect.	Process.	Alert	Power	Conn.
1	D1	P1	A1	S1	C1
2	D1	P1	A1	S1	C2
3	D1	P1	A1	S2	C1
4	D1	P1	A1	S2	C2
5	D1	P1	A1	S3	C1
6	D1	P1	A1	S3	C2
7	D1	P1	A2	S1	C1
8	D1	P1	A2	S1	C2
9	D1	P1	A2	S2	C1
10	D1	P1	A2	S2	C2
11	D1	P1	A2	S3	C1
12	D1	P1	A2	S3	C2
13	D1	P1	A3	S1	C1
14	D1	P1	A3	S1	C2
15	D1	P1	A3	S2	C1
16	D1	P1	A3	S2	C2
17	D1	P1	A3	S3	C1
18	D1	P1	A3	S3	C2
19	D1	P2	A1	S1	C1
20	D1	P2	A1	S1	C2
21	D1	P2	A1	S2	C1
22	D1	P2	A1	S2	C2
23	D1	P2	A1	S3	C1
24	D1	P2	A1	S3	C2
25	D1	P2	A2	S1	C1
26	D1	P2	A2	S1	C2
27	D1	P2	A2	S2	C1
28	D1	P2	A2	S2	C2
29	D1	P2	A2	S3	C1
30	D1	P2	A2	S3	C2

Idea #	Detect.	Process.	Alert	Power	Conn.
31	D1	P2	A3	S1	C1
32	D1	P2	A3	S1	C2
33	D1	P2	A3	S2	C1
34	D1	P2	A3	S2	C2
35	D1	P2	A3	S3	C1
36	D1	P2	A3	S3	C2
37	D2	P1	A1	S1	C1
38	D2	P1	A1	S1	C2
39	D2	P1	A1	S2	C1
40	D2	P1	A1	S2	C2
41	D2	P1	A1	S3	C1
42	D2	P1	A1	S3	C2
43	D2	P1	A2	S1	C1
44	D2	P1	A2	S1	C2
45	D2	P1	A2	S2	C1
46	D2	P1	A2	S2	C2
47	D2	P1	A2	S3	C1
48	D2	P1	A2	S3	C2
49	D2	P1	A3	S1	C1
50	D2	P1	A3	S1	C2
51	D2	P1	A3	S2	C1
52	D2	P1	A3	S2	C2
53	D2	P1	A3	S3	C1
54	D2	P1	A3	S3	C2
55	D2	P2	A1	S1	C1
56	D2	P2	A1	S1	C2
57	D2	P2	A1	S2	C1
58	D2	P2	A1	S2	C2
59	D2	P2	A1	S3	C1
60	D2	P2	A1	S3	C2

5. Concept screening and selection:

Following the concept generation stage, the considerable number of proposed concepts required a systematic method for preliminary evaluation and reduction. To narrow the initial concept bank from approximately sixty concepts to a smaller and more manageable group, the Plus and Minus Method was utilized as an initial concept screening technique.

5.1 Plus-Minus method:

The Plus-Minus Method evaluates each proposed concept relative to a selected reference concept, commonly referred to as the *datum concept*. The datum concept serves as a baseline against which all remaining concepts are compared using a set of predefined evaluation criteria. These criteria included factors such as device cost, power consumption, complexity, portability, reliability, and overall feasibility. The criteria used in the comparison are taken from the PDS.

During the evaluation process, each concept was compared to the datum concept on an individual criterion basis. A score of **+1** was assigned if the evaluated concept performed better than the datum concept for a particular criterion, a score of **0** was assigned if the performance was considered equivalent, and a score of **–1** was assigned if the evaluated concept performed worse than the datum concept.

After completing the evaluation process, the scores for each concept were totaled and compared. Concepts with lower overall scores were eliminated, while the highest-performing concepts advanced to the next stage of evaluation. This process allowed the initial set of concepts to be systematically reduced from sixty concepts (Situated in the appendix is the Plus-Minus table which contains all 60 concepts) to the top fifteen candidates for further analysis. Table 5 shows the top 15 concepts.

Table 5. Top fifteen concepts

Metric	Idea 1 (Datum)	Idea 13	Idea 19	Idea 23	Idea 25	Idea 31	Idea 35	Idea 37	Idea 41	Idea 43	Idea 47	Idea 49	Idea 53	Idea 55	Idea 59
Emergency Sound Detection Accuracy	0	0	1	1	1	1	1	0	0	0	0	0	0	1	1
Event to Perception latency	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Maximum Ambient Noise Tolerated	0	0	0	0	0	0	0	1	1	1	1	1	1	1	1
Safe Design	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Device Cost	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Time Between Maintenance	0	0	0	0	0	0	0	-1	-1	-1	-1	-1	-1	-1	-1
Installation Time	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Display Size	0	0	0	0	-1	0	0	0	0	-1	-1	0	0	0	0
Power Consumption	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Operating Surface Temperature Range	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Firmware Upgradability	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Mounting Vibration Resistance	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Road Shock / Drop Resistance	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Maximum Vehicle Operating Speed	0	0	0	0	0	0	1	1	1	1	1	1	1	1	1
Device Lifetime	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Time to First Critical Failure	0	0	0	-1	0	0	-1	1	0	1	0	1	0	1	0
Human-Interface Adjustability (brightness + sensitivity range)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Sum	0	0	1	0	0	1	1	2	1	1	0	2	1	3	2

Not all concepts generated during the idea bank phase were represented within the top fifteen results. Concepts that failed to appear in Table 5 generally performed poorly in critical engineering metrics such as emergency sound detection accuracy, mounting vibration resistance, maintenance requirements, or operational reliability. Several concepts also received lower evaluations because they introduced unnecessary complexity, increased installation difficulty, or exceeded the desired cost limitations established in the PDS.

Some engineering features appeared repeatedly among the highest-ranked concepts. Concepts capable of operating under high ambient noise conditions and maintaining functionality at higher vehicle operating speeds consistently received positive evaluations. These features were frequently represented because they directly support the primary safety objective of the system, which is to reliably alert deaf drivers under realistic driving conditions. Similarly, concepts emphasizing durability, vibration resistance, and reliable mounting mechanisms were favored due to the automotive environment in which the device is intended to operate.

Following the preliminary concept screening process, visual illustrations (Figures 2 through 5) of the selected top fifteen concepts were developed to provide a clearer representation of each proposed design. These concept sketches allowed for easier visualization, comparison, and evaluation of the different system configurations prior to the next stage of concept selection. These are organized on their total score on the plus-minus method.

5.2 Visual Illustrations of top 15 concepts:

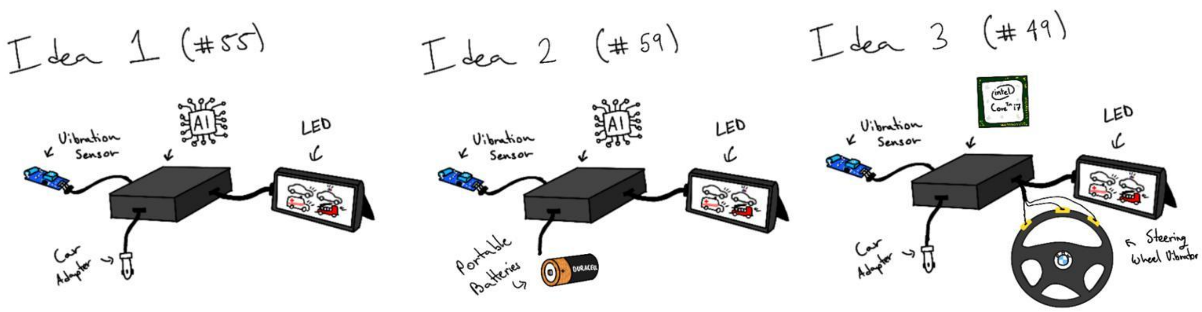


Figure 2. Visual concepts of Ideas 1, 2 and 3

Idea 1 (Idea 55):

This concept consists of a centralized processing unit integrated with an AI-based sound classification system, a vibration sensor, and an external LED alert display powered through a vehicle adapter.

Idea 2 (Idea 59):

This concept incorporates an AI-based sound classification module combined with a vibration sensor, LED visual alert display, and portable battery power supply.

Idea 3 (Idea 49):

This concept utilizes an embedded processor-based sound detection system connected to a vibration sensor, steering wheel vibration motors, and LED visual display.

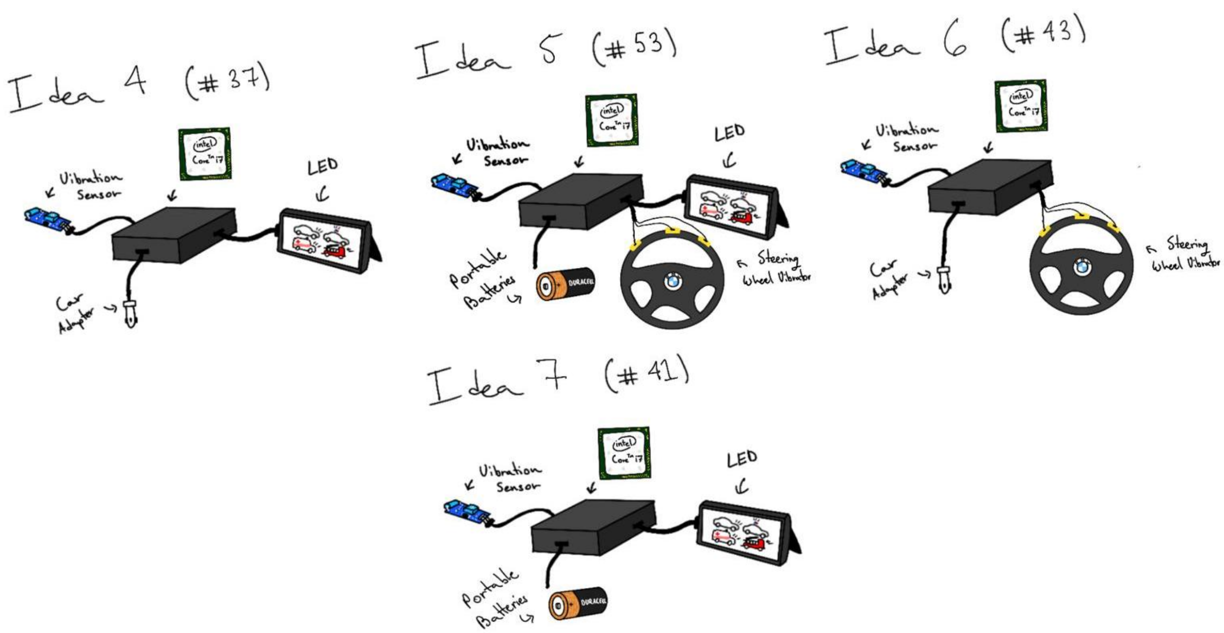


Figure 3. Visual concepts of Ideas 4, 5, 6 and 7

Idea 4 (Idea 37):

This concept uses an embedded processor-based sound detection system integrated with a vibration sensor, LED visual alert display, and vehicle adapter power supply.

Idea 5 (Idea 53):

This concept combines an embedded processor sound detection module with a vibration sensor, steering wheel vibration feedback system, LED display, and portable battery power source.

Idea 6 (Idea 43):

This concept features an embedded processor-based detection system powered through a vehicle adapter and integrated with a steering wheel vibration alert method.

Idea 7 (Idea 41):

This concept consists of an embedded processor sound detection system connected to a vibration sensor, LED alert display, and portable battery power supply.

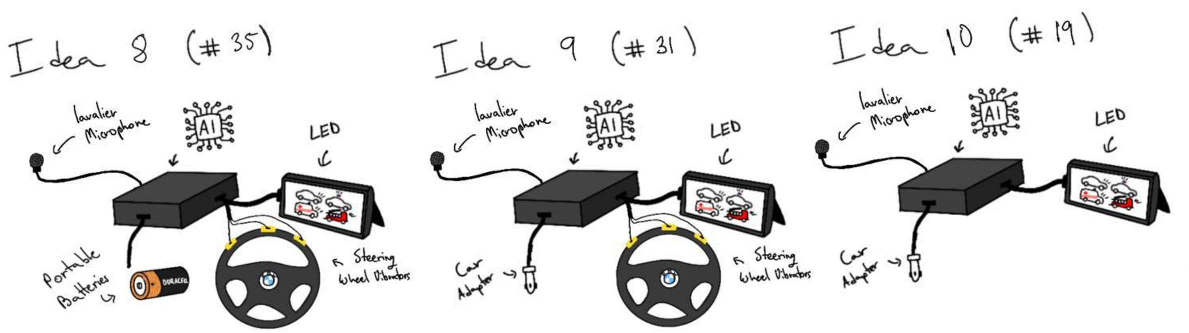


Figure 4. Visual concepts of Ideas 8, 9 and 10

Idea 8 (Idea 35):

This concept integrates an AI-based sound classification system with a lavalier microphone, steering wheel vibration feedback mechanism, LED visual alert display, and portable battery power source.

Idea 9 (Idea 31):

This concept utilizes an AI-based emergency sound recognition module connected to a lavalier microphone, steering wheel vibration motors, LED visual display, and vehicle adapter power supply.

Idea 10 (Idea 19):

This concept features an AI-based sound classification system paired with a lavalier microphone and LED visual alert display powered through a vehicle adapter.

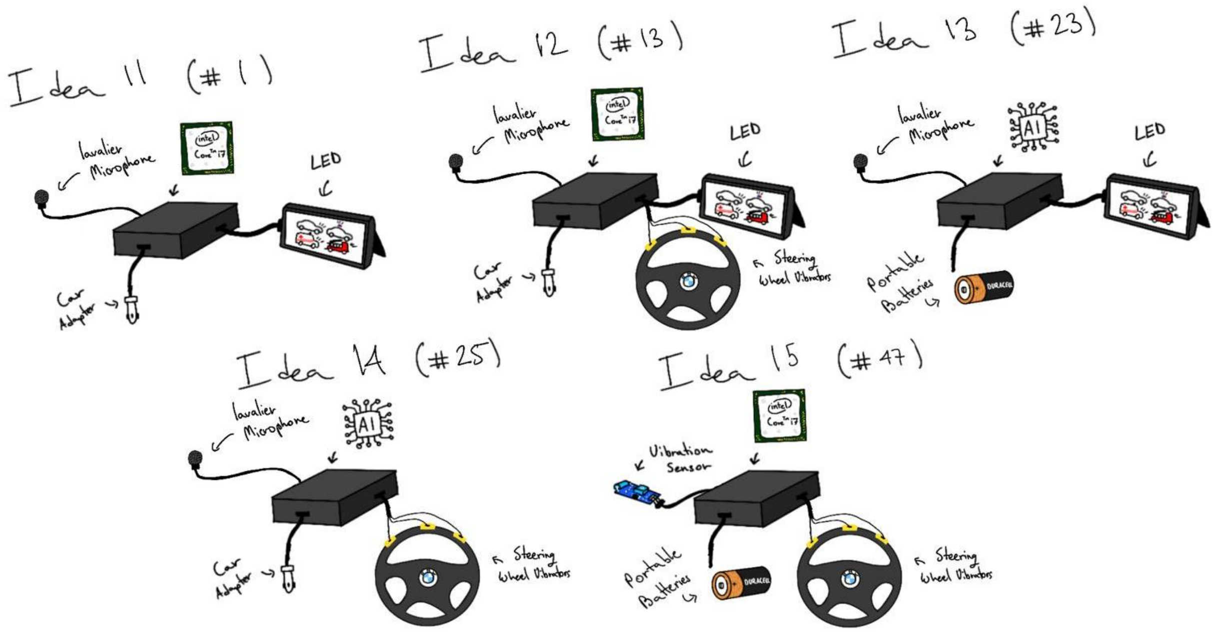


Figure 5. Visual concepts of Ideas 11, 12, 13, 14 and 15

Idea 11 (Idea 1):

This concept uses an embedded processor-based sound detection system combined with a lavalier microphone, LED visual alert display, and vehicle adapter power supply.

Idea 12 (Idea 13):

This concept incorporates an embedded processor sound detection module with a lavalier microphone, steering wheel vibration feedback system, LED display, and vehicle-powered configuration.

Idea 13 (Idea 23):

This concept features an AI-based sound classification system integrated with a lavalier microphone, LED visual alert display, and portable battery power source.

Idea 14 (Idea 25):

This concept combines an AI-based sound classification module with a lavalier microphone and steering wheel vibration feedback mechanism powered through a vehicle adapter.

Idea 15 (Idea 47):

This concept utilizes an embedded processor-based sound detection system integrated with a vibration sensor, steering wheel vibration motors, and portable battery power supply.

5.3 Weighted rated method:

Following the preliminary reduction of concepts using the Plus and Minus Method, a more detailed evaluation process was required to identify the strongest design candidates from the remaining top fifteen concepts. To accomplish this, the Weighted Rating Method was utilized as a secondary concept selection technique.

The evaluation process was based on the Product Design Specifications (PDS) developed earlier in the project. Each design concept was analyzed according to engineering and performance criteria defined within the PDS.

Each criterion within the PDS contained:

- a marginal value representing the minimum acceptable performance,
- an ideal value representing the desired target performance,
- a weighting factor indicating the relative importance of the criterion,
- and a preferred design direction indicating whether the parameter should be minimized or maximized.

Using these specifications, the Top performing fifteen concepts were evaluated through engineering calculations for the corresponding metric and comparative analysis. The resulting metric values for each concept were then compared against the corresponding marginal and ideal values defined in the PDS and a score was assigned.

The weighted scores for all evaluation criteria were combined to produce an overall rating for each concept. This process provided a more quantitative and objective method for comparing the remaining concepts and identifying the highest-performing designs. (Situated in the appendix is the weighted rated method tables which contain all 15 concepts)

Based on the final weighted ratings, the top five concepts (Table 6) with the highest overall scores were selected for further evaluation and development.

Table 6. Top 5 concepts

Metric	Units	Direction	Marginal	Ideal	Weight	Idea 1		Idea 13		Idea 23		Idea 31		Idea 19	
						Metric	Score	Metric	Score	Metric	Score	Metric	Score	Metric	Score
Emergency sound detection accuracy	%	Max	80	100	10	97	9.68	97	9.68	100	10	100	10	100	10
Detection-to-alert latency	ms	Min	1000	500	10	450	10	450	10	250	10	250	10	250	10
maximum ambient noise tolerated	dB	Max	70	85	7	88	7	88	7	90	7	90	7	90	7
user alert recognition time	s	Min	1.5	1	10	0.6	10	0.3	10	0.6	10	0.3	10	0.6	10
device cost	USD	Min	120	50	9	68	6.61	78	5.76	104	4.32	101	4.45	91	4.94
time between maintenance	Months	Max	6	12	5	24	5	24	5	24	5	24	5	24	5
installation time	hr	Min	1	0.25	5	0.25	5	0.333	3.75	0.333	3.75	0.333	3.75	0.25	5
device frontal area	cm^2	Min	80	60	4	20	4	25	4	20	4	25	4	20	4
power consumption	W	Min	10	5	5	2.7	5	3.4	5	4.7	5	5.4	4.62	4.7	5
operating surface temperature range	Celsius	Max	35	70	5	70	5	70	5	70	5	70	5	70	5
firmware upgradability	Score	Max	0.8	1	3	0.9	2.7	0.9	2.7	1	3	1	3	1	3
privacy protection	Score	Max	0.8	1	3	1	3	1	3	1	3	1	3	1	3
mounting vibration resistance	Hz	Max	50	80	6	70	5.25	70	5.25	70	5.25	70	5.25	70	5.25
road shock / drop resistance	ft drop	Max	3	3	4	3	4	3	4	3	4	3	4	3	4
maximum vehicle operating speed	mph	Max	50	100	3	100	3	100	3	100	3	100	3	100	3
device lifetime	years	Max	2	8	4	6	3	6	3	6	3	6	3	6	3

time to 1st critical failure	years	Max	1	3	3	3	3	3	3	2.5	2.5	2.5	2.5	2.5	2.5
human interface adjustability	score	Max	0.7	1	4	0.85	3.4	1	4	0.85	3.4	1	4	0.85	3.4
Total weighted score						94.65		93.16		91.23		91.59		93.10	

6. Top five concept evaluations:

Following the initial weighted rating process, the five highest-performing design concepts were subjected to a more detailed engineering evaluation to identify the optimal final solution. While the preliminary selection process focused primarily on generalized subsystem configurations, this secondary evaluation incorporated more specific component-level analysis for each candidate design. This included the selection of realistic hardware options for processors, sound detection modules, power systems, and alert mechanisms, allowing for more accurate performance predictions and refined Product Design Specification (PDS) scoring.

Each of the top five concepts was further developed by assigning practical components and implementation strategies consistent with their proposed subsystem architecture. Parameters such as actual processor capabilities, sensor compatibility, component cost, manufacturability, power efficiency, software flexibility, and integration complexity were analyzed in greater detail. This deeper engineering assessment allowed the project team to generate more realistic numerical estimates for critical PDS categories including detection accuracy, latency, power consumption, device cost, reliability, and maintainability. The top five illustrations are shown below.

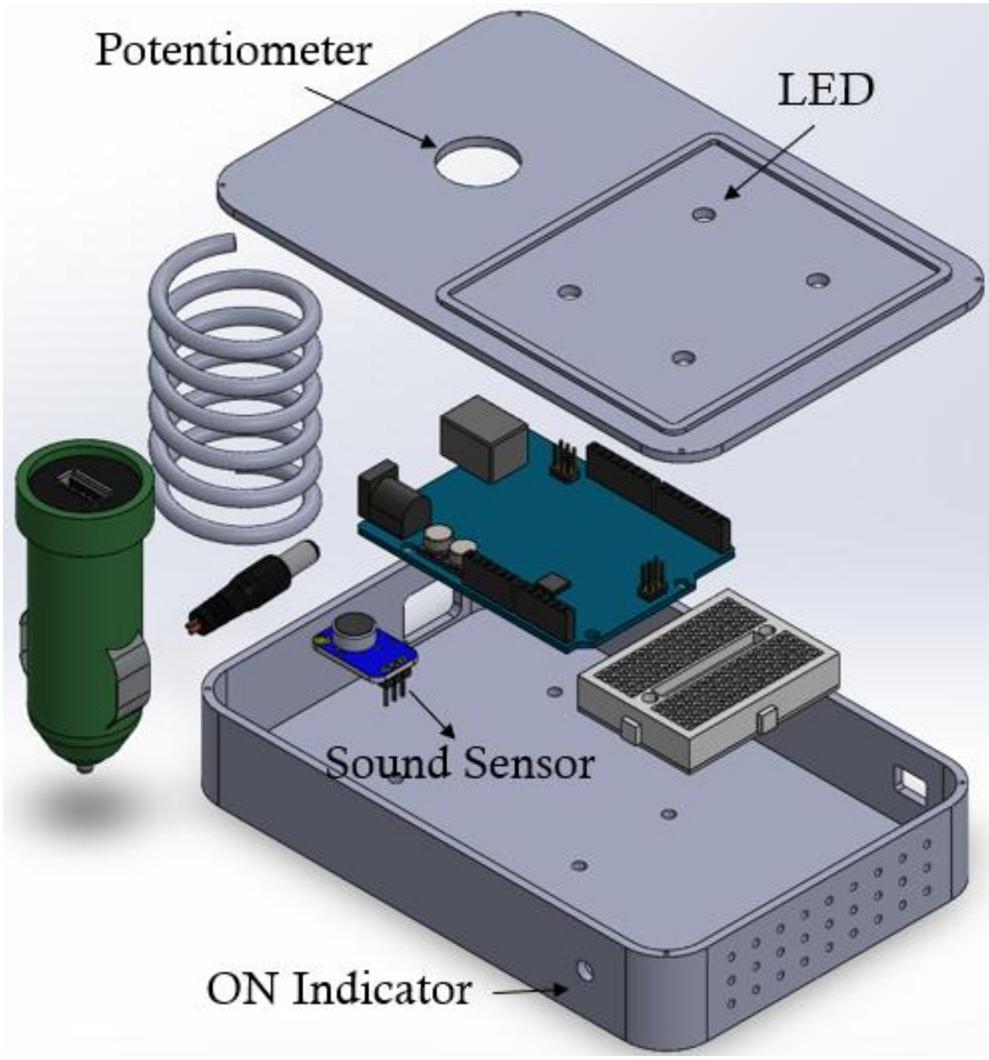


Figure 6. Top 5 concepts: Concept 1.

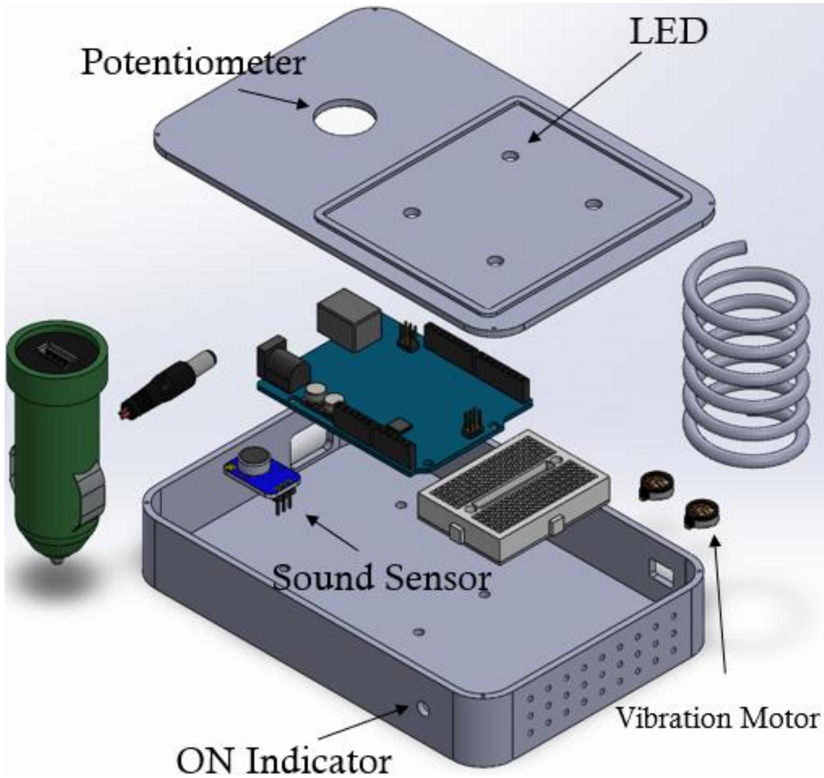


Figure 7. Top 5 concepts: Concept 2.

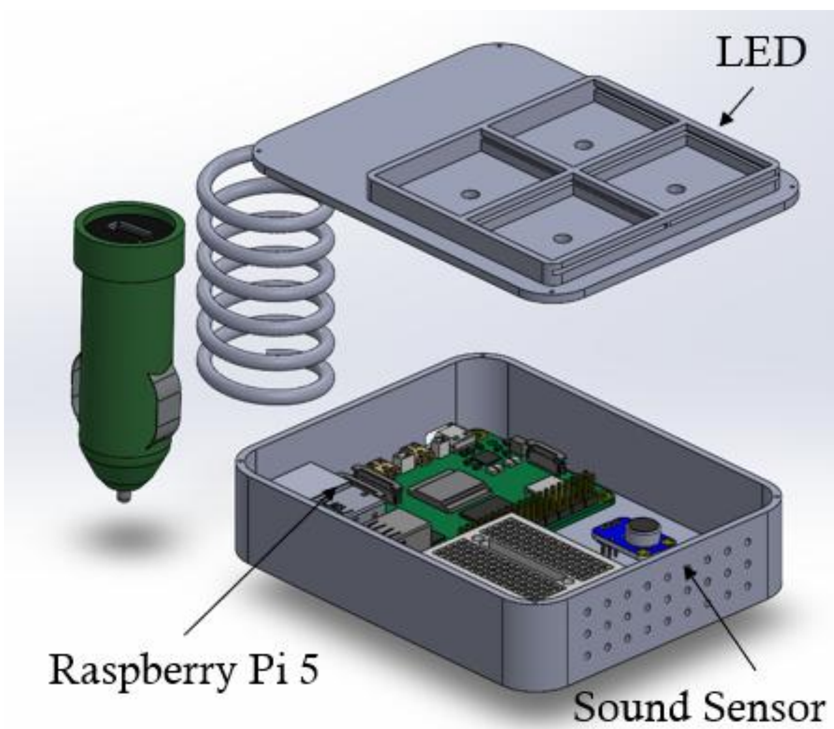


Figure 8. Top 5 concepts: Concept 3.

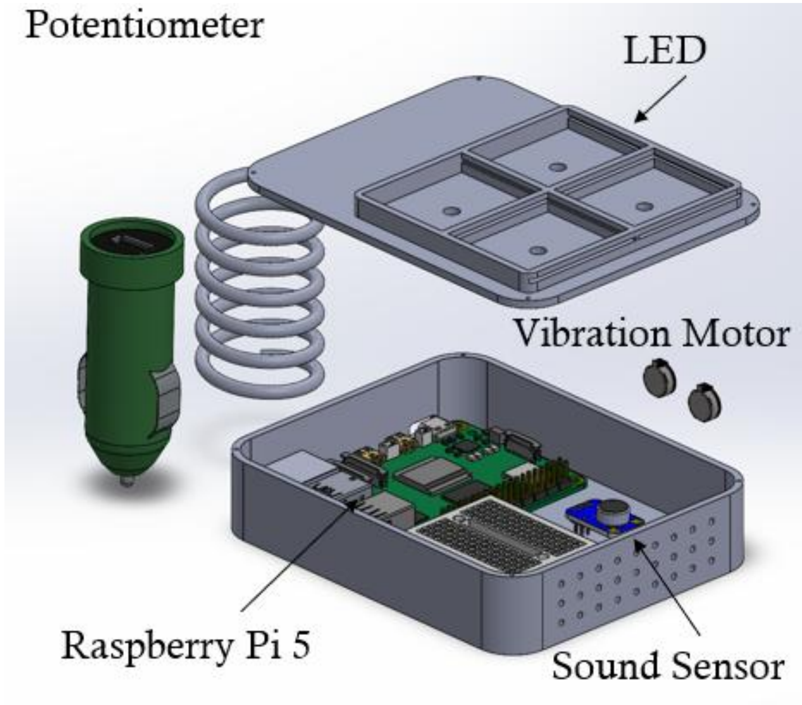


Figure 9. Top 5 concepts: Concept 4.

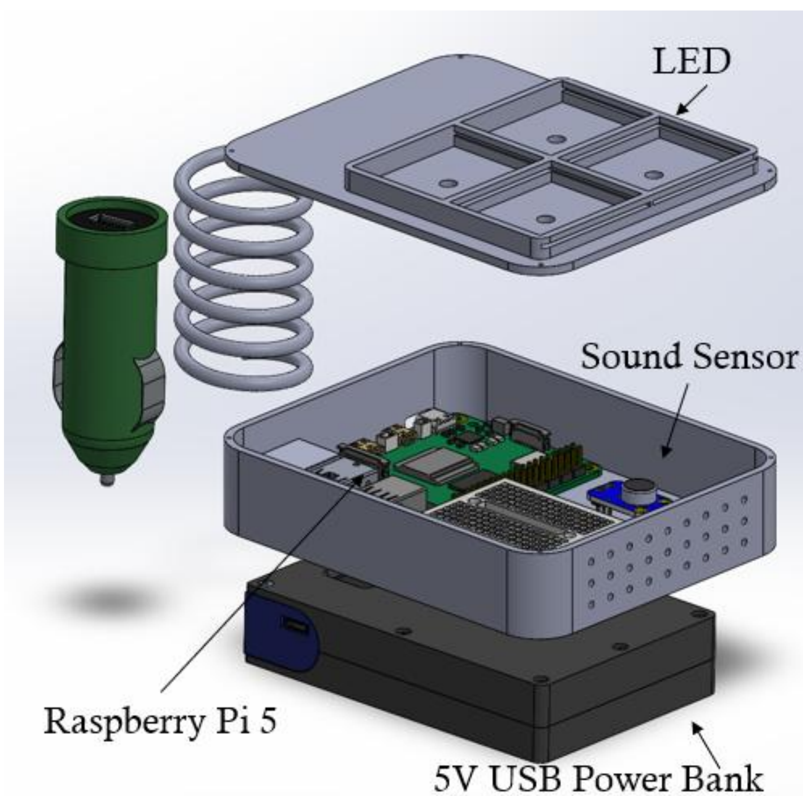


Figure 10. Top 5 concepts: Concept 5.

Using this refined data, the original PDS weighted evaluation table was updated and recalculated for all five leading concepts. This secondary weighted rated analysis provided a more accurate comparative ranking by replacing preliminary assumptions with realistic engineering values. Through this process, the design team was able to more effectively distinguish between concepts that initially appeared similar in performance but differed significantly when practical implementation factors were considered. The results of the secondary weighted rated analysis were tabulated in table 7.

Table 7. Top 5 concepts

Metric	Idea 1		Idea 2		Idea 3		Idea 4		Idea 5	
	Actual	Weighted (capped)	Actual	Weighted (capped)	Actual	Weighted (capped)	Actual	Weighted (capped)	Actual	Weighted (capped)
Emergency Sound Detection Accuracy	85	8.947	85	8.947	85	8.947	85	8.947	85	8.947
Detection-to-Alert Latency	450	10	450	10	450	10	450	10	450	10
Maximum Ambient Noise Tolerated	90	7	90	7	90	7	90	7	90	7
User Alert Recognition Time	0.6	10	0.3	10	0.6	10	0.3	10	0.6	10
Device Cost	75.42	5.967	82.1	5.481	168.87	2.665	175.55	2.563	245.76	1.831
Time Between Maintenance	12	5	12	5	12	5	12	5	6	2.5
Installation Time	0.25	5	0.333	3.754	0.333	3.754	0.417	2.998	0.333	3.754
Device Frontal Area	25	4	25	4	35	4	35	4	50	4
Power Consumption (Active)	4	5	4.5	5	7.5	3.333	8	3.125	8	3.125
Operating Surface Temperature Range	70	5	70	5	70	5	70	5	70	5
Firmware Upgradability	0.9	2.7	0.9	2.7	1	3	1	3	1	3
Privacy Protection (No Audio Storage)	1	3	1	3	1	3	1	3	1	3
Mounting Vibration Resistance	70	5.25	70	5.25	70	5.25	70	5.25	70	5.25
Road Shock / Drop Resistance	3	4	3	4	3	4	3	4	3	4
Maximum Vehicle Operating Speed	100	3	100	3	100	3	100	3	100	3
Device Lifetime	6	3	6	3	5	2.5	5	2.5	4	2
Time to First Critical Failure	2.5	2.5	2.3	2.3	2.2	2.2	2	2	1.8	1.8
Human-Interface Adjustability (brightness + sensitivity range)	0.85	3.4	0.85	3.4	0.85	3.4	0.85	3.4	0.85	3.4
TOTAL WEIGHTED SCORE (CAPPED)		92.764		90.832		86.049		84.783		81.607

The updated rankings confirmed that concepts utilizing embedded processors with microphone-based sound detection and LED visual alert systems consistently outperformed more complex alternatives. Systems incorporating vibration alerts, hybrid alert mechanisms, or more advanced AI-based processing often introduced unnecessary complexity, increased power demands, higher costs, and more difficult manufacturing requirements without delivering sufficiently greater functional benefits to justify their inclusion.

As a result, the final top-ranking concepts emphasized simplicity, affordability, rapid response time, and ease of implementation while still meeting or exceeding the majority of PDS requirements.

7. Final concept selection:

After the refined engineering analysis established the final ranking of the top five concepts, the ultimate concept selection process was conducted collaboratively with PRAPT stakeholders. The five leading design candidates were formally presented, including their updated weighted scores (table 7), subsystem configurations, projected performance, and practical implementation considerations.

This collaborative selection process ensured that both technical engineering analysis and client/user preference were incorporated into the final design decision. Following stakeholder review and deliberation, the concept selected was the embedded processor design utilizing microphone-based sound detection with a purely LED-based visual alert system (Idea #1, as shown in Figure 11). This concept was favored due to its strong balance of affordability, intuitive operation, manufacturability, and direct alignment with the primary project objective of assisting deaf or hearing-impaired drivers through clear visual emergency alert

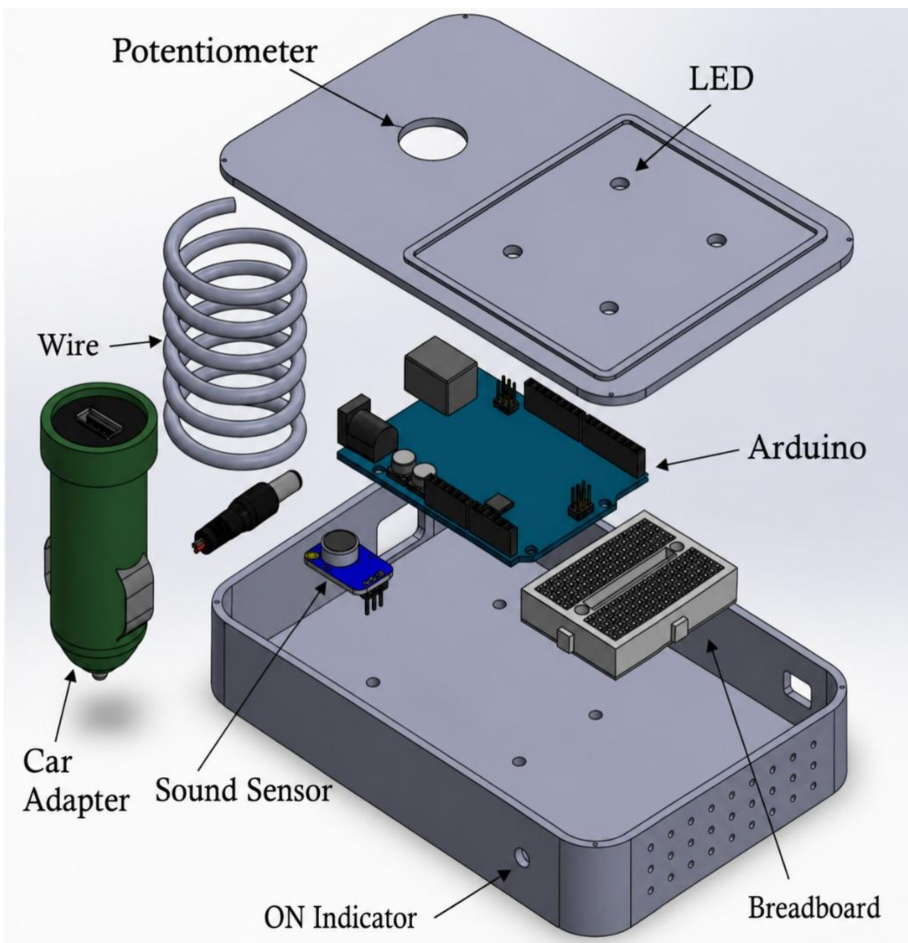


Figure 11. Final Concept Chosen.

The selected initial design configuration utilized an Arduino-based processing platform due to its accessibility, low cost, and ease of development during the conceptual stage. However, as prototype development progressed, further technical investigation revealed that the ESP32 microcontroller offered substantial advantages over the originally selected Arduino platform. These advantages included greater processing power, improved audio handling capabilities, enhanced firmware flexibility, superior scalability, and better compatibility with advanced digital sound sensors.

Consequently, the design team made the engineering decision to upgrade the processing subsystem from Arduino to ESP32. To complement this improved platform, the sound detection hardware was also upgraded to the INMP441 digital MEMS microphone, which provided better sound sensitivity, digital output compatibility, and improved integration with the ESP32 architecture.

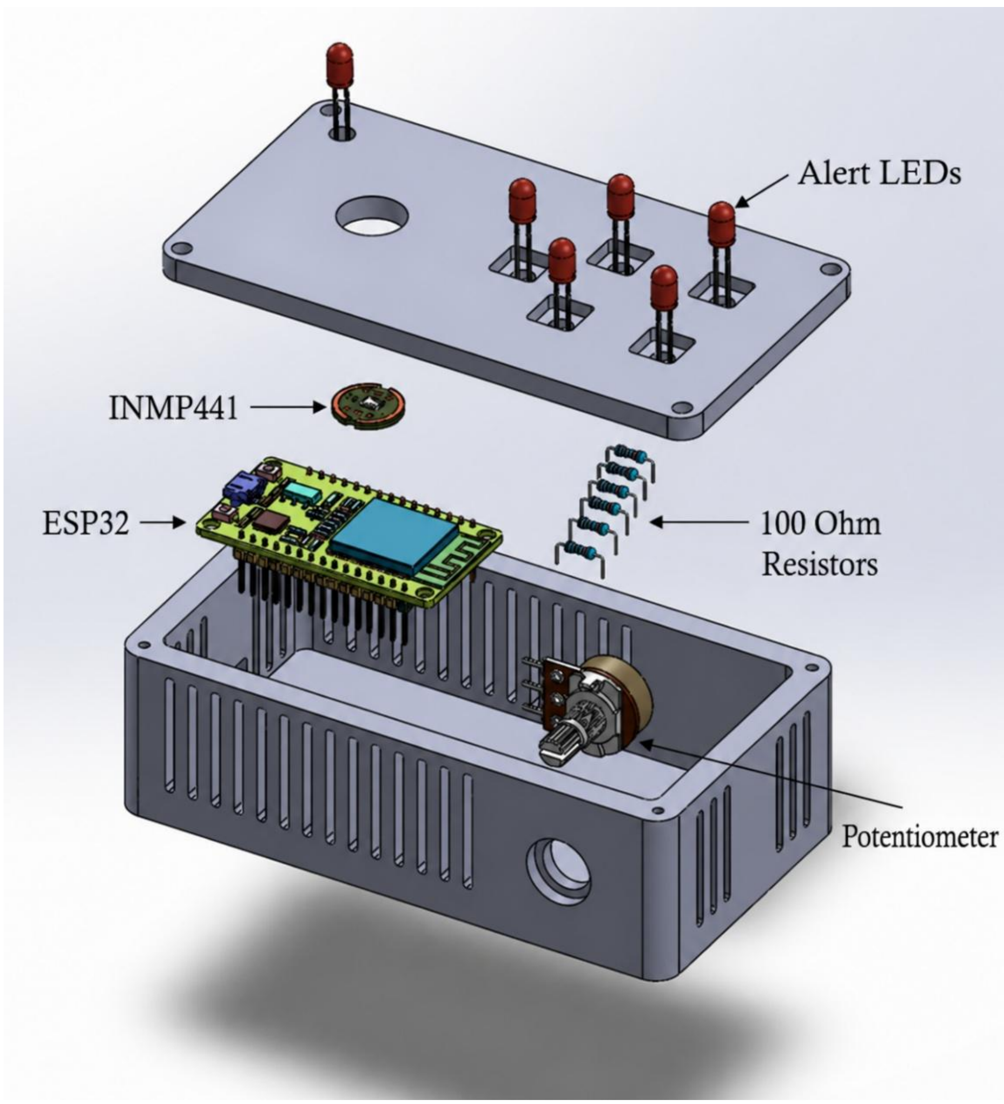


Figure 12. Updated Final Selection with ESP32 and INMP441.

This transition significantly enhanced system performance while preserving the core functionality and design philosophy of the selected concept. Importantly, the upgrade did not substantially increase manufacturing complexity or overall system cost, making it practical and effective refinement rather than a major conceptual redesign.

Overall, the transition from the top five concepts to the final selected prototype was straightforward due to the clear performance advantages identified through engineering analysis and stakeholder feedback. The final design successfully combined stakeholder preferences, practical manufacturability, and technical optimization to produce a robust, scalable, and cost-effective Emergency Alert Recognition System prototype.

8. Prototype development:

Following the final concept selection, the prototype development phase focused on transforming the selected design into a fully functional physical system through subsystem integration, enclosure development, circuit implementation, and software programming. Due to the straightforward nature of the chosen concept, this phase progressed efficiently with minimal major design obstacles.

The primary hardware components required for the prototype were commercially sourced through readily available online suppliers, primarily through Amazon, to minimize procurement delays, maintain affordability, and simplify the manufacturing process. Core components included the ESP32 microcontroller, INMP441 digital MEMS microphone, LED alert modules, resistors, power control elements, and supporting circuit hardware. This approach aligned strongly with the project's low-cost and accessible manufacturing objectives.

Once the core components were selected, enclosure development became a central focus of prototype refinement. The casing was designed using CAD software to ensure proper spatial accommodation of all internal electronic components while maintaining compact dimensions suitable for vehicle dashboard use. Special consideration was given to internal component arrangement, wiring management, accessibility, ventilation, and mounting practicality.

Multiple enclosure iterations were developed throughout the project. Most of these design revisions resulted from the transition from the originally planned Arduino platform to the more compact and capable ESP32 microcontroller architecture. This hardware substitution required dimensional adjustments, revised mounting points, and updated internal layouts to ensure proper fitment and thermal performance. Despite these revisions, the casing development process remained smooth, with no significant manufacturing barriers encountered.

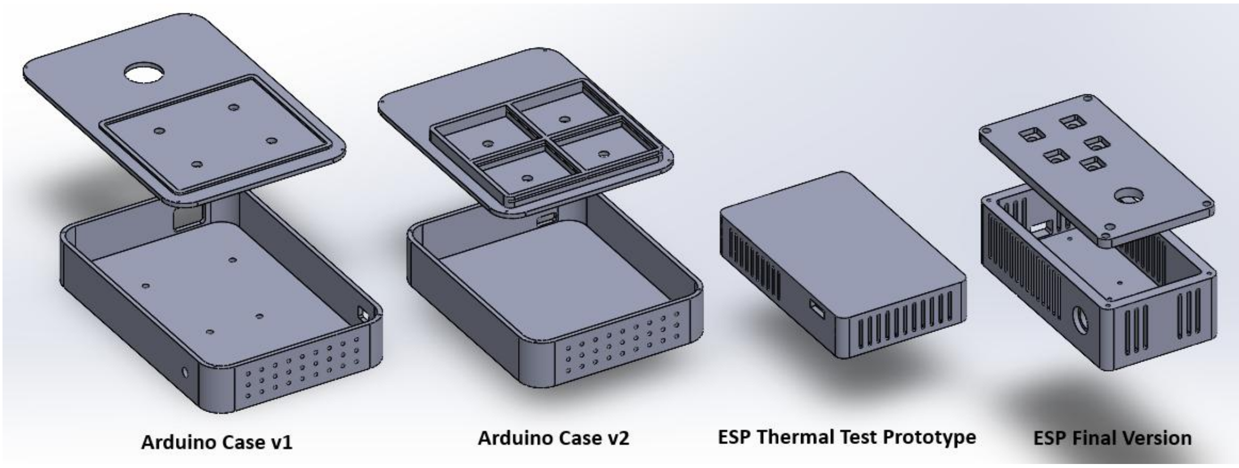


Figure 13: Left-Right Enclosure Evolution

From a circuit design standpoint, the system architecture proved similarly straightforward. The integration of the ESP32 with the INMP441 microphone and visual LED indicators required simple electrical interfacing due to the compatibility of the selected components. Circuit schematics were developed to ensure reliable signal processing, stable power distribution, and effective visual alert output. Because of the simplicity of the final subsystem arrangement, the project team encountered minimal complications during hardware integration.

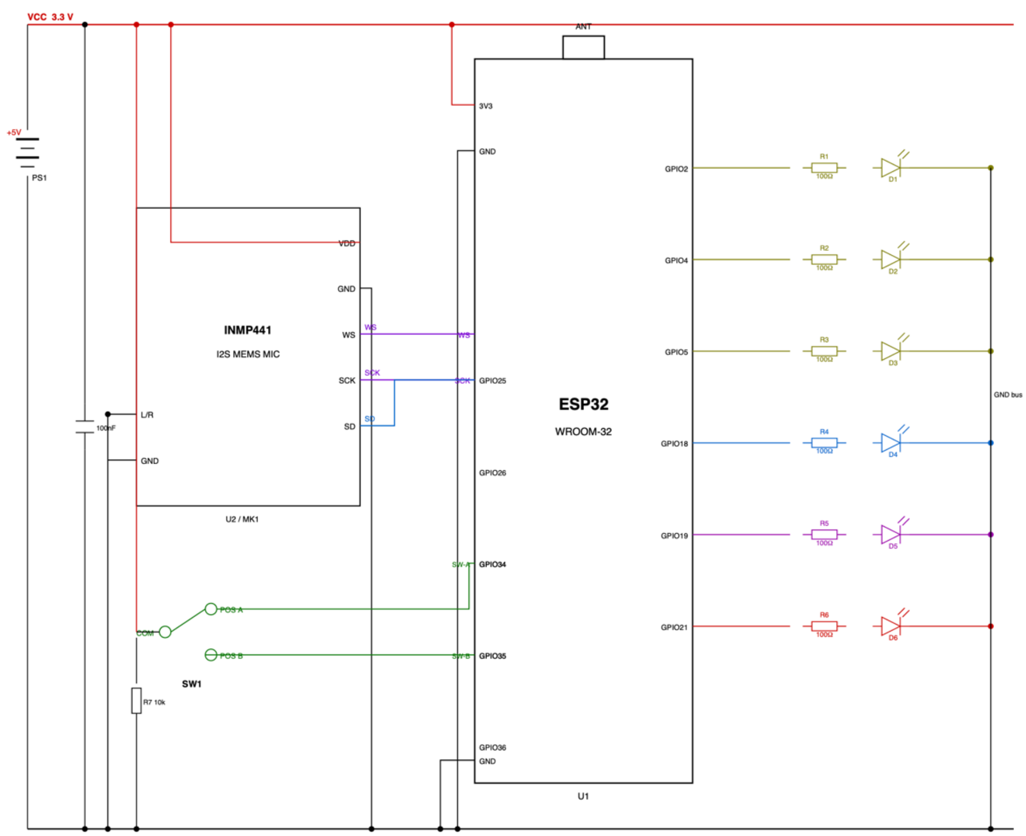


Figure 14: System Schematic

On the software side, development primarily focused on implementing reliable sound classification capabilities capable of distinguishing between emergency sirens and standard vehicle horns. To accomplish this, the system utilized an INMP441 I2S MEMS microphone continuously feeding audio into an Edge Impulse ML classifier running entirely on-chip, no cloud. The model recognizes four sound classes (ambulance, police, fire truck, and car horn) and only accepts results above a 90% confidence threshold to avoid false triggers from background noise.

Edge Impulse is a platform for training and deploying machine learning models on embedded hardware. For this project, audio samples of each siren type were collected and uploaded to the platform, which handles the full ML pipeline, extracting audio features using MFCCs, which compress raw audio into a representation of its frequency content over time, training a neural network classifier on those features, and then exporting the trained model as a C++ library that runs directly on the ESP32. This library uses a simple run_classifier() function that the firmware calls each loop.

Rather than reacting to every single inference frame, the firmware runs a series of rules. A sound must be consistently detected across multiple frames before an alert activates, and 3 consecutive silent frames must pass before it clears. This prevents flickering alerts from brief misclassifications or momentary noise.

Output is delivered through six LEDs, with the alert mode selected at startup via a potentiometer. Mode 1 dedicates a separate LED to each siren type, while Mode 2 simplifies this to just two outputs — one for car horns and one generic emergency LED for all other sirens. All LEDs blink at 500ms intervals rather than staying solid, making them more noticeable in peripheral vision while driving.

Several software iterations were required to refine detection sensitivity, improve classification accuracy, and minimize false positives in noisy automotive environments. Through repeated testing and algorithm optimization, system performance progressively improved until the final prototype successfully achieved the project's marginal Product Design Specification requirement of at least 80% sound detection accuracy.

Although software development represented the most iterative component of prototype development, the use of machine learning provided a computationally efficient and practical solution that remained compatible with the processing limitations of the embedded hardware platform.

Overall, prototype development proceeded as an efficient and highly manageable phase due to the simplicity of the selected concept, the accessibility of components, and the practical manufacturability of the design. Through iterative hardware refinement, enclosure optimization, and software tuning, the final prototype successfully evolved into a functional system capable of meeting core project objectives while maintaining affordability, scalability, and user-centered performance.

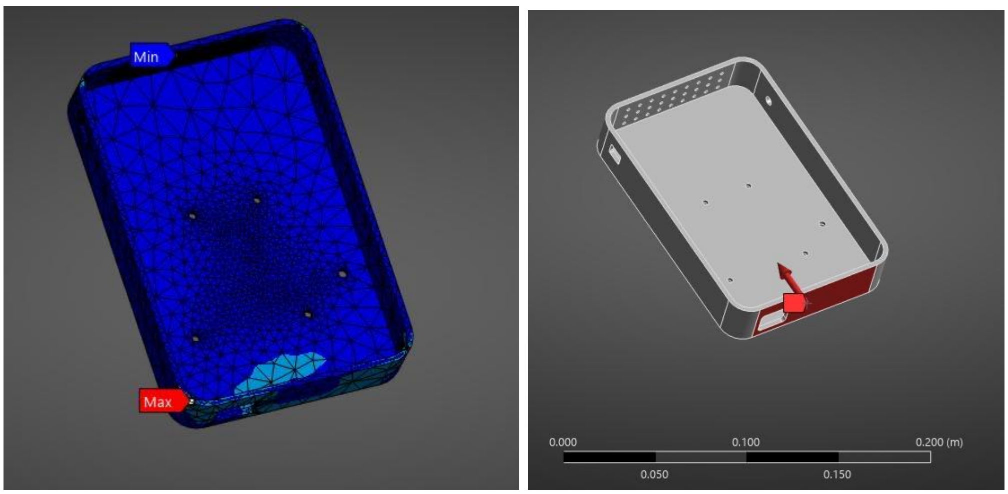
Figure 15: Software Flowchart

9. Design and manufacturing analysis:

Following the final concept selection and prototype development phases, detailed engineering analyses were conducted to validate the structural integrity, thermal reliability, and manufacturability of the Emergency Alert Recognition System under realistic and worst-case operating conditions. These analyses were essential to ensure that the final prototype met critical Product Design Specification (PDS) requirements related to durability, safety, and long-term operational performance.

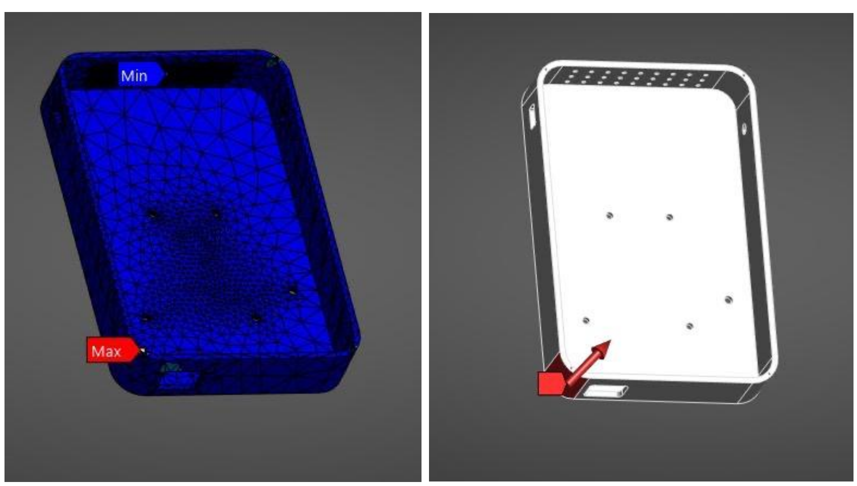
A structural drop test analysis was performed on the final enclosure design to evaluate the system's ability to withstand accidental impacts during regular use. In accordance with the PDS requirement for road shock and drop resistance, a worst-case scenario was assumed in which the device experiences an accidental drop from approximately three feet onto a rigid surface with negligible stopping time. Under these assumptions, an estimated impact force of approximately 400 N was applied to the enclosure model. Two critical impact orientations were evaluated as pictured in figures 16 and 17: corner impact and side-surface impact, as these conditions represented the most severe potential loading cases for the enclosure geometry.

Simulation results indicated that the enclosure remained structurally sound under both loading scenarios. Stress concentrations remained within acceptable material limits for ASA (~45 MPa), and no permanent deformation or catastrophic structural failure was observed in figures 16 and 17. Minor elastic deformation occurred in localized impact regions; however, all stress remained below the material's yield strength (26.8 MPa and 16.2 MPa for side and corner drops rspectively), confirming that the casing design provides sufficient mechanical protection for the internal electronic components during accidental handling or installation-related drops. These results validated the enclosure's compliance with the project's durability and survivability requirements.



	Time [s]	Minimum [Pa]	Maximum [Pa]	Average [Pa]
1	1.	3947.1	2.6815e+007	4.7588e+005

Figure 16: Side drop test



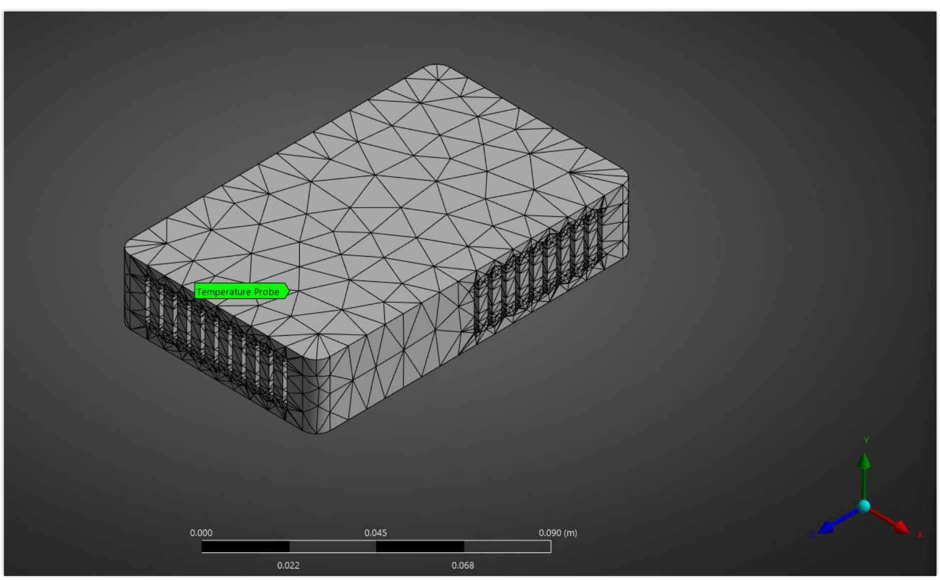
	Time [s]	Minimum [Pa]	Maximum [Pa]	Average [Pa]
1	1.	54021	1.6257e+007	7.613e+006

Figure 17: Corner drop test

In addition to structural analysis, a thermal analysis as pictured in figure 18 was conducted to evaluate system performance under extreme environmental conditions. Since the device is intended for automotive dashboard installation, a worst-case thermal scenario was defined as a parked vehicle exposed to direct sunlight for prolonged periods while the system remained inside the dashboard area. Under these conditions, thermal simulations and experimental temperature monitoring focused primarily on the ESP32 microcontroller, as it represents one of the most thermally sensitive and functionally critical components within the system architecture.

Results showed that the surface temperature of the ESP32 reached approximately 88°C under worst-case exposure conditions. This temperature exceeds the preferred operating range of several system components and enters a potentially hazardous zone for long-term reliability, performance stability, and component lifespan. While immediate catastrophic failure was not observed, sustained exposure to such temperatures could accelerate degradation or induce thermal instability.

To address this limitation, several design modifications were implemented, these are shown in figure 16. Additional ventilation slits were incorporated into the enclosure geometry to improve passive airflow and reduce internal heat accumulation. This manufacturing revision improved thermal dissipation without significantly increasing production complexity or material cost. Furthermore, operational recommendations were established for end users, advising that the device be removed from direct dashboard exposure when not in active use and stored in shaded vehicle compartments such as the glovebox. These recommendations significantly reduce the likelihood of prolonged extreme thermal exposure.



	Time [s]	Temperature Probe [°C]
1	1.	88.239

Figure 18: Ambient thermal test

A drop test analysis was performed to evaluate the mechanical reliability of the system components under accidental impact conditions. The analysis considered the ESP32, INMP441 microphone, and breadboard assembly, using their respective masses to estimate both static and dynamic loading conditions.

For each component, the static force due to weight was calculated and distributed across the mounting screws. This allowed the determination of the force per screw, which was then compared to the screw capacity (78 N) to compute the safety factor. All components resulted in safety factors greater than two, indicating acceptable performance under normal operating conditions.

To simulate a worst-case scenario, an impact force calculation was performed based on drop conditions. The resulting forces were significantly higher than the static forces, with peak values reaching approximately 388 N. However, these values represent instantaneous forces that occur during a noticeably short impact duration rather than continuous loading.

The system is still considered safe because the forces are not sustained and occur only momentarily during impact. Additionally, the load is distributed across multiple screws, reducing the effective force experienced by each fastener. The screws are also capable of withstanding short-duration impulse loads that exceed their static ratings. Furthermore, real-world conditions such as slight material deformation and damping effects help reduce the actual peak forces experienced during impact.

Table 7: Component drop test analysis.

Component	Mass (kg)	Total Force (N)	Screws Considered	Force per Screw (N)	Capacity (N)	Safety Factor	Result	Static Factor	Impact Force Calculation (N)
ESP32	0.015	30	2	15	78	5.2	Safe	0.04	224.609
INMP441 Microphone	0.005	10	2	5	78	15.6	Safe	0.013	388.300
Breadboard Assembly	0.030	60	2	30	78	2.6	Safe	0.08	159.117

From a manufacturing perspective, the enclosure design was optimized for additive manufacturing using 3D printing processes, allowing rapid prototyping, low production cost, and straightforward design iteration. The use of 3D printing enabled efficient integration of custom mounting features, ventilation improvements, and compact packaging while maintaining affordability in alignment with project cost objectives. Material selection prioritized lightweight construction, structural resilience, thermal resilience, and ease of fabrication.

Overall, the design and manufacturing analyses confirmed that the Emergency Alert Recognition System prototype satisfies major mechanical durability requirements while identifying and addressing key thermal management challenges. These evaluations not only improved the final prototype design but also provided critical engineering validation for future product refinement, scalability, and potential commercialization.

10. Testing and validation:

Following prototype fabrication and subsystem integration, comprehensive testing and validation procedures were conducted to evaluate the Emergency Alert Recognition System's real-world performance relative to the established Product Design Specification (PDS). Testing efforts primarily focused on functional reliability, structural durability, thermal survivability, and sound recognition effectiveness under representative operating conditions.

To validate the physical durability of the enclosure, real-world drop testing was performed to supplement prior simulation analyses. The prototype casing was subjected to multiple accidental drop scenarios representative of expected user mishandling, installation accidents, or vehicle-related movement. These practical tests involved repeated drops from moderate handling heights of around 3-4 feet onto hard surfaces. Results demonstrated that the enclosure maintained structural integrity without significant visible damage, functional impairment, or component displacement. Figure 19 shows no catastrophic failures or permanent deformations were observed, confirming that the physical prototype successfully met core mechanical durability expectations.

Figure 19: Device on floor after drop tests

Functional validation of the sound recognition system focused heavily on the software's ability to correctly identify emergency sirens and vehicle horns. Multiple prerecorded audio samples representing various siren types, emergency vehicle signals, and standard horn sounds were evaluated under controlled conditions. Across most trials, the system consistently produced positive detection outcomes, successfully activating the corresponding visual alert mechanisms. These results confirmed that the implemented machine learning classification algorithm could meet the project's required marginal performance threshold for emergency sound detection.

Recognizing that occasional classification ambiguity between specific siren categories could occur due to overlapping acoustic characteristics, specifically between fire truck and police sirens, an additional safety-oriented system refinement was implemented. A generalized siren alert LED indicator was incorporated to activate whenever any emergency siren is detected, regardless of exact classification confidence. This redundancy ensures that drivers are still visually alerted to the presence of nearby emergency vehicles even when precise siren classification may be uncertain. This design improvement enhances system safety by prioritizing driver awareness and reaction capability over strict categorical specificity.

Thermal validation was also conducted through practical environmental exposure testing. The device was placed inside a parked vehicle for extended periods under elevated temperature conditions to simulate realistic worst-case automotive heat exposure. Following these tests at around 110 °F, no immediate component failures, critical malfunctions, or operational interruptions were observed. While prolonged thermal exposure remains an important consideration for design, the system demonstrated acceptable resilience under extreme environmental conditions as observed in figure 20.

Figure 20: Device in glove compartment after test

Overall, testing and validation results demonstrated that the Emergency Alert Recognition System performs reliably across key operational categories. The prototype successfully achieved its primary objectives of structural resilience, emergency sound recognition, visual alert functionality, and practical survivability within realistic automotive environments. These validation efforts confirmed the system's viability as an assistive safety device capable of improving driver awareness and supporting safer vehicle operation under emergency conditions.

11. Discussion:

The development of the Emergency Alert Recognition System successfully demonstrated the feasibility of creating an affordable, compact, and functionally reliable assistive device designed to improve driver awareness of emergency-related auditory signals through visual notification methods. Through the structured application of engineering design methodology, including Product Design Specification development, concept generation, weighted selection processes, iterative prototyping, and practical testing, the project achieved its primary objective of providing hearing-impaired or noise-isolated drivers with enhanced situational awareness in critical road environments.

One of the project's major strengths was its highly systematic design process. Beginning with broad concept generation and progressing through multiple objective selection stages, the project ensured that final design decisions were rooted in both quantitative engineering analysis and stakeholder collaboration. The use of both preliminary and refined weighted evaluations allowed the team to balance practical constraints such as affordability, manufacturability, reliability, and functionality. This process led to the selection of a design that emphasized simplicity and effectiveness over unnecessary complexity, which proved beneficial during manufacturing and implementation.

The decision to transition from the originally selected Arduino platform to the ESP32 microcontroller represented a significant technical improvement during prototype development. These changes increased system processing capabilities, improved microphone compatibility, and enhanced software flexibility without fundamentally altering the original design philosophy. The integration of the INMP441 microphone further strengthened sound detection performance, allowing the system to better process real-world audio signals using FFT-based classification techniques.

Software development emerged as one of the most critical aspects of the project, as accurate sound recognition directly determined overall system effectiveness. While the FFT-based algorithm successfully achieved the marginal Product Design Specification target for detection accuracy, testing revealed that precise classification between certain siren categories may occasionally present challenges due to similarities in acoustic signatures. The addition of a generalized siren alert LED served as an effective design compromise, improving safety by ensuring that emergency vehicle presence is still communicated even when exact identification confidence is reduced. This design refinement illustrates the project's emphasis on practical user safety over purely technical precision.

From a structural and manufacturing standpoint, the project performed exceptionally well. The enclosure design proved durable under both simulated and practical drop testing, validating its ability to withstand accidental impacts and typical handling scenarios. The use of additive manufacturing techniques provided rapid iteration capability, enabling efficient accommodation of hardware modifications such as the ESP32 transition and thermal ventilation improvements. This manufacturing approach maintained low production costs while supporting iterative optimization throughout development.

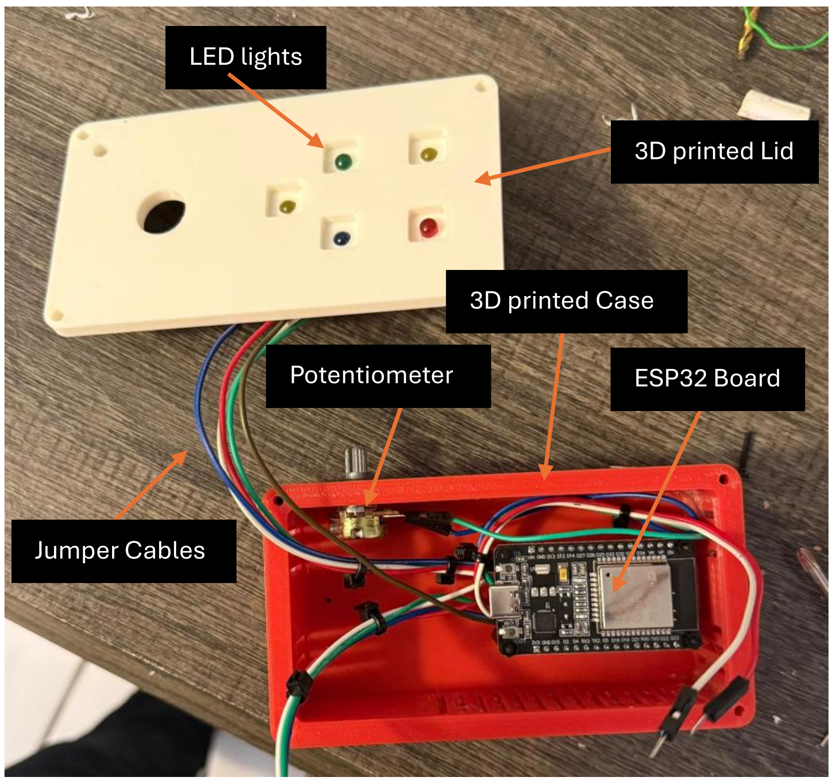


Figure 21: Open prototype with components attached

Thermal analysis revealed one of the more important design limitations of the system. Under extreme heat conditions typical of enclosed vehicles in direct sunlight, internal temperatures approached levels that may compromise long-term component reliability. Although immediate failures were not observed, this finding highlighted the importance of passive cooling features and informed the implementation of additional ventilation slits and user handling recommendations. This aspect of the project demonstrated the value of environmental testing in identifying realistic operational risks that may not be immediately apparent during conceptual design stages.

Figure 22: Final closed prototype

Overall, the final prototype successfully balanced cost, manufacturability, functional performance, and user-centered design priorities. While opportunities for future improvements remain, particularly in advanced machine learning sound classification, long-term durability studies, and thermal management optimization; the current system represents a highly viable proof-of-concept capable of delivering meaningful safety benefits.

In conclusion, the Emergency Alert Recognition System demonstrates strong potential as a practical assistive technology for drivers who may otherwise experience reduced awareness of emergency auditory cues. The project validates the effectiveness of combining embedded systems, digital sound processing, and intuitive visual alerts into a cohesive safety solution while providing a solid foundation for future refinement, scalability, and broader real-world application.

11.1 Placement Considerations

The Emergency Alert Recognition System is designed to be mounted inside a vehicle using a mounting solution like commercially available smartphone dashboard mounts. Any location that provides clear visibility of the visual indicators while maintaining driver comfort and avoiding obstruction of vehicle controls is considered acceptable for operation, as shown in Figure 24. The mounting location should not interfere with airbag deployment zones, obstruct the driver's view of the road, or block access to vehicle instrumentation.

For optimal performance, the recommended mounting location is directly above the steering wheel on the dashboard, as illustrated in Figure 23. This position places the visual alerts within the driver's primary field of view, minimizing the time required to detect and interpret emergency notifications while maintaining attention on the road. Locating the device near the driver's normal line of sight reduces reaction time compared to placements farther from the instrument cluster or windshield.

The enclosure dimensions of approximately 12 cm × 6.5 cm allow compatibility with a wide range of commercially available dashboard and windshield mounts commonly designed for smartphones and GPS devices. The selected mounting method should securely support the device during normal vehicle operation and typical road vibrations while allowing easy removal for storage when the vehicle is parked for extended periods.

Although dashboard placement provides the shortest visual response time, prolonged exposure to direct sunlight may increase internal device temperatures. Based on the thermal analysis performed, elevated temperatures may affect long-term component reliability. Therefore, the recommended operating configuration is to mount the device above the steering wheel during use to maximize visibility and minimize reaction time, while storing the device in a shaded compartment, such as the glovebox or center console, when the vehicle is parked for extended periods.

Figure 23. Recommended mounting location directly above the steering wheel for maximum visibility and reduced driver reaction time.

Figure 24. Alternative acceptable mounting locations within the driver's field of view that maintain accessibility and do not obstruct vehicle controls or airbag deployment zones.

11.2 Ergonomic Design Considerations

The Emergency Alert Recognition System was designed with human factors and driver ergonomics in mind to ensure safe interaction without increasing cognitive or physical workload during vehicle operation. Since the device is intended for in-vehicle use, minimizing driver distraction and maintaining clear visibility of alerts were prioritized during the design process.

A key ergonomic consideration is visual accessibility. The device is intended to be positioned within the driver’s primary field of view, preferably above the steering wheel on the dashboard. This location reduces the need for head or eye movement away from the road, thereby minimizing reaction time and visual scanning effort. The display size and layout were selected to ensure readability at a typical driving distance without requiring the driver to focus closely or adjust posture.

Reachability and physical interaction were also considered. The system does not require continuous manual input during driving, reducing the need for driver reach and interaction while the vehicle is in motion. Any required controls, such as power switching or sensitivity adjustment, are intended to be configured prior to driving to prevent mid-operation distraction.

Cognitive load was minimized by using simple and intuitive visual alert indicators rather than text-heavy outputs. This reduces interpretation time and allows the driver to quickly associate alerts with predefined emergency categories without requiring extensive attention or decision-making.

Finally, mounting stability and vibration resistance were considered to ensure that the device remains securely fixed under normal driving conditions. The recommended use of commercially available dashboard or windshield mounts ensures consistent positioning while allowing safe removal when the vehicle is parked. Overall, the ergonomic design prioritizes reduced driver distraction, rapid information recognition, and safe physical interaction within the driving environment.

11.3 PDS review

Table 9. Final PDS review.

#	Metric	Units	Marginal Value	Ideal Value	Importance	Completion
1	Emergency Sound Detection Accuracy	%	≥80	≥95	14	✅ ✅ 97%
2	Detection-to-Alert Latency	ms	≤1000	≤500	10	✅ ✅ 400ms
3	Maximum Ambient Noise Tolerated	dB	70	85	7	✅ ✅ 110 dB
4	User Alert Recognition Time	s	≤1.5	≤1.0	10	✅ ✅
5	Device Cost	$	≤120	≤50	9	✅ ✅ ~$30
6	Time Between Maintenance	months	≥6	≥12	5	✅ ✅ >12
7	Installation Time	hr	1	≤0.25	5	✅ ✅ <0.1 hr
8	Device Frontal Area	cm^2	≤80	≤60	4	✅ 78cm^2
9	Power Consumption	W	≤10	≤5	5	✅ ✅ ~2 W
10	Operating Surface Temperature Range	°C	25 < T < 60	10 < T < 80	5	✅ ✅ 10-90 C
11	Firmware Upgradability	Binary	Required	Seamless	3	✅ ✅
12	Privacy Protection	Binary	No storage	Verified	3	✅ ✅
13	Mounting Vibration Resistance	Hz	50	80+	6	✅ ✅ >80
14	Road Shock / Drop Resistance	g / drop	3-ft drop	No failure	4	✅ ✅
15	Maximum Vehicle Operating Speed	mph	50	100	3	✅ ✅ 100+
16	Device Lifetime	years	≥2	≥8–10	4	✅ ✅ 5-9 yrs
17	Time to First Critical Failure	years	≥1	≥3	3	✅ ✅ >5yrs
18	Human-Interface Adjustability	%	Functional	Wide range	4	✅

12. Other Considerations

Table 10: ABET Factors Evaluation table.

Factors	Relevant to Project	Not Relevant to Project
Public Health	X	
Safety	X	
Welfare	X	
Global aspects	X	
Cultural aspects	X	
Social aspects	X	
Environmental aspects	X	
Economic aspects	X	

The Emergency Alert Recognition System was developed with strong consideration of public health, safety, welfare, and broader societal constraints, ensuring that the final design extends beyond purely technical performance and addresses real-world human and environmental contexts.

12.1 Public Health, Safety, and Welfare:

Public safety represents the core driving factor of this project. The system directly targets improved road safety by enhancing awareness of emergency vehicles for drivers who may be deaf, hard of hearing, or operating in acoustic limited environments. By converting critical auditory cues into immediate visual alerts, the system reduces reaction time and helps mitigate risks associated with delayed emergency vehicle detection.

Safety was also incorporated into the design through multiple engineering decisions, including redundant alert logic (general siren detection LED), enclosure durability validation through drop testing, and thermal risk mitigation strategies such as improved ventilation. These considerations ensure that the device remains dependable under automotive conditions, including impact, vibration, and elevated temperatures.

Welfare considerations are reflected in the system’s emphasis on ease of use, non-intrusive installation, and intuitive visual feedback. The use of simple LED-based indicators ensures that alerts are immediately understandable without requiring cognitive interpretation or training, reducing driver distraction, and improving usability.

12.2 Social and Cultural Aspects:

From a social perspective, the system promotes inclusivity by addressing a long-standing accessibility gap in vehicle safety systems. Drivers with hearing impairments often rely solely on visual cues and vibrations within their environment; this system enhances their ability to perceive critical external events, supporting independent mobility and equal access to safe transportation.

Culturally, the design reflects a broader shift toward inclusive engineering solutions that prioritize accessibility and assistive technologies. The project acknowledges diversity in user capability and seeks to integrate adaptive safety mechanisms into everyday automotive environments without requiring modification to existing vehicle infrastructure.

12.3 Global Considerations:

While the system was developed within a local context, its application is globally relevant. Emergency vehicle detection and driver awareness are universal road safety concerns, and similar accessibility challenges exist across different countries and transportation systems. The simplicity of the low-cost embedded hardware with scalable software supports potential adaptation in both developed and developing regions where advanced vehicle safety systems may not be widely available.

12.4 Environmental Aspects:

Environmental considerations were addressed primarily through low power consumption design and compact hardware selection. The ESP32-based architecture and LED output system ensures minimal energy demand from the vehicle electrical system. Additionally, the use of lightweight materials and 3D-printed enclosure components reduces material waste during prototyping and supports efficient iterative development.

However, thermal exposure within parked vehicles highlighted an environmental limitation related to heat accumulation in enclosed automotive spaces. This was mitigated through passive ventilation design improvements and operational recommendations to minimize prolonged exposure.

12.5 Economic Aspects:

Economic feasibility was a key design constraint throughout the project. Component selection prioritized affordability and accessibility, ensuring that the final system could be realistically adopted without imposing a significant financial burden on users. The use of commercially available components and open-source development platforms significantly reduced overall system cost while maintaining functional performance.

This economic efficiency directly supports scalability, making the system viable for broader adoption in assistive technology markets or as a retrofit safety enhancement for existing vehicles.

12.6 Performance Analysis and Validation:

Prototype validation was performed through a combination of real-world and controlled testing methodologies. Structural performance was evaluated through physical drop testing, confirming that the enclosure-maintained integrity under accidental impact conditions. Functional performance was assessed using recorded emergency siren and horn samples, demonstrating consistent detection capability, and achieving the minimum required performance threshold defined in the PDS.

Thermal validation was conducted through prolonged exposure inside a parked vehicle under elevated temperature conditions. While the system remained operational, results identified thermal stress as a key design constraint, leading to enclosure ventilation improvements.

These validation procedures confirmed that the system meets its primary functional and safety requirements while also identifying areas for future optimization.

12.7 Engineering Standards and Guidelines:

Although the project does not explicitly implement a single formal industrial standard such as ASME or SAE in its entirety, several engineering best practices and standard-aligned considerations were applied:

- Automotive environmental and reliability standards (ISO 16750 / SAE J1455): The system was designed considering in-vehicle environmental conditions such as vibration, thermal variation, and electrical stress in accordance with *ISO 16750 (Road vehicles — Environmental conditions and testing for electrical and electronic equipment)* and *SAE J1455 (Recommended Environmental Practices for Electronic Equipment Design in Heavy-Duty Vehicle Applications)*. These guided assumptions for vibration exposure, temperature range operation, and mechanical robustness of the enclosure and PCB-mounted components.

- Electromagnetic compatibility and electrical noise immunity (IEC 61000 / ISO 11452): Embedded signal processing and power design considerations were informed by *IEC 61000 (Electromagnetic Compatibility standards)* and *ISO 11452 (Road vehicles — Component test methods for electrical disturbances from narrowband radiated electromagnetic energy)*. These standards guided mitigation strategies for noise susceptibility in microphone signal acquisition and ESP32 processing stability in a vehicle electrical environment.

- Electrical safety and low-voltage embedded system design (IEC 62368-1): Electrical safety principles followed *IEC 62368-1 (Audio/video, information and* *communication technology equipment safety requirements)* to ensure safe low-voltage operation, proper power regulation from the 12V vehicle supply, and prevention of hazardous heating or electrical fault conditions.

- Ingress protection and enclosure design considerations (IEC 60529): The enclosure design considered *IEC 60529 (Degrees of protection provided by enclosures – IP Code)* to guide decisions regarding dust and moisture resistance, particularly for dashboard-mounted deployment in automotive environments.
- Human factors and accessibility design (ISO 9241-210 / ADA Standards): The user interface and alert system were designed using *ISO 9241-210 (Human-centred design for interactive systems)* and aligned with *Americans with Disabilities Act (ADA) Standards for Accessible Design (2010)*. These informed the decision to use high-visibility LED-based alerts and minimize cognitive load for hearing-impaired drivers.

Ethical Considerations

Several ethical considerations were addressed during the development process. The system does not store or transmit audio data, ensuring user privacy and avoiding potential misuse of recorded environmental sounds. This design decision aligns with ethical expectations for surveillance-free assistive technologies.

Additionally, care was taken to avoid over-reliance on classification certainty, as false negatives in emergency detection could pose safety risks. The inclusion of a generalized siren alert system reflects an ethical design choice prioritizing user safety over strict algorithmic precision.

12.8 Intellectual Property and Legal Considerations:

From an intellectual property perspective, the system integrates commonly available open-source hardware and widely used signal processing techniques (FFT-based analysis). No proprietary algorithms or restricted technologies were replicated.

However, potential legal considerations may arise in relation to automotive device usage, particularly regarding driver distraction laws or aftermarket electronic installations depending on jurisdiction. The design mitigates these risks by maintaining non-intrusive visual alerts and avoiding auditory or distracting feedback mechanisms.

Additionally, the system avoids unauthorized audio recording storage, reducing potential legal concerns related to privacy or surveillance regulations.

12.9 Learning and Knowledge Acquisition:

Throughout the project, significant self-directed learning was required, particularly in embedded systems integration, digital signal processing, and real-time audio classification. Additional knowledge in ESP32 architecture, INMP441 microphone interfacing, and FFT-based frequency analysis was acquired to successfully implement the system.

Resources used included technical documentation (ESP32 and INMP441 datasheets), online engineering forums, signal processing references, and embedded systems tutorials. This knowledge was directly applied during software development, hardware integration, and system debugging phases.

This experience strengthened the ability to independently acquire and apply new engineering knowledge in a structured and goal-oriented manner, particularly in situations where initial design assumptions required adaptation during implementation.

13. Conclusion:

The Emergency Alert Recognition System project successfully achieved its primary objective of designing, developing, and validating a functional assistive device capable of improving driver awareness of emergency-related auditory signals through visual alerts. By converting critical external sounds such as sirens and vehicle horns into intuitive visual notifications, the system provides an effective safety solution for deaf or hearing-impaired drivers as well as individuals operating in high-noise or sound-isolated environments.

Through the application of a structured engineering design process, the project progressed from problem identification and Product Design Specification development through concept generation, concept selection, prototype manufacturing, subsystem integration, and final testing. Each phase contributed to the refinement of a practical and manufacturable solution that balanced affordability, simplicity, reliability, and user-centered performance.

The final prototype, utilizing an ESP32 microcontroller, INMP441 digital microphone, and LED-based alert system, demonstrated reliable sound recognition capabilities while meeting key marginal performance requirements established within the Product Design Specification. Structural testing confirmed that the enclosure design provides adequate durability under realistic handling and drop conditions, while thermal testing identified environmental limitations that were addressed through enclosure ventilation improvements and practical user recommendations.

One of the project's greatest strengths was its ability to maintain functional effectiveness while minimizing complexity and production cost. The use of commercially available components, additive manufacturing techniques, and efficient embedded signal processing allowed for the development of a scalable prototype with strong potential for future refinement and broader implementation.

Although certain limitations remain, particularly in thermal management and advanced sound classification precision, the final system represents a successful proof-of-concept with meaningful real-world application. Future improvements may include enhanced machine learning algorithms, expanded testing under diverse driving conditions, and further optimization of enclosure materials and thermal resistance.

Overall, this project demonstrates that affordable embedded systems technology can be effectively leveraged to create practical safety devices that address real accessibility challenges. The Emergency Alert Recognition System provides a solid foundation for continued development and highlights the potential of engineering innovation to improve transportation safety, inclusiveness, and user independence.

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Appendix:

Plus-minus method, full table of 60 ideas:

Metric	Idea 1 (Datum)	Idea 2	Idea 3	Idea 4	Idea 5	Idea 6	Idea 7	Idea 8	Idea 9	Idea 10	Idea 11	Idea 12	Idea 13	Idea 14	Idea 15	Idea 16	Idea 17	Idea 18	Idea 19	Idea 20	Idea 21	Idea 22	Idea 23	Idea 24	Idea 25	Idea 26	Idea 27	Idea 28	Idea 29	Idea 30
Emergency Sound Detection Accuracy	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	1	1	1	1	1	1	1	1	1
Event to Perception latency	0	-1	0	-1	0	-1	0	-1	0	-1	0	-1	0	-1	0	-1	0	-1	0	-1	0	-1	0	-1	0	-1	0	-1	0	-1
Maximum Ambient Noise Tolerated	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Safe Design	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Device Cost	0	-1	-1	-1	0	-1	0	-1	-1	-1	0	-1	0	-1	-1	-1	0	-1	0	-1	-1	-1	0	-1	0	-1	-1	-1	0	-1
Time Between Maintenance	0	0	-1	-1	0	0	0	0	-1	-1	0	0	0	0	-1	-1	0	0	0	0	-1	-1	0	0	0	0	-1	-1	0	0
Installation Time	0	1	-1	0	0	1	0	1	-1	0	0	1	0	1	-1	0	0	1	0	1	-1	0	0	1	0	1	-1	0	0	1
Display Size	0	0	0	0	0	0	-1	-1	-1	-1	-1	-1	0	0	0	0	0	0	0	0	0	0	0	0	-1	-1	-1	-1	-1	-1
Power Consumption (Active)	0	-1	0	-1	0	-1	0	-1	0	-1	0	-1	0	-1	0	-1	0	-1	0	-1	0	-1	0	-1	0	-1	0	-1	0	-1
Operating Surface Temperature Range	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Firmware Upgradability	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Mounting Vibration Resistance	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Road Shock / Drop Resistance	0	0	-1	-1	0	0	0	0	-1	-1	0	0	0	0	-1	-1	0	0	0	0	-1	-1	0	0	0	0	-1	-1	0	0
Maximum Vehicle Operating Speed	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Device Lifetime	0	-1	0	-1	0	-1	0	-1	0	-1	0	-1	0	-1	0	-1	0	-1	0	-1	0	-1	0	-1	0	-1	0	-1	0	-1
Time to First Critical Failure	0	0	1	1	-1	-1	0	0	1	1	-1	-1	0	0	1	1	-1	-1	0	0	1	1	-1	-1	0	0	1	1	-1	-1
Human-Interface Adjustability (brightness + sensitivity range)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Sum	0	-3	-3	-5	-1	-4	-1	-4	-4	-6	-2	-5	0	-3	-3	-5	-1	-4	1	-2	-2	-4	0	-3	0	-3	-3	-5	-1	-4

Idea 31	Idea 32	Idea 33	Idea 34	Idea 35	Idea 36	Idea 37	Idea 38	Idea 39	Idea 40	Idea 41	Idea 42	Idea 43	Idea 44	Idea 45	Idea 46	Idea 47	Idea 48	Idea 49	Idea 50	Idea 51	Idea 52	Idea 53	Idea 54	Idea 55	Idea 56	Idea 57	Idea 58	Idea 59	Idea 60
1	1	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	1	1	1
0	-1	0	-1	0	-1	0	-1	0	-1	0	-1	0	-1	0	-1	0	-1	0	-1	0	-1	0	-1	0	-1	0	-1	0	-1
0	0	0	0	0	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	-1	-1	-1	0	-1	0	-1	-1	-1	0	-1	0	-1	-1	-1	0	-1	0	-1	-1	-1	0	-1	0	-1	-1	-1	0	-1
0	0	-1	-1	0	0	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1
0	1	-1	0	0	1	0	1	-1	0	0	1	0	1	-1	0	0	1	0	1	-1	0	0	1	0	1	-1	0	0	1
0	0	0	0	0	0	0	0	0	0	0	0	-1	-1	-1	-1	-1	-1	0	0	0	0	0	0	0	0	0	0	0	0
0	-1	0	-1	0	-1	0	-1	0	-1	0	-1	0	-1	0	-1	0	-1	0	-1	0	-1	0	-1	0	-1	0	-1	0	-1
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	-1	-1	0	0	0	0	-1	-1	0	0	0	0	-1	-1	0	0	0	0	-1	-1	0	0	0	0	-1	-1	0	0
0	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
0	-1	0	-1	0	-1	0	-1	0	-1	0	-1	0	-1	0	-1	0	-1	0	-1	0	-1	0	-1	0	-1	0	-1	0	-1
0	0	1	1	-1	-1	1	1	1	1	0	0	1	1	1	1	0	0	1	1	1	1	0	0	1	1	1	1	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1	-2	-1	-3	1	-2	2	-1	-1	-3	1	-2	1	-2	-2	-4	0	-3	2	-1	-1	-3	1	-2	3	0	0	-2	2	-1

Weighted rated method, full table of Top 15 ideas:

Metric	Units	Direction	Marginal	Ideal	Weight	Idea 55 Vibration Sensor | AI-Based | LED Pictograms | Car Battery | Wired		Idea 59 Vibration Sensor | AI-Based | LED Pictograms | Portable Battery | Wired		Idea 49 Vibration Sensor | Embedded Processor | LED + Steering Vibration | Car Battery | Wired		Idea 37 Vibration Sensor | Embedded Processor | LED Pictograms | Car Battery | Wired		Idea 53 Vibration Sensor | Embedded Processor | LED + Steering Vibration | Portable Battery | Wired	
						Actual	Weighted (capped)	Actual	Weighted (capped)	Actual	Weighted (capped)	Actual	Weighted (capped)	Actual	Weighted (capped)
Emergency Sound Detection Accuracy	%	Max	80	95	**10**	72	7.578947368	72	7.578947368	65	6.842105263	65	6.842105263	65	6.842105263
Detection-to-Alert Latency	ms	Min	1000	500	**10**	250	10	250	10	450	10	450	10	450	10
Maximum Ambient Noise Tolerated	dB	Max	70	85	**7**	70	5.764705882	70	5.764705882	70	5.764705882	70	5.764705882	70	5.764705882
User Alert Recognition Time (UPDATED)	s	Min	1.5	1	**10**	0.6	10	0.6	10	0.3	10	0.6	10	0.3	10
Device Cost	USD	Min	120	50	**9**	89	5.056179775	102	4.411764706	76	5.921052632	66	6.818181818	89	5.056179775
Time Between Maintenance	months	Max	6	12	**5**	18	5	18	5	18	5	18	5	18	5
Installation Time	hr	Min	1	0.25	**5**	0.25	5	0.333	3.753753754	0.333	3.753753754	0.25	5	0.417	2.997601918
Device Frontal Area (ADJUSTED UP)	cm^2	Min	80	60	**4**	20	4	20	4	25	4	20	4	25	4
Power Consumption (Active)	W	Min	10	5	**5**	4.65	5	4.65	5	3.35	5	2.65	5	3.35	5
Operating Surface Temperature Range (FIXED)	°C range	Max	35	70	**5**	70	5	70	5	70	5	70	5	70	5
Firmware Upgradability	score	Max	0.8	1	**3**	1	3	1	3	0.9	2.7	0.9	2.7	0.9	2.7
Privacy Protection (No Audio Storage)	score	Max	0.8	1	**3**	1	3	1	3	1	3	1	3	1	3
Mounting Vibration Resistance (EXPANDED)	Hz	Max	50	80	**6**	80	6	80	6	80	6	80	6	80	6
Road Shock / Drop Resistance	ft drop	Max	3	3	**4**	3	4	3	4	3	4	3	4	3	4
Maximum Vehicle Operating Speed (ADDED)	mph	Max	50	100	**3**	100	3	100	3	100	3	100	3	100	3
Device Lifetime (ADDED)	years	Max	2	8	**4**	5	2.5	5	2.5	5	2.5	5	2.5	5	2.5
Time to First Critical Failure	years	Max	1	3	**3**	2.5	2.5	2.5	2.5	3	3	3	3	3	3
Human-Interface Adjustability (brightness + sensitivity range)	score	Max	0.7	1	**4**	0.85	3.4	0.85	3.4	1	4	0.85	3.4	1	4
TOTAL WEIGHTED SCORE (CAPPED)							**89.79983303**		**87.90917171**		**89.48161753**		**91.02499296**		**87.86059284**

Metric	Units	Direction	Marginal	Ideal	Weight	Idea 43 Vibration Sensor | Embedded Processor | Steering Wheel Vibration | Car Battery | Wired		Idea 41 Vibration Sensor | Embedded Processor | LED Pictograms | Portable Battery | Wired		Idea 35 Microphone (Sound Sensor) | AI-Based | LED + Steering Vibration | Portable Battery | Wired		Idea 31 Microphone (Sound Sensor) | AI-Based | LED + Steering Vibration | Car Battery | Wired		Idea 19 Microphone (Sound Sensor) | AI-Based | LED Pictograms | Car Battery | Wired	
						Actual	Weighted (capped)	Actual	Weighted (capped)	Actual	Weighted (capped)	Actual	Weighted (capped)	Actual	Weighted (capped)
Emergency Sound Detection Accuracy	%	Max	80	95	**10**	65	6.842105263	65	6.842105263	95	10	95	10	95	10
Detection-to-Alert Latency	ms	Min	1000	500	**10**	450	10	450	10	250	10	250	10	250	10
Maximum Ambient Noise Tolerated	dB	Max	70	85	**7**	70	5.764705882	70	5.764705882	90	7	90	7	90	7
User Alert Recognition Time (UPDATED)	s	Min	1.5	1	**10**	0.9	10	0.6	10	0.3	10	0.3	10	0.6	10
Device Cost	USD	Min	120	50	**9**	70	6.428571429	79	5.696202532	114	3.947368421	101	4.455445545	91	4.945054945
Time Between Maintenance	months	Max	6	12	**5**	18	5	18	5	24	5	24	5	24	5
Installation Time	hr	Min	1	0.25	**5**	0.417	2.997601918	0.333	3.753753754	0.417	2.997601918	0.333	3.753753754	0.25	5
Device Frontal Area (ADJUSTED UP)	cm^2	Min	80	60	**4**	5	4	20	4	25	4	25	4	20	4
Power Consumption (Active)	W	Min	10	5	**5**	3.15	5	2.65	5	5.4	4.62962963	5.4	4.62962963	4.7	5
Operating Surface Temperature Range (FIXED)	°C range	Max	35	70	**5**	70	5	70	5	70	5	70	5	70	5
Firmware Upgradability	score	Max	0.8	1	**3**	0.9	2.7	0.9	2.7	1	3	1	3	1	3
Privacy Protection (No Audio Storage)	score	Max	0.8	1	**3**	1	3	1	3	1	3	1	3	1	3
Mounting Vibration Resistance (EXPANDED)	Hz	Max	50	80	**6**	80	6	80	6	70	5.25	70	5.25	70	5.25
Road Shock / Drop Resistance	ft drop	Max	3	3	**4**	3	4	3	4	3	4	3	4	3	4
Maximum Vehicle Operating Speed (ADDED)	mph	Max	50	100	**3**	100	3	100	3	100	3	100	3	100	3
Device Lifetime (ADDED)	years	Max	2	8	**4**	5	2.5	5	2.5	6	3	6	3	6	3
Time to First Critical Failure	years	Max	1	3	**3**	3	3	3	3	2.5	2.5	2.5	2.5	2.5	2.5
Human-Interface Adjustability (brightness + sensitivity range)	score	Max	0.7	1	**4**	0.75	3	0.85	3.4	1	4	1	4	0.85	3.4
TOTAL WEIGHTED SCORE (CAPPED)							**88.23298449**		**88.65676743**		**90.32459997**		**91.58882893**		**93.09505495**

Metric	Units	Direction	Marginal	Ideal	Weight	Idea 1 Microphone (Sound Sensor) | Embedded Processor | LED Pictograms | Car Battery | Wired		Idea 13 Microphone (Sound Sensor) | Embedded Processor | LED + Steering Vibration | Car Battery | Wired		Idea 23 Microphone (Sound Sensor) | AI-Based | LED Pictograms | Portable Battery | Wired		Idea 25 Microphone (Sound Sensor) | AI-Based | Steering Wheel Vibration | Car Battery | Wired		Idea 47 Vibration Sensor | Embedded Processor | Steering Wheel Vibration | Portable Battery | Wired	
						Actual	Weighted (capped)	Actual	Weighted (capped)	Actual	Weighted (capped)	Actual	Weighted (capped)	Actual	Weighted (capped)
Emergency Sound Detection Accuracy	%	Max	80	95	**10**	92	9.684210526	92	9.684210526	95	10	95	10	65	6.842105263
Detection-to-Alert Latency	ms	Min	1000	500	**10**	450	10	450	10	250	10	250	10	450	10
Maximum Ambient Noise Tolerated	dB	Max	70	85	**7**	88	7	88	7	90	7	90	7	70	5.764705882
User Alert Recognition Time (UPDATED)	s	Min	1.5	1	**10**	0.6	10	0.3	10	0.6	10	0.9	10	0.9	10
Device Cost	USD	Min	120	50	**9**	68	6.617647059	78	5.769230769	104	4.326923077	95	4.736842105	83	5.421686747
Time Between Maintenance	months	Max	6	12	**5**	24	5	24	5	24	5	24	5	18	5
Installation Time	hr	Min	1	0.25	**5**	0.25	5	0.333	3.753753754	0.333	3.753753754	0.417	2.997601918	0.5	2.5
Device Frontal Area (ADJUSTED UP)	cm^2	Min	80	60	**4**	20	4	25	4	20	4	5	4	5	4
Power Consumption (Active)	W	Min	10	5	**5**	2.7	5	3.4	5	4.7	5	5.2	4.807692308	3.15	5
Operating Surface Temperature Range (FIXED)	°C range	Max	35	70	**5**	70	5	70	5	70	5	70	5	70	5
Firmware Upgradability	score	Max	0.8	1	**3**	0.9	2.7	0.9	2.7	1	3	1	3	0.9	2.7
Privacy Protection (No Audio Storage)	score	Max	0.8	1	**3**	1	3	1	3	1	3	1	3	1	3
Mounting Vibration Resistance (EXPANDED)	Hz	Max	50	80	**6**	70	5.25	70	5.25	70	5.25	70	5.25	80	6
Road Shock / Drop Resistance	ft drop	Max	3	3	**4**	3	4	3	4	3	4	3	4	3	4
Maximum Vehicle Operating Speed (ADDED)	mph	Max	50	100	**3**	100	3	100	3	100	3	100	3	100	3
Device Lifetime (ADDED)	years	Max	2	8	**4**	6	3	6	3	6	3	6	3	5	2.5
Time to First Critical Failure	years	Max	1	3	**3**	3	3	3	3	2.5	2.5	2.5	2.5	3	3
Human-Interface Adjustability (brightness + sensitivity range)	score	Max	0.7	1	**4**	0.85	3.4	1	4	0.85	3.4	0.75	3	0.75	3
TOTAL WEIGHTED SCORE (CAPPED)							**94.65185759**		**93.15719505**		**91.23067683**		**90.29213633**		**86.72849789**

Thermal Analysis Additional Information

The thermal performance of the enclosure was evaluated using ANSYS Steady-State Thermal Analysis. The objective was to estimate the maximum temperature reached by the electronic components when exposed to worst-case environmental conditions representative of a vehicle parked under direct sunlight.

To simplify the analysis, the enclosure was modeled using a prototype housing developed during the transition between the Arduino-based and ESP32-based design stages. The prototype enclosure maintained similar overall dimensions, wall thickness, and ventilation characteristics as the final design, making it suitable for estimating thermal behavior while reducing modeling complexity.

The enclosure material was modeled as Acrylonitrile Styrene Acrylate (ASA), selected for its superior thermal resistance and UV durability compared to standard PLA. The following material properties were used:

• Thermal Conductivity: 0.17 W/m·K
• Density: 1070 kg/m^3
• Specific Heat Capacity: 1300 J/kg·K

The ESP32 microcontroller was represented as a simplified solid body with an equivalent thermal conductivity of 0.3 W/m·K. Internal heat generation was applied to the ESP32 volume to represent power dissipation during operation. A total heat generation rate of approximately 1 W was assumed based on typical ESP32 operating conditions.

A worst-case ambient temperature of 70°C was applied to represent the interior of a vehicle exposed to direct sunlight for extended periods. Natural convection boundary conditions were applied to the external enclosure surfaces using a heat transfer coefficient of 5 W/m^2·K. Internal enclosure surfaces were assigned a convection coefficient of 3 W/m^2·K to approximate limited passive airflow through enclosure openings and cable passages.

The analysis assumed steady-state conditions, meaning temperatures were allowed to stabilize over time and transient heating effects were not considered. Radiation heat transfer was neglected to simplify the model and produce a conservative estimate of internal component temperatures.

Results indicated a maximum ESP32 temperature of approximately 88°C under the specified conditions. The analysis identified prolonged dashboard exposure as a potential thermal risk and justified the incorporation of additional ventilation features and operational recommendations for shaded storage when the device is not in use.

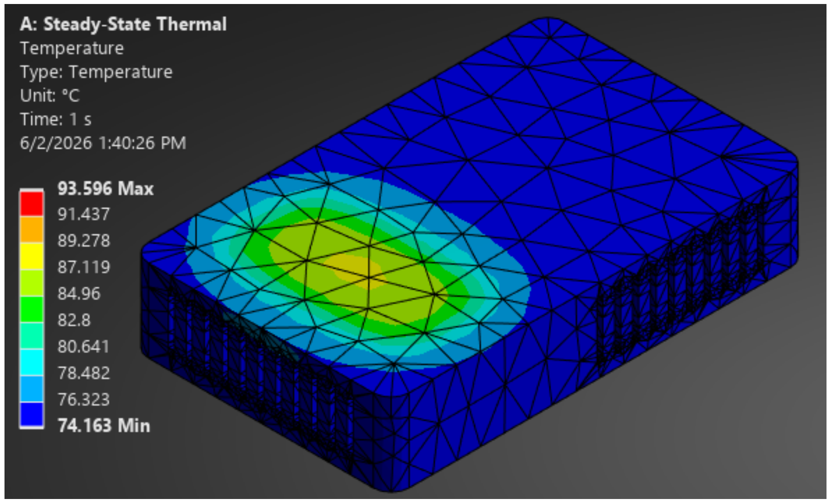


Figure 25: Case Temperature Contour showing ESP hot region

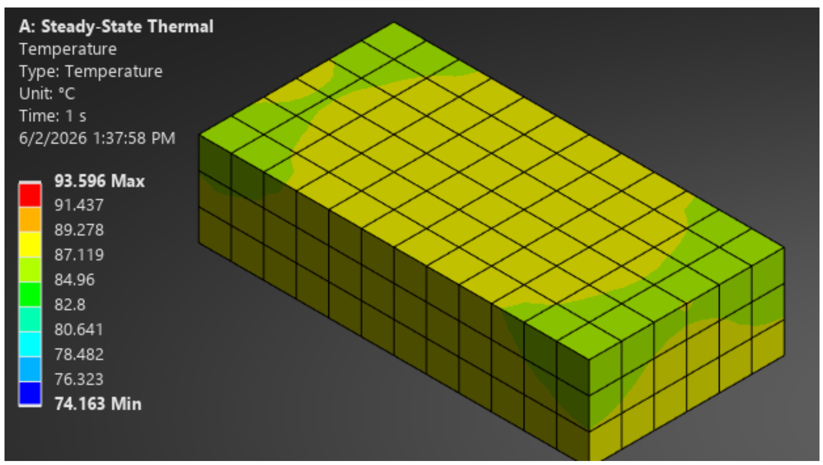


Figure 26: ESP Temperature Contour

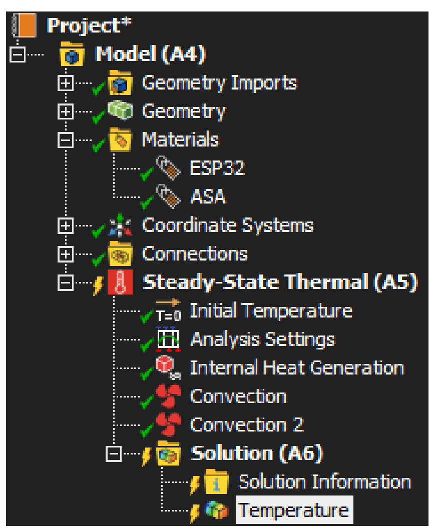


Figure 27: Project Model Tree

Details of "Initial Temperature"	
Definition	
Initial Temperature	Uniform Temperature
Initial Temperature Value	22. °C

Figure 28: Initial Temperature settings

Details of "Internal Heat Generation"	
Scope	
Scoping Method	Geometry Selection
Geometry	1 Body
Definition	
Type	Internal Heat Generation
Magnitude	1.3133e-005 W/mm³ (ramped)
Suppressed	No

Figure 29: Internal ESP Heat generation settings

Details of "Convection"	
Scope	
Scoping Method	Geometry Selection
Geometry	10 Faces
Definition	
Type	Convection
Film Coefficient	5.e-006 W/mm²·°C (step a...
Ambient Temperature	70. °C (ramped)
Convection Matrix	Program Controlled
Element APDL Name	
Suppressed	No

Figure 30: External Convection settings

Details of "Convection 2"	
Scope	
Scoping Method	Geometry Selection
Geometry	6 Faces
Definition	
Type	Convection
Film Coefficient	3.e-006 W/mm²·°C (step a...
Ambient Temperature	70. °C (ramped)
Convection Matrix	Program Controlled
Element APDL Name	
Suppressed	No

Figure 31: Internal Convection Settings

Software:

```
#include <SirenDetection_inferencing.h>
#include <driver/i2s.h>

//Microphone pins
#define I2S_WS  15
#define I2S_SCK 14
#define I2S_SD  32

// LED pins
#define LED_POWER      33
#define LED_AMBULANCE  25
#define LED_POLICE     26
#define LED_FIRETRUCK  27
#define LED_CARHORN    13
#define LED_EMERGENCY  12

// Potentiometer pin

#define POT_PIN        34

// Detection thresholds
#define SILENCE_THRESHOLD    3
#define SWITCH_THRESHOLD     1
#define CONFIDENCE_THRESHOLD 0.90
#define BLINK_INTERVAL       500

//  Audio
#define SAMPLE_RATE 16000
static float sampleBuffer[EI_CLASSIFIER_DSP_INPUT_FRAME_SIZE];

// Runtime state
int    MODE           = 2;
String lastDetected   = "";
String newCandidate   = "";
int    silenceCount   = 0;
int    candidateCount = 0;

unsigned long lastBlinkTime = 0;
bool          blinkState    = false;
int           activeLedPin  = -1;


void resolveMode() {
  // Average a few readings to debounce noise on the ADC line
  long sum = 0;
  for (int i = 0; i < 8; i++) {
```

```
    sum += analogRead(POT_PIN);
    delay(5);
  }
  int potVal = sum / 8;

  MODE = (potVal < 2048) ? 1 : 2;

  Serial.print("Potentiometer value: ");
  Serial.println(potVal);
  Serial.print("Mode selected: ");
  Serial.println(MODE);
}


// MIC setup

void setupI2S() {
  i2s_config_t i2s_config = {
    .mode                 = (i2s_mode_t)(I2S_MODE_MASTER | I2S_MODE_RX),
    .sample_rate          = SAMPLE_RATE,
    .bits_per_sample      = I2S_BITS_PER_SAMPLE_32BIT,
    .channel_format       = I2S_CHANNEL_FMT_ONLY_LEFT,
    .communication_format = I2S_COMM_FORMAT_I2S,
    .intr_alloc_flags     = ESP_INTR_FLAG_LEVEL1,
    .dma_buf_count        = 4,
    .dma_buf_len          = 1024,
    .use_apll             = false
  };
  i2s_pin_config_t pin_config = {
    .bck_io_num   = I2S_SCK,
    .ws_io_num    = I2S_WS,
    .data_out_num = I2S_PIN_NO_CHANGE,
    .data_in_num  = I2S_SD
  };
  i2s_driver_install(I2S_NUM_0, &i2s_config, 0, NULL);
  i2s_set_pin(I2S_NUM_0, &pin_config);
}


// LED

void allLedsOff() {
  digitalWrite(LED_AMBULANCE,  LOW);
  digitalWrite(LED_POLICE,     LOW);
  digitalWrite(LED_FIRETRUCK,  LOW);
  digitalWrite(LED_CARHORN,    LOW);
  digitalWrite(LED_EMERGENCY,  LOW);
  activeLedPin = -1;
```

```
}

void setActiveLed(String label) {
  allLedsOff();
  if (label == "") return;

  if (MODE == 1) {
    // Each siren type → dedicated LED
    if      (label == "Ambulance")  activeLedPin = LED_AMBULANCE;
    else if (label == "Police")     activeLedPin = LED_POLICE;
    else if (label == "Fire Truck") activeLedPin = LED_FIRETRUCK;
    else if (label == "Car Horn")   activeLedPin = LED_CARHORN;
  } else {
    // Mode 2: simplified — car horn or generic emergency
    if (label == "Car Horn") activeLedPin = LED_CARHORN;
    else                     activeLedPin = LED_EMERGENCY;
  }
}

void updateBlink() {
  if (activeLedPin == -1) return;
  unsigned long now = millis();
  if (now - lastBlinkTime >= BLINK_INTERVAL) {
    lastBlinkTime = now;
    blinkState = !blinkState;
    digitalWrite(activeLedPin, blinkState ? HIGH : LOW);
  }
}


// Audio capture

void captureAudio() {
  int32_t rawBuffer[512];
  size_t  bytesRead;
  int     samplesRead  = 0;
  int     totalSamples = EI_CLASSIFIER_DSP_INPUT_FRAME_SIZE;

  while (samplesRead < totalSamples) {
    i2s_read(I2S_NUM_0, rawBuffer, sizeof(rawBuffer), &bytesRead, portMAX_DELAY);
    int samples = bytesRead / sizeof(int32_t);
    for (int i = 0; i < samples && samplesRead < totalSamples; i++) {
      sampleBuffer[samplesRead++] = (float)(rawBuffer[i] >> 8) / 8388608.0f;
    }
  }
}
```

```
// Detection

void handleDetection(String confirmed) {
 if (confirmed != "Noise" && confirmed != "unknown") {
  silenceCount = 0;

  if (lastDetected == "") {
   // Fresh detection
   Serial.println("\n>>> " + confirmed + " detected <<< [Mode " + String(MODE) + "]\n");
   lastDetected   = confirmed;
   newCandidate   = "";
   candidateCount = 0;
   setActiveLed(lastDetected);

  } else if (confirmed == lastDetected) {
   // Same label — reset candidate tracker
   newCandidate   = "";
   candidateCount = 0;

  } else {
   // Different label — need SWITCH_THRESHOLD confirmations to switch
   if (confirmed == newCandidate) {
    candidateCount++;
    if (candidateCount >= SWITCH_THRESHOLD) {
     Serial.println("\n>>> " + confirmed + " detected <<< [Mode " + String(MODE) + "]\n");
     lastDetected   = confirmed;
     newCandidate   = "";
     candidateCount = 0;
     setActiveLed(lastDetected);
    }
   } else {
    newCandidate   = confirmed;
    candidateCount = 1;
   }
  }

 } else {
  // Noise / unknown frame
  silenceCount++;
  newCandidate   = "";
  candidateCount = 0;

  if (silenceCount >= SILENCE_THRESHOLD && lastDetected != "") {
   Serial.println("  (stopped)");
   lastDetected = "";
   silenceCount = 0;
   allLedsOff();
  }
```

```
  }
}


// Setup

void setup() {
  Serial.begin(115200);
  delay(2000);

  // Resolve mode from potentiometer BEFORE anything else
  resolveMode();

  // LED pins
  pinMode(LED_POWER,     OUTPUT);
  pinMode(LED_AMBULANCE, OUTPUT);
  pinMode(LED_POLICE,    OUTPUT);
  pinMode(LED_FIRETRUCK, OUTPUT);
  pinMode(LED_CARHORN,   OUTPUT);
  pinMode(LED_EMERGENCY, OUTPUT);
  allLedsOff();
  digitalWrite(LED_POWER, HIGH);

  // I2S microphone
  setupI2S();

  Serial.println("Ready — listening for sirens [Mode " + String(MODE) + "]...");
}


// Main loop

void loop() {
  updateBlink();

  captureAudio();

  // Build signal from buffer
  signal_t signal;
  int err = numpy::signal_from_buffer(sampleBuffer, EI_CLASSIFIER_DSP_INPUT_FRAME_SIZE, &signal);
  if (err != 0) return;

  // Run classifier
  ei_impulse_result_t result = {0};
  EI_IMPULSE_ERROR res = run_classifier(&signal, &result, false);
  if (res != EI_IMPULSE_OK) return;

  // Find top label
```

```
  float  maxScore  = 0;
  String topLabel  = "unknown";

  for (int i = 0; i < EI_CLASSIFIER_LABEL_COUNT; i++) {
    if (result.classification[i].value > maxScore) {
      maxScore = result.classification[i].value;
      topLabel = result.classification[i].label;
    }
  }

  if (maxScore < CONFIDENCE_THRESHOLD) topLabel = "unknown";

  handleDetection(topLabel);
}
```

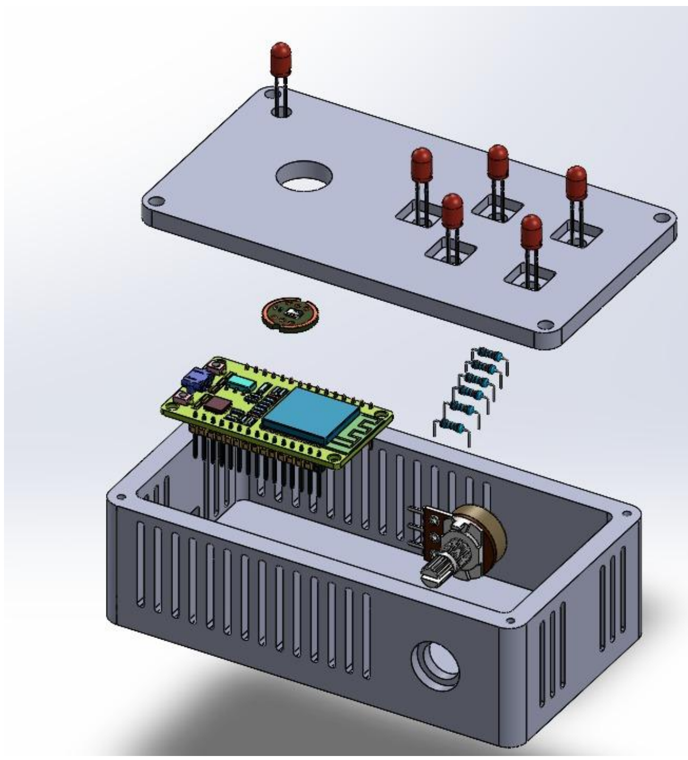
University of Puerto Rico

Mayagüez Campus

Department of Mechanical Engineering

Manufacturing Manual

Emergency Alert Recognition System (EARS)



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INME4236-077L

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4/23/2026

Table of Contents

Overview:

This document describes the manufacturing process for The Emergency Recognition and Alert System (ERAS), a System that is meant to help deaf or hard of hearing drivers detect emergency sirens visually without relying on auditory senses. The system works by combining three main parts; (1) a sound sensor, (2) An embedded processor, meant to accurately detect emergency sirens, and (3) a visual alert. It outlines the materials, tools, and step-by-step procedures required to assemble the system. This manual is intended for students or technicians replicating the prototype.

Bill Of Materials (BOM):

Inserted below is a table that compiles all the necessary Components and Cost to create one unit of the product.

Table 1. Bill Of Materials

Part	Component	Component description	Quantity	Unit Cost (USD)	Total Cost (USD)	Supplier link
1	ESP32 Dev Board	ESP32-WROOM-32 WiFi + Bluetooth Development Board, 30-pin microcontroller module	1	$15.00	$15.00	Amazon / Espressif
2	INMP441	INMP441 I2S Omnidirectional MEMS microphone module for digital audio input	1	$3.00	$3.00	Amazon / Adafruit
3	5 mm LEDs	5 mm Red LED indicators, standard through-hole type	6	$0.10	$0.60	Amazon
4	220Ω Resistors	220 Ohm ±5% carbon film resistors, 1/4 W through-hole type	6	$0.02	$0.12	Amazon
5	Jumper Wires	Male-to-male Dupont jumper cables set for prototyping connections	One set	$5.00	$5.00	Amazon
6	Potentiometer	10 kΩ rotary potentiometer for adjustable sensitivity control	1	$1.00	$1.00	Amazon
7	On/Off Switch	SPST miniature rocker switch for device power control	1	$1.50	$1.50	Amazon

8	USB Cable	USB Type-C cable for ESP32 power and programming	1	$3.00	$3.00	Amazon
9	3D Printer Filament	PLA filament, 1.75 mm diameter, gray color, used for enclosure fabrication	~0.15 kg	$4.00	$4.00	Amazon / Hatchbox
10	Nylon Screws	For mounting and closing case	1	$9.99 (large quantity)	$9.99	Amazon
11	Double sided Adhesive	For more secure mounting	1	$3.99($0.40 per feet)	$3.99	Amazon
—	**Total**	—	—	—	$47.20	—

Inserted below are visual representations of parts:

Figure 1. *Part 5:* Jumper Wires

Figure 2. Part 7: On/Off switch

Figure 3. Part 8: UBS Cale

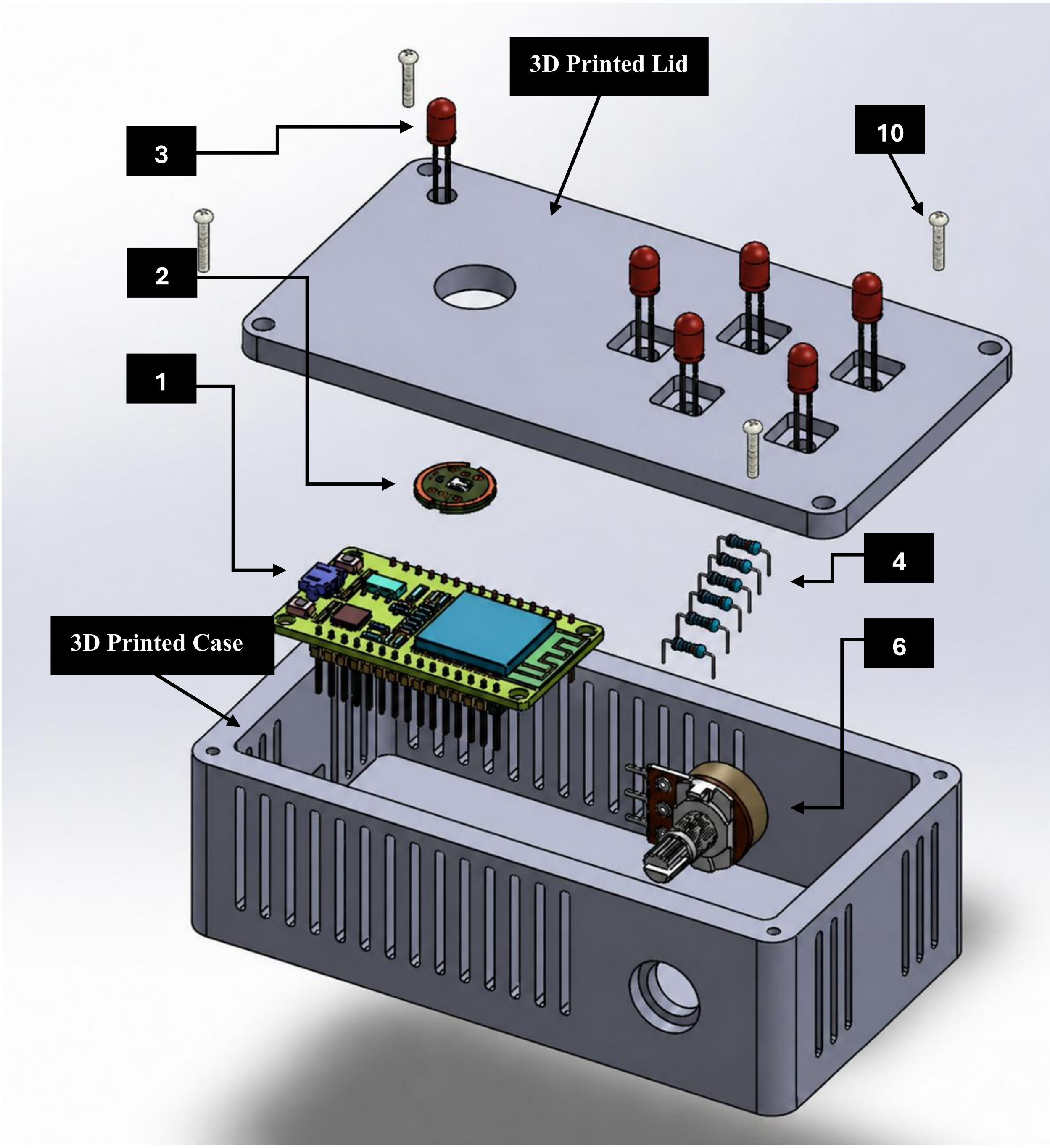


Figure 4. Parts 1, 2, 3, 4, and 6.

Tools And Equipment:

Table 2. Tools and equipment

Tool	Specification	Purpose
Soldering Iron	30–60 W temperature-controlled soldering iron with fine tip	Soldering electronic components
Solder Wire	60/40 rosin-core solder, 0.8 mm diameter	Electrical connections
Precision Screwdriver	Phillips #0 precision screwdriver	Assembly of enclosure screws
3D Printer	FDM 3D printer with PLA filament compatibility	Printing enclosure
Wire Cutter	Precision flush cutter	Trimming jumper wires and LED leads
Needle-Nose Pliers	Fine-tip pliers	Managing small components
Multimeter	Digital multimeter	Voltage and continuity testing
Computer with CAD software	Desktop or laptop computer capable of running SOLIDWORKS for 3D modeling and STL generation	Used for enclosure design, dimensional modeling, assembly visualization, and preparation of files for 3D printing

Manufacturing Process:

a. **5.1 Enclosure fabrication (3D printing):**
    i. Procedure:
        1. Open the provided CAD files in SolidWorks or export them as STL files. (STL files are posted in Google Drive. The STL file name is Case ESP.STL and Lid ESP.STL, Drive link: https://drive.google.com/drive/folders/1gf7Rs9Y4Bx1Tz5B0GRkFavQmsosql0H1?usp=sharing)
        2. Import STL files into Slicing Software.
        3. Configure printing settings:
            - Material: ASA
            - layer height: 0.2 mm.
            - Infill: 20 - 30%
        4. Generate G-code file.
        5. Print the enclosure and lid using a 3D printer.
        6. Allow parts to cool and remove any support material if used.

b. 5.3 Circuit assembly:

i. System is assembled on a breadboard for prototyping and testing.

ii. Procedure:

1. Connect the ESP32 power and ground, by connecting the 3V3 pin on the ESP32 to the 3.3 V power rail. Then connect one of the ESP32 GND pins to the ground rail (As shown in Figure 5)

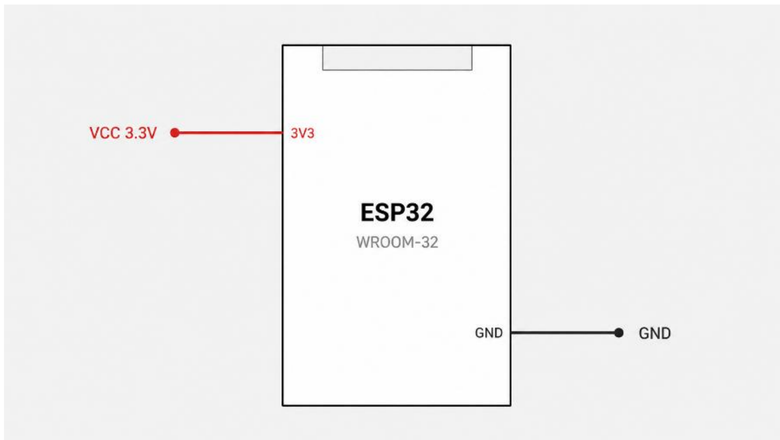


Figure 5. Circuit power and ground connection.

2. Connect the LEDs with their respective resistors. The LED connections are:
   GPIO2 → R1 220 Ω → D1 → GND
   GPIO4 → R2 220 Ω → D2 → GND
   GPIO5 → R3 220 Ω → D3 → GND
   GPIO18 → R4 220 Ω → D4 → GND
   GPIO19 → R5 220 Ω → D5 → GND
   GPIO21 → R6 220 Ω → D6 → GND
   (As shown in Figure 6)

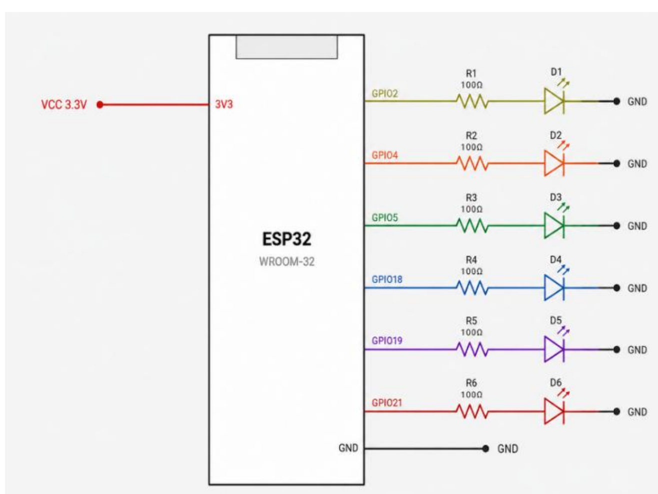


Figure 6. Circuit LED and Resistor connection.

3. Connect the INMP441 microphone to the ESP32. Connect the microphone **VDD** pin to **3.3 V** and the microphone **GND** pin and **L/R** pin to **GND**. Then connect the three I2S signal pins to the ESP32:
   WS → GPIO25
   SCK → GPIO26
   SD → GPIO34
   (As shown in Figure 7)

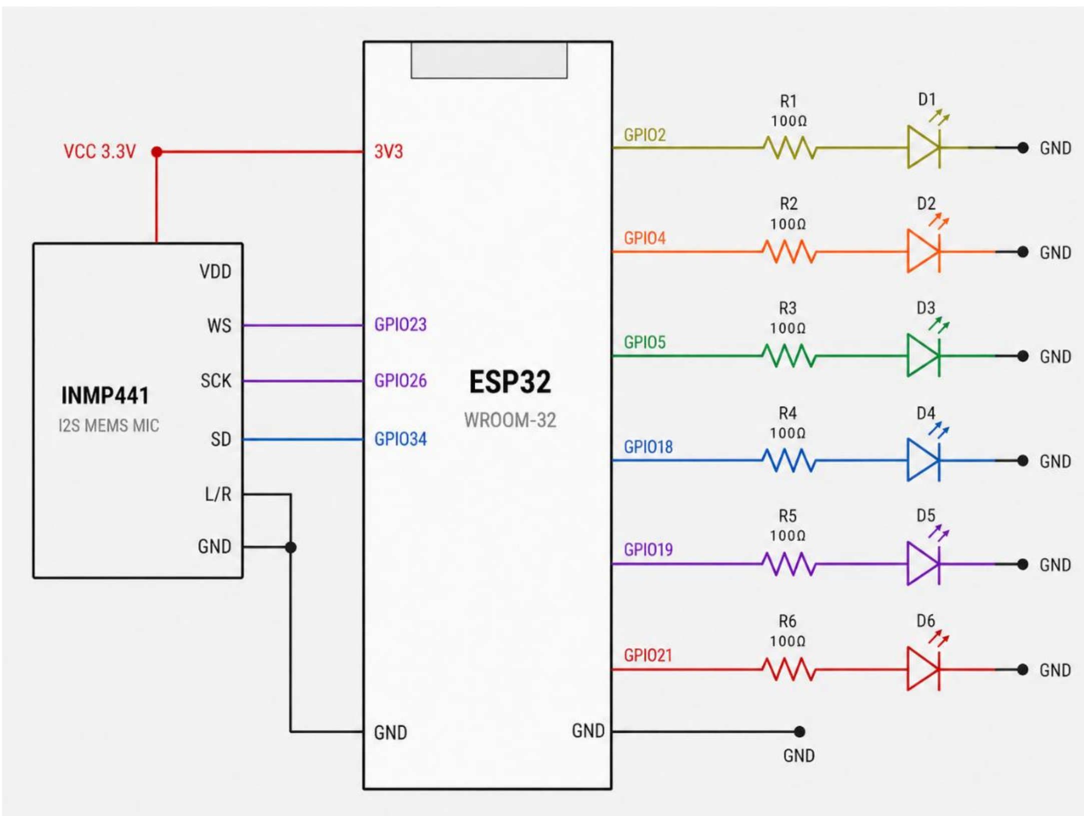


Figure 7. Circuit INMP441 Mic connection.

4. Connect the switch to the ESP32. Connect POS A and POS B of the switch to GPIO35 and GPIO35 respectively on the ESP32. Connect the switch COM terminal to one side of the 10 kΩ resistor R7, then connect the other side of R7 to GND. (As shown in Figure 8)

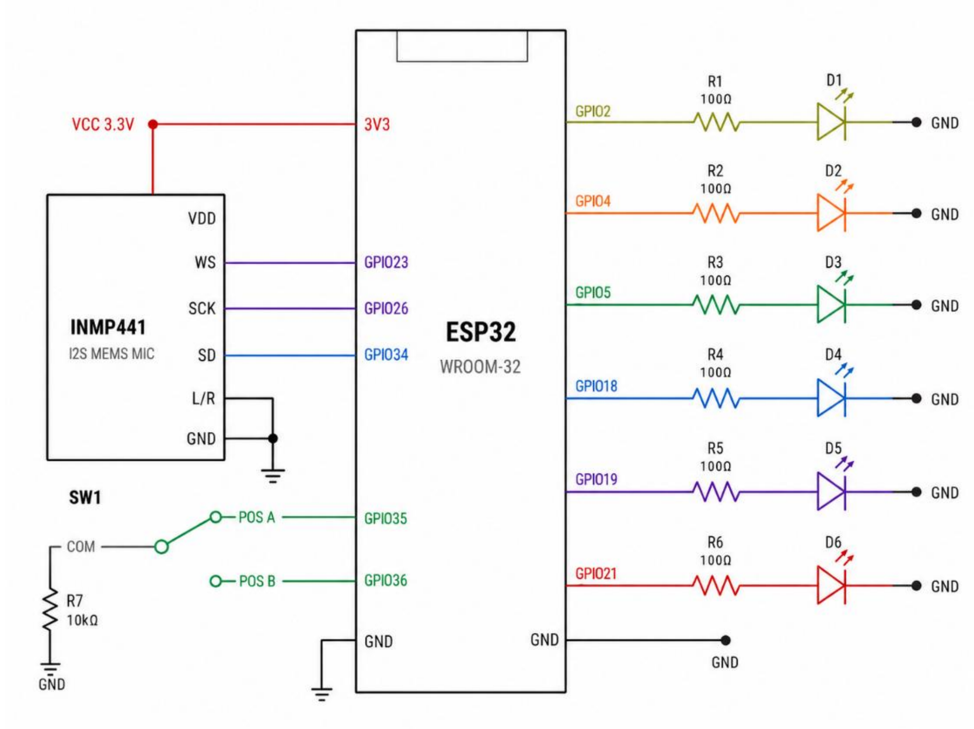


Figure 8. Circuit Switch on and off connection.

c. **5.5 Programming ESP32:**
   i. The ESP32 must be programmed with the siren detection algorithm.
   ii. Procedure:
      1. Connect ESP32 to a computer using USB cable. (As shown in figure 15)
      2. Open the programming environment (e.g., Arduino IDE)
      3. Load the siren detection code developed for the project.
      4. Select the correct board and port. (As shown in Figure 9)

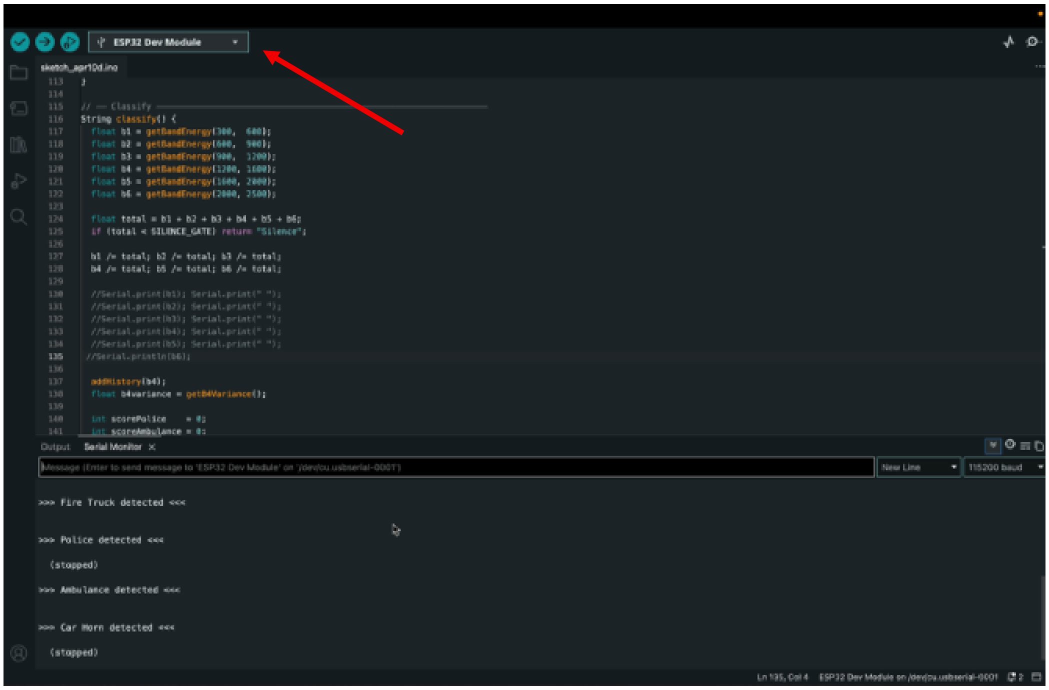


Figure 9. Check the correct board and port.

5. Upload the code to ESP32.

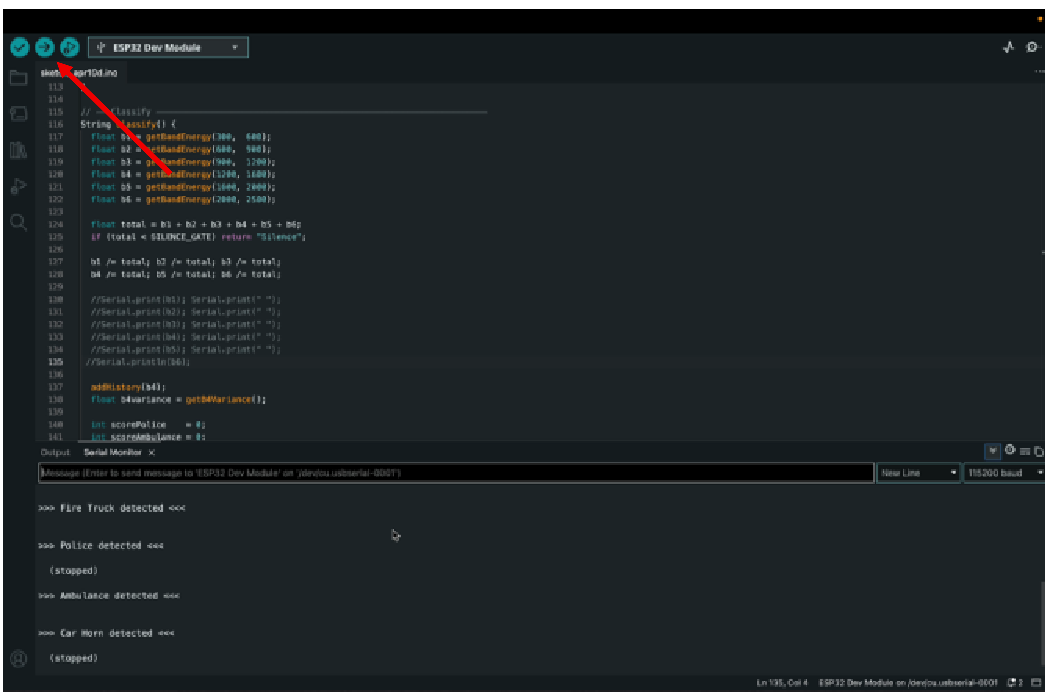


Figure 10. Check the correct board and port.

6. confirm successful upload via serial monitor or LED response.

d. 5.6 Final assembly into enclosure:

i. Once the circuit is verified, components are secured to the enclosure.

ii. Procedure:

1. Align four units of LED with the designated openings in the case.

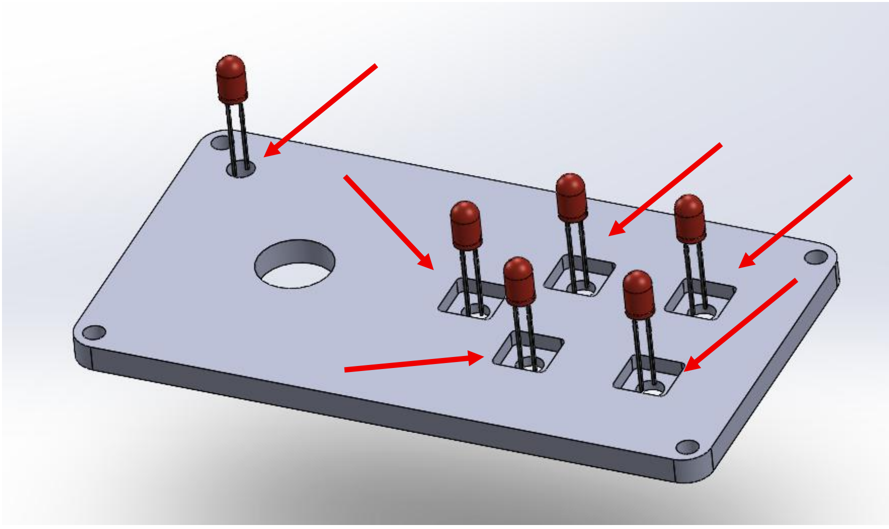


Figure 11. LED in their designated spots.

2. Secure components using screws.

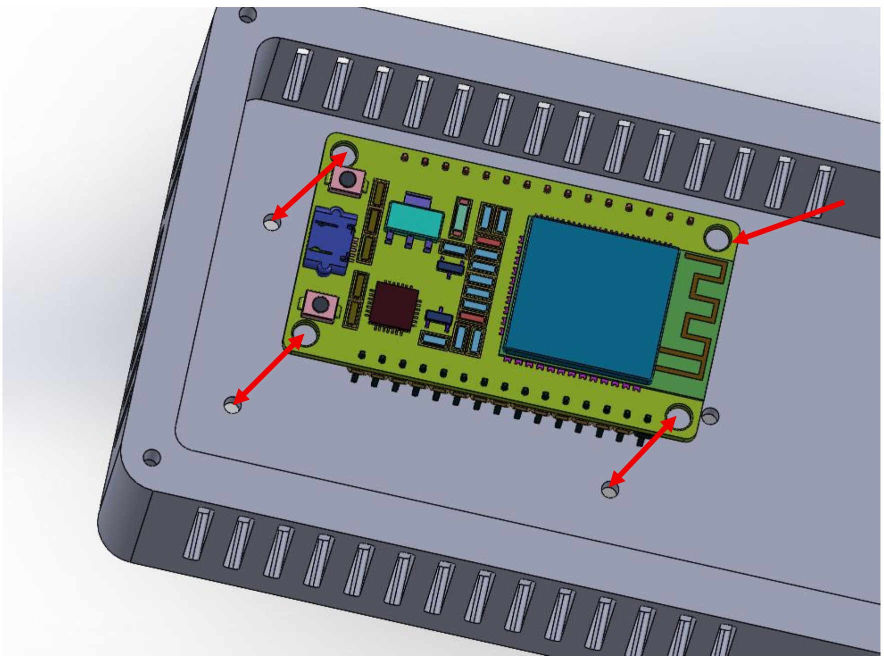


Figure 12. Secure components to case.

(for additional mounting safety a double-sided adhesive can be added under the ESP 32 Board)

3. Route USB cable and Potentiometer through the designated openings.

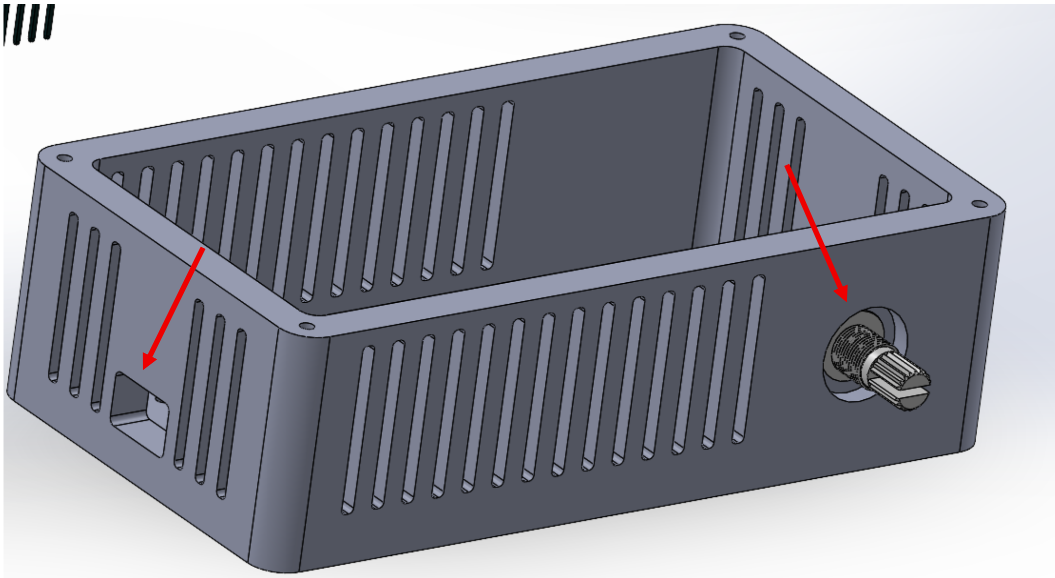


Figure 13. Potentiometer and USB designated spots.

4. Attach the enclosure lid and secure it.

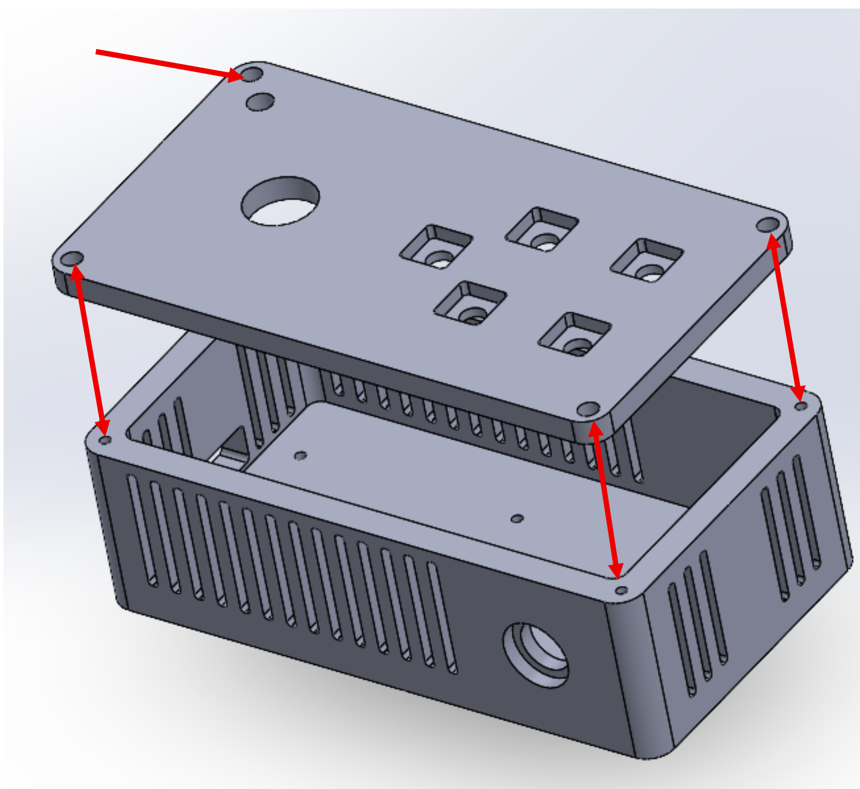


Figure 14. Case and Lid secured.

e. **5.7 System testing and verification:**

   i. After assembly, the system must be assessed to ensure proper operation.

   ii. Procedure:

      1. Power on the system.

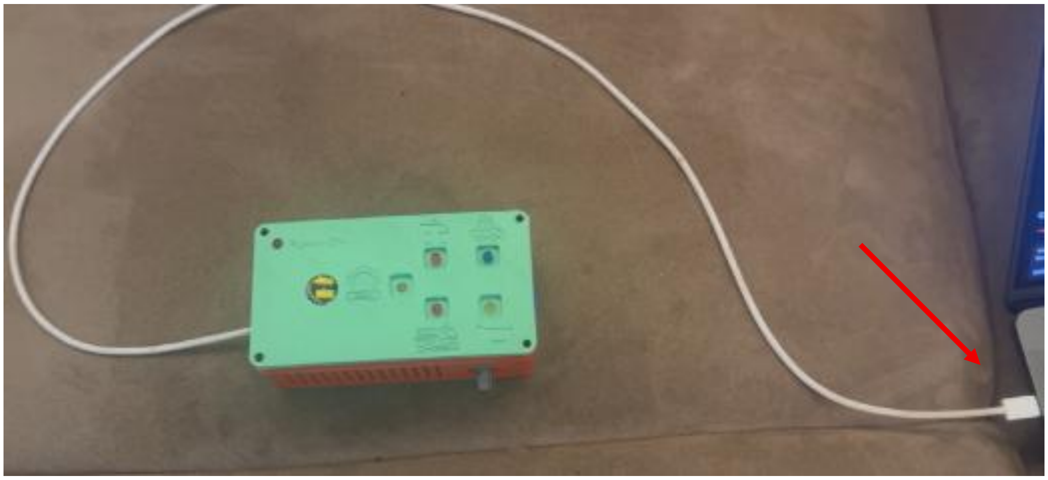


Figure 15. UBS connection to power on.

      2. Confirm the power indicator LED is active (As Shown in Figure 4).

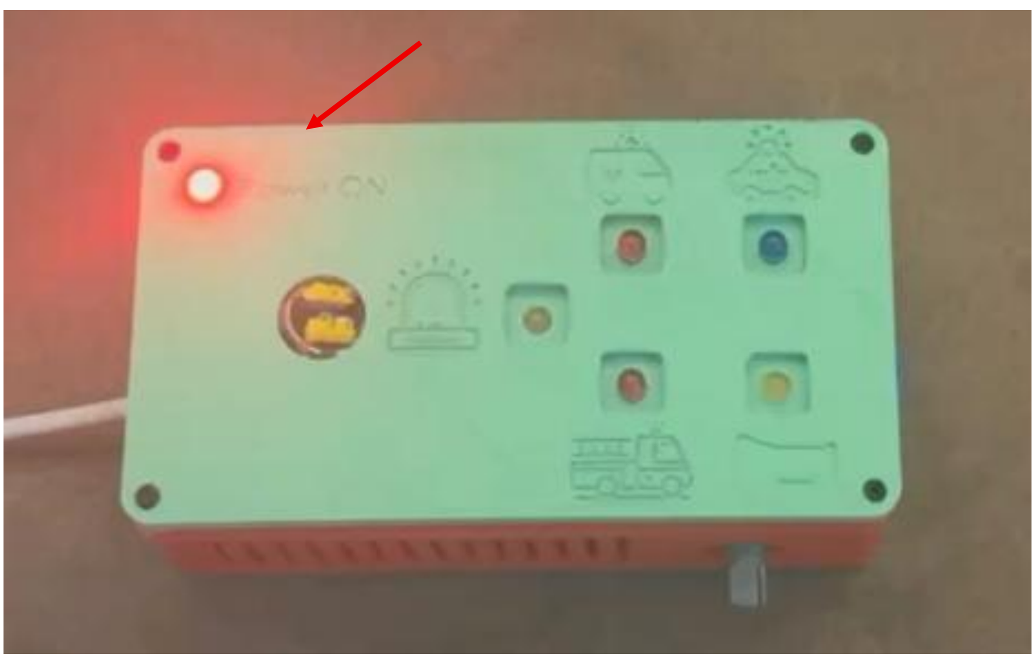


Figure 16. Power On LED.

3. Simulate emergency siren sounds.
4. Verify that the correct LED activates the detected siren type.

Figure 17. Police LED activated.

Figure 19. Firetruck LED activated.

Figure 20. Ambulance LED activated.

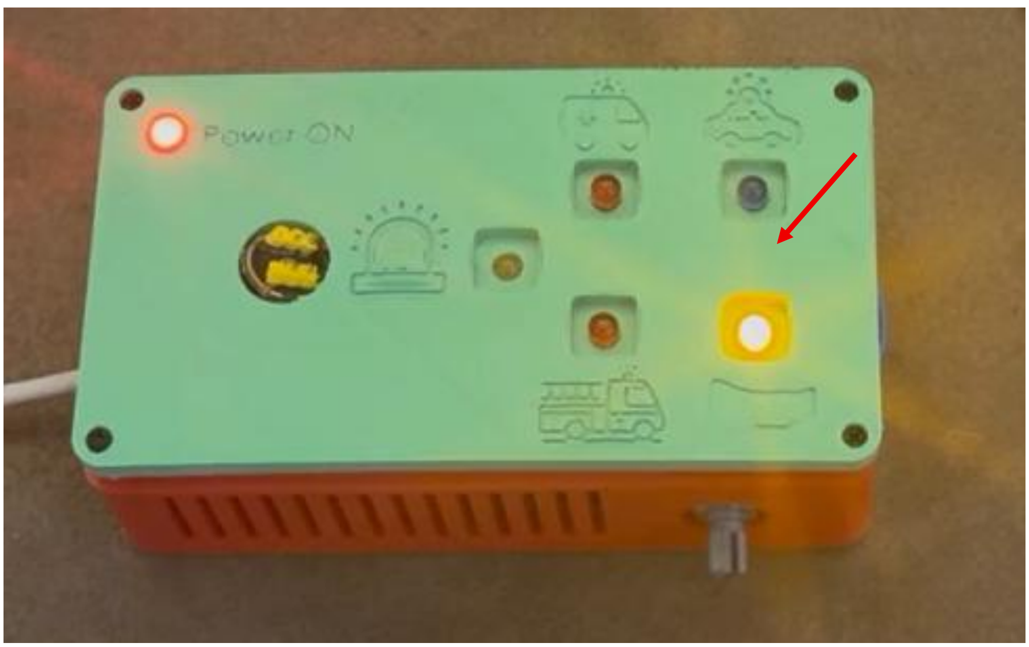


Figure 21. car horn LED activated.

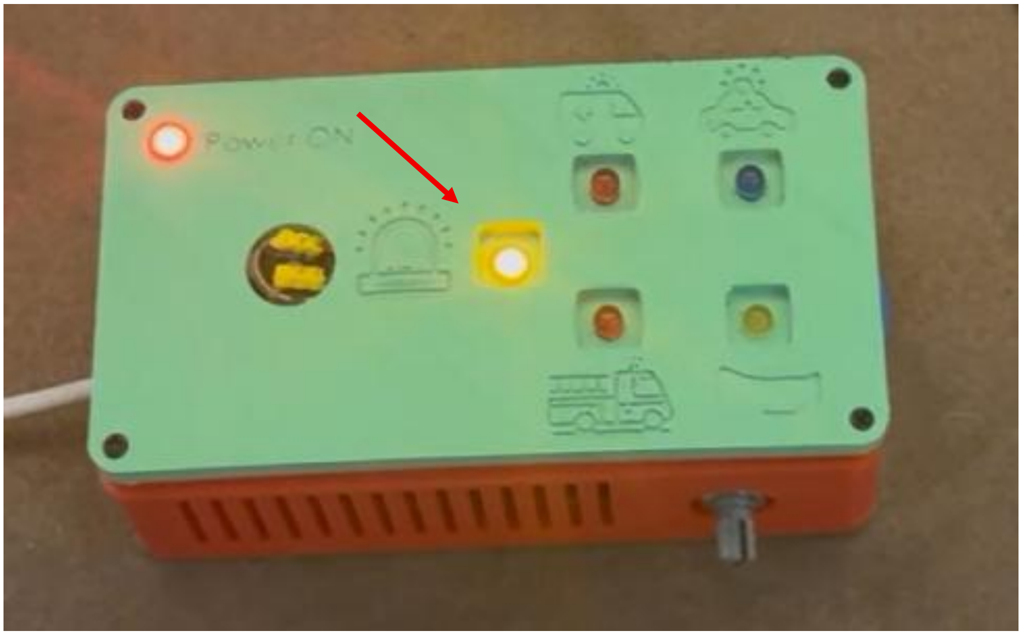


Figure 22. General alerts LED activated.

5. Check for consistent and accurate detection. (As shown in these demo videos: https://drive.google.com/drive/folders/1ojqiChXNrsIxEwL8xZR78jVgAruPesSh?usp=drive_link)

Quality Checks and Testing:

1. Power on the system and verify the power indicator LED is active (As Shown in Figure 4).
2. Verify the microphone sensor is capturing sound input correctly.
3. Simulate emergency siren sounds and confirm detection, by playback on recorded sirens of police cars, firetrucks, ambulances and finally multiple different car horns.
4. Verify that the correct LED activates for each detected siren type.
5. Ensure stable operation during continuous use.

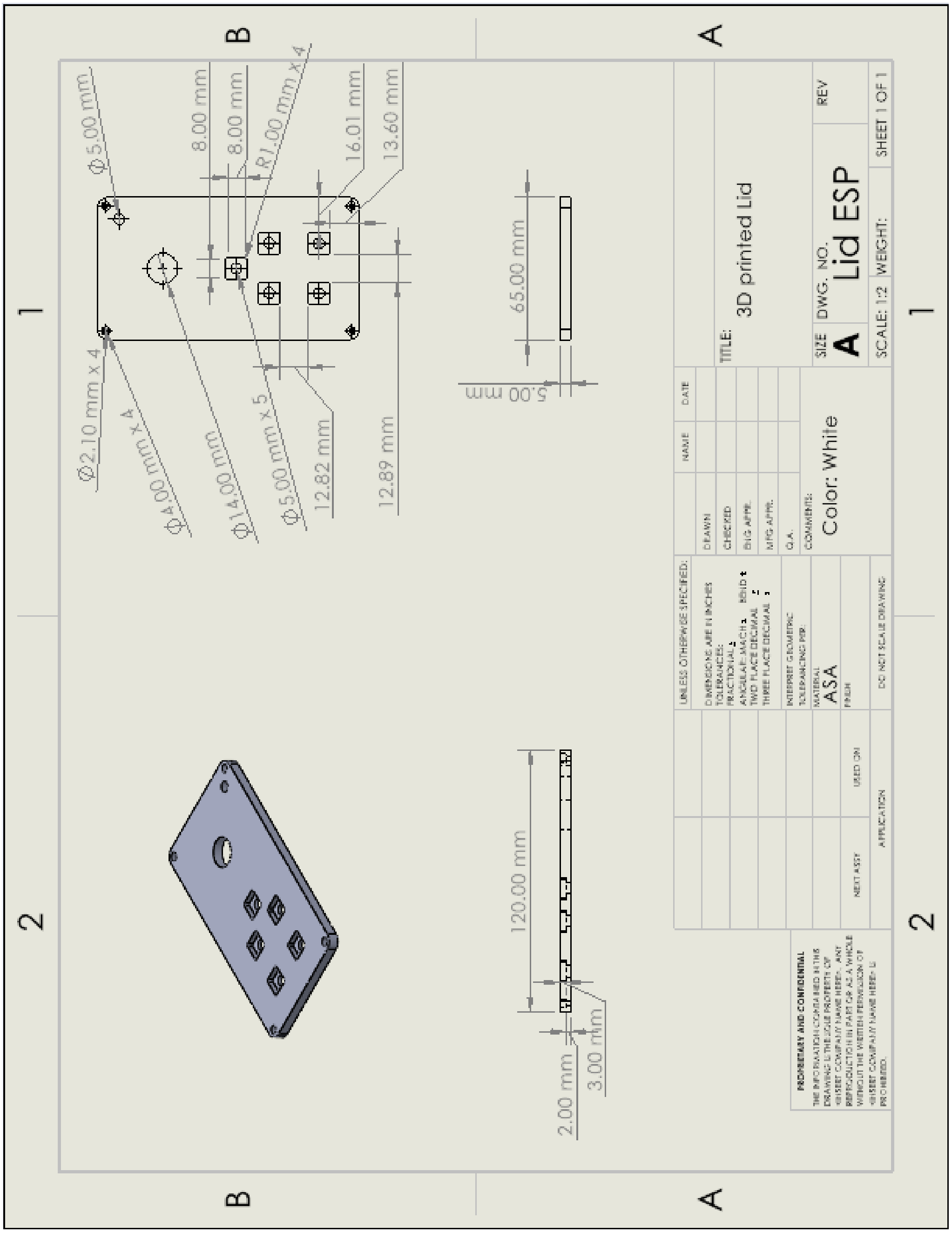
Safety Notes:

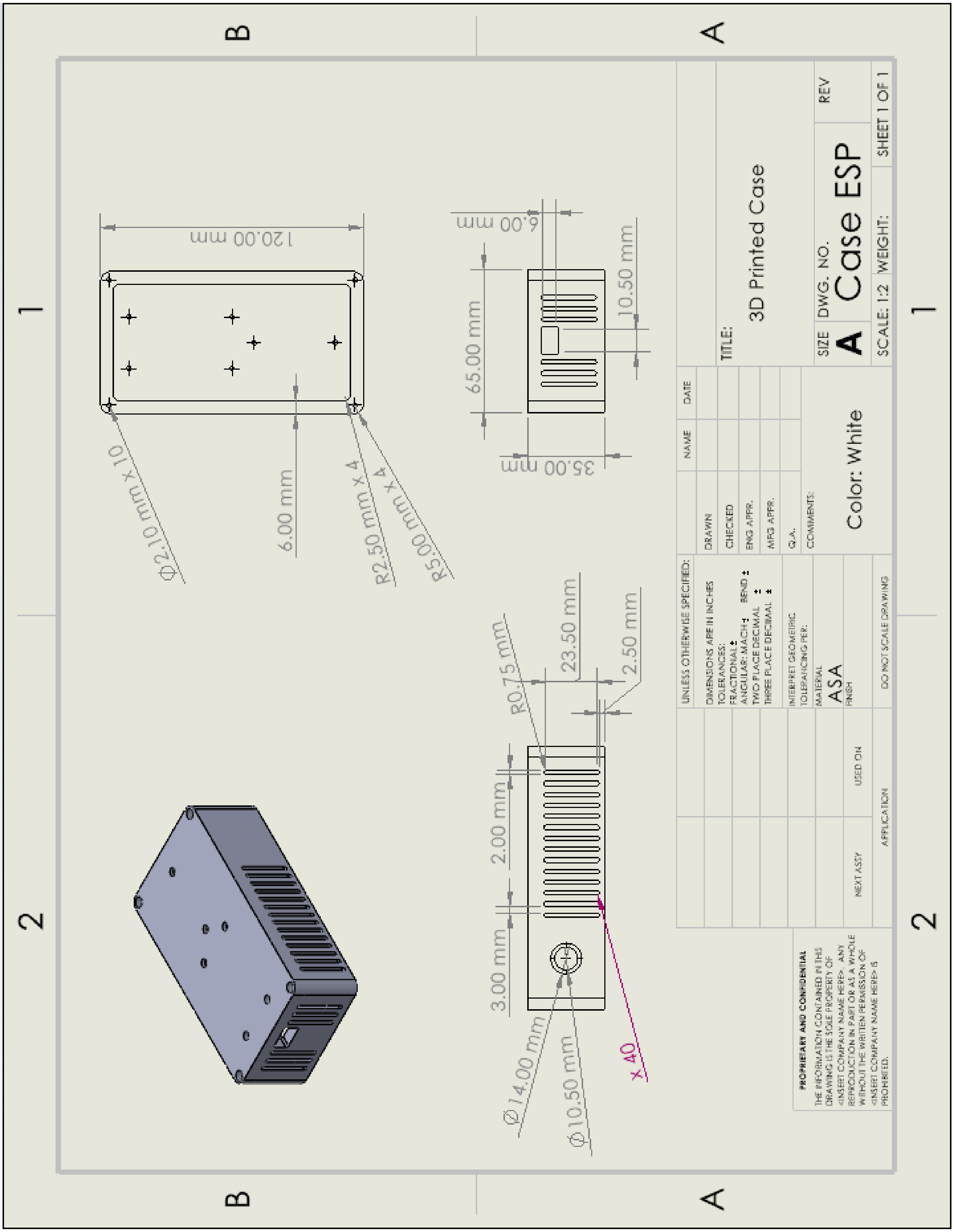
1. Avoid short circuits during assembly.
2. Do not touch hot soldering equipment.
3. Ensure correct voltage supply to all components.
4. Avoid exposing the system to moisture or excessive heat.

Appendix:

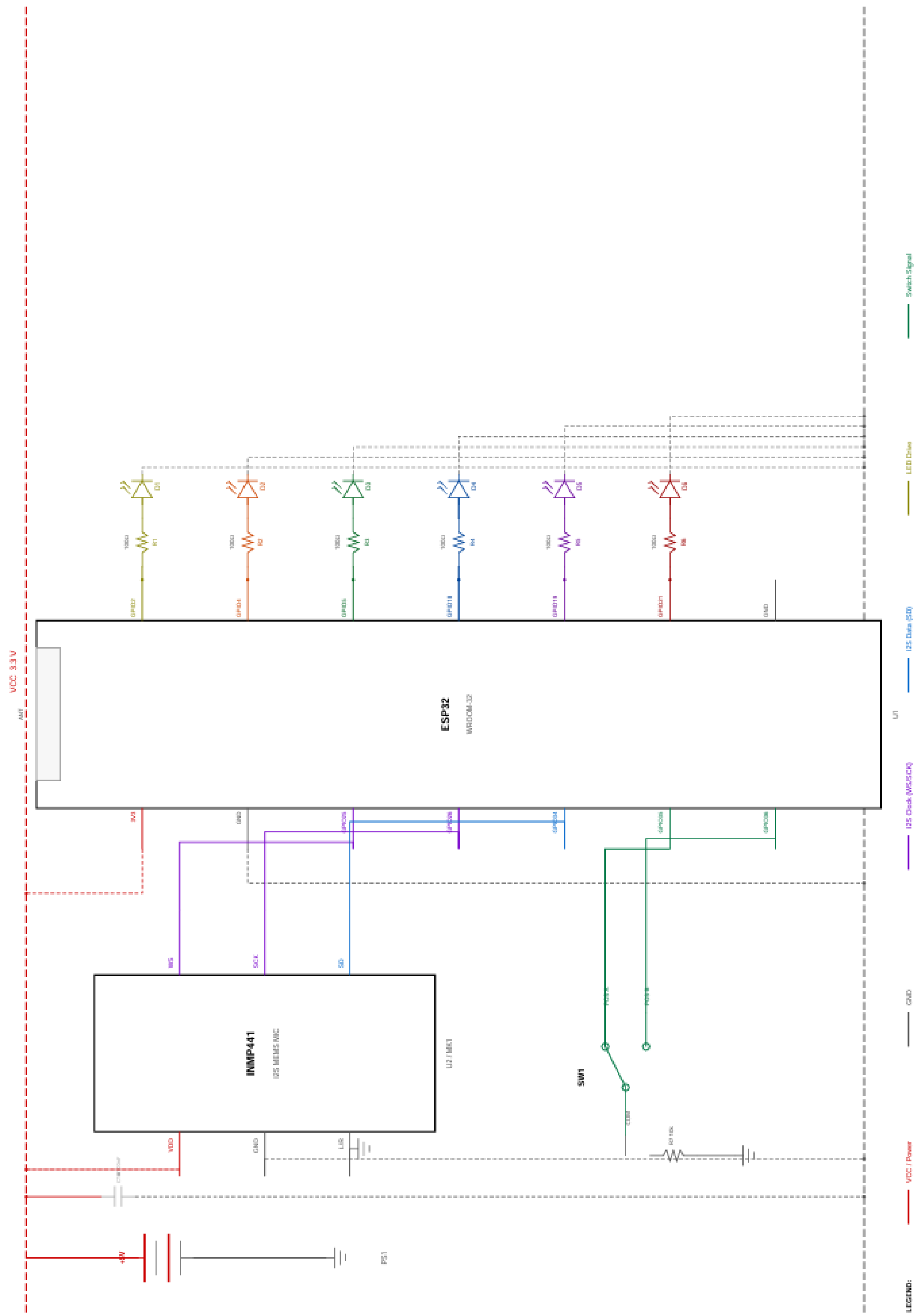
Engineering Drawings:

The enclosure was designed using SolidWorks. The files can be used for 3D printing.




120.00 mm
6.00 mm
Ø2.10 mm x 10
R2.50 mm x 4
R5.00 mm x 4
65.00 mm
35.00 mm
10.50 mm
3.00 mm
2.00 mm
R0.75 mm
23.50 mm
2.50 mm
Ø14.00 mm
Ø10.50 mm
x 40
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL ±
ANGULAR: MACH ± BEND ±
TWO PLACE DECIMAL ±
THREE PLACE DECIMAL ±
INTERPRET GEOMETRIC TOLERANCING PER:
MATERIAL
ASA
FINISH
DO NOT SCALE DRAWING
NEXT ASSY
USED ON
APPLICATION
NAME
DATE
DRAWN
CHECKED
ENG APPR.
MFG APPR.
Q.A.
COMMENTS:
Color: White
TITLE:
3D Printed Case
SIZE
A
DWG. NO.
Case ESP
REV
SCALE: 1:2
WEIGHT:
SHEET 1 OF 1
PROPRIETARY AND CONFIDENTIAL
THE INFORMATION CONTAINED IN THIS DRAWING IS THE SOLE PROPERTY OF <INSERT COMPANY NAME HERE>. ANY REPRODUCTION IN PART OR AS A WHOLE WITHOUT THE WRITTEN PERMISSION OF <INSERT COMPANY NAME HERE> IS PROHIBITED.

Engineering Circuit Drawing.



Component Links:

Part	Component	Links
1	ESP32 Dev Board	https://www.amazon.com/s?k=esp32&ref=nb_sb_noss
2	INMP441	https://www.amazon.com/s?k=INMP441+I2S+microphone
3	5 mm LEDs	https://www.amazon.com/s?k=5mm+red+LED
4	100Ω Resistors	https://www.amazon.com/s?k=100+ohm+resistor+1%2F4+watt
5	Jumper Wires	https://www.amazon.com/s?k=male+to+male+jumper+wires
6	Potentiometer	https://www.amazon.com/s?k=10k+rotary+potentiometer
7	On/Off Switch	https://www.amazon.com/s?k=SPST+mini+toggle+switch
8	USB Cable	https://www.amazon.com/s?k=USB-A+to+micro+USB+cable
9	Nylon Screws	https://www.amazon.com/dp/B0BYSHZ2TD?th=1
10	Mounting tape	https://www.amazon.com/Art3d-Double-Sided-Traceless-Removable-Reusable/dp/B09K58K13V?s=industrial

E.A.R.S.

Item #1

Model #1

USE AND CARE MANUAL

Questions, problems, not working properly?

Check here!

Read This Manual Before Operating the Emergency Recognition and Alert System

Please read this entire manual carefully before installing, operating, or maintaining the system. This manual contains important instructions, safety precautions, maintenance guidelines, and troubleshooting information needed to use the device properly.

Failure to follow the instructions in this manual may result in improper operation, reduced system performance, damage to the device, or unsafe use.

This manual should be kept in a safe and accessible location for future reference. All users should review the operating instructions before using the system for the first time.

Important

Before using the device:

- Check that the system is securely mounted. **Page 15**
- Verify that the LEDs and visual indicators are working correctly. **Page 9**
- Do not use the device if it appears damaged.
- Do not expose the device to water, or harsh chemicals.
- Follow the cleaning and maintenance instructions provided in this manual. **Page 18**
- **The device should be stored while not in use, away from sunlight and in a cool location. The system is sensitive to direct sunlight.**

TABLE OF CONTENTS

1. General View of Device

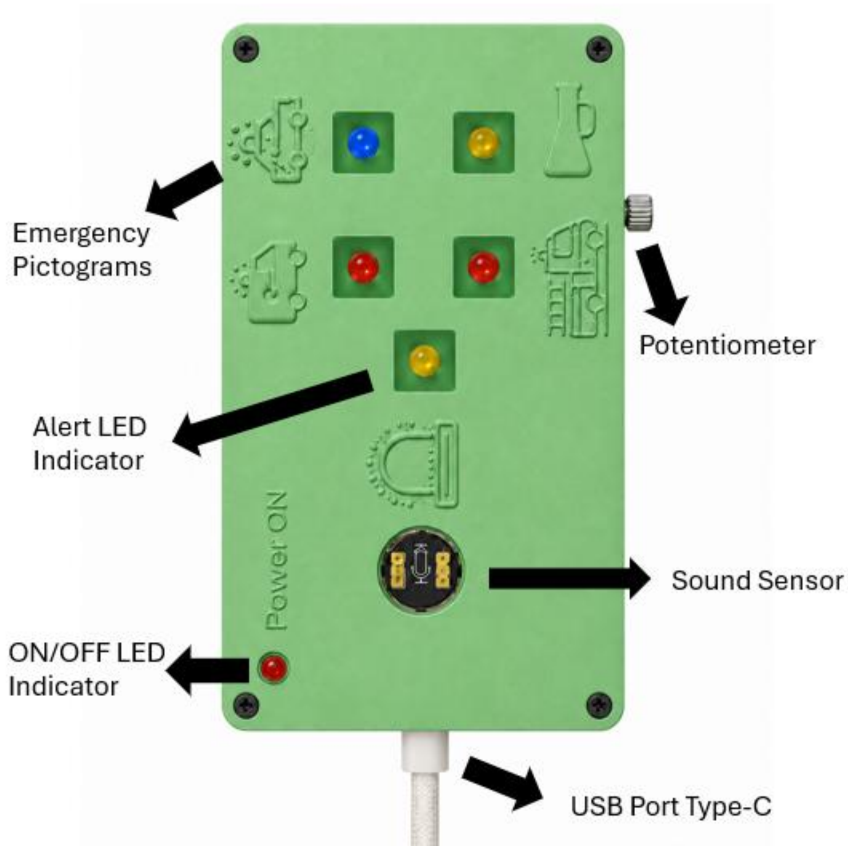


Figure 1. Front View of Device

General Description

The E.A.R.S. (Emergency Alert Recognition System) is a device that detects important emergency sounds and converts them into a visual alert. The purpose of this system is to assist deaf or hard-of-hearing users through an easy and recognizable light signal.

2. USER INTERFACE

- Status Indicator: Shows if the system is ON/OFF (**Figure 1**)
- LED Alert Light: Activates when the system detects a sound above the programmed threshold. This light serves as the main visual notification for the user (**Figure 1**).
- Sound Sensor: Captures the sounds from the environment for the system to process **(Figure 1**)
- Power Port USB Type-C: Allows the system to be connected to a power source (**Figure 1**)
- Potentiometer: Used for sensitivity adjustment of the LED's intensity for the user's comfort (**Figure 1**). Additionally, turning it, all the way clockwise turns ON the system, and all the way counterclockwise turns the system OFF.
- Pictograms: There is a pictogram for each individual alert and a general alert one. (**Page 6, Figures 2-6**)

Pictograms

Figure 2. Police Car Pictogram, represented with the Blue LED

Figure 4. Car Horn Pictogram, represented with the Yellow LED

Figure 3. Ambulance Pictogram, represented with the Red LED

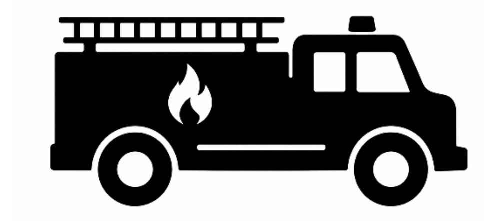


Figure 5. Fire Fighter Truck Pictogram, represented with the Red LED

Figure 6. General Alert Pictogram, represented with the Yellow LED

NOTICE

The **Yellow LED** is used for both Car Horn alert and General Alert, and the **Red LED** is used for the Fire Fighter Alert, the Ambulance Alert, and the Power Indicator. Users should rely on the corresponding pictogram, label, or operating context to distinguish between these functions.

3. ⚠ WARNINGS

⚠ General Warnings

- This device is a supplemental aid and does not replace the user's awareness of their surroundings
- Do not use this device as the only safety method
- Do not expose the device to water or excessive moisture, especially the exposed Sound Senser (**Figure 1**)
- Do not throw the device or subject it to strong impacts
- Do not disassemble the product while it is connected to a power source
- Keep the device out of reach of small children
- Store the device away from sunlight and in a cool place when not in use

⚠ Small Internal Parts Warning

- This product may contain small internal parts
- This is not a toy
- Small parts may present a choking hazard if swallowed

⚠ Electrical Warning

- Use only the recommended power source (USB Type-C)
- Do not use damaged cables
- Disconnect the device before cleaning

⚠ Installation Warning

- Use a compatible device mount (**Page 15**)
- Do not place the device in a location that blocks visibility or interferes with normal user activity

⚠ Performance Warning

- Very low-volume sounds or environmental interference may affect detection.

- The system may produce false alerts in very noisy environments

⚠ **Protective Case Warning**

- For day-to-day use, do not open the protective case, especially if the device is connected to power.
- Do not touch the internal electronics.
- Do not insert fingers or objects into the sound sensor
- Internal components should only be handled by the project designer or under instructor supervision.

4. INSTRUCTIONS

Mounting Device

- Place the device in a secure location inside and on the dash of the vehicle
- A **car phone holder** mount is the recommended mounting method for this system**. Additional information and more examples of different mounts are shown on Page 15.**
- Position the device where the LED indicators are clearly visible to the driver
- Do not place the device where it blocks the windshield, mirrors, dashboard controls, or airbags
- Make sure the sound sensor is not covered or obstructed

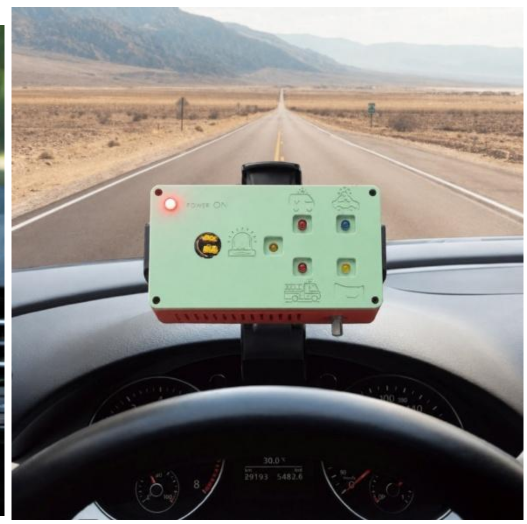



Figure 7. Potential Mounts for System

Connection to Power Supply

- A USB Cable Type-C is necessary for the system's operations
- Locate the USB power input on the device (**Figure 8**)
- Plug into USB Power Source
- Ensure the cable is firmly connected before operating the device

Figure 8. The red arrow points to the system's power input. USB Type-C

Verifying the System is ON

- After connecting the power cable or after fully rotating the Potentiometer clockwise (**Figure 11**), check the Red ON LED (**Figure 9**)
- If the Red ON LED is illuminated, the system is powered on.
- If the ON LED does not turn on, inspect the USB connection and power source.
- Reconnect the system, if necessary, until the ON LED is visible.

Figure 9. The red arrow points to the system’s ON LED indicator. When ON, it will glow Red

Confirming the Device is Ready for Use

- Check that the device is securely mounted.
- Make sure all alert LEDs and pictograms are clearly visible.
- Confirm that the sound sensor is unobstructed to the surrounding environment.
- Verify that the system remains powered on before beginning use.

Understanding the Alerts and Pictograms

Examples of the pictograms can be found back on **Figures 2** through **Figure 6,** and a close-up of their positions are shown on **Figure 10**.

When the system detects a programmed sound, the corresponding LED indicator will illuminate.

- Blue LED with Police car pictogram: Police-related Alert
- Red LED with Ambulance pictogram: Ambulance-related Alert
- Red LED with Fire Truck pictogram: Firefighter-related Alert

- Yellow LED: Car horn alert or general alert: Car horn-related alert and a general alert that the system is picking up emergency related sounds

The user should identify each alert by observing both the LED color and the associated pictogram. Note that some LED colors are being repeated, the Yellow LED is being used for the General Alert (**Figure 6**) and the Car Horn Alert (**Figure 4**) and the Red LED is being used for the Ambulance Alert (**Figure 3**), Firefighter Alert (**Figure 5**), and the Power Indicator LED (**Figure 9**).

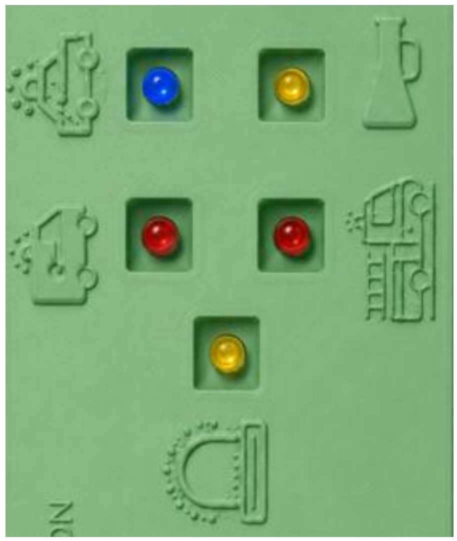


Figure 10. Close up on the device's Alert Pictograms

Adjusting LED Brightness

- Locate the potentiometer on the device (**Figure 11**).
- Turn the potentiometer clockwise to increase the brightness of the LED indicators. Rotating it fully clockwise turns the system ON. If the system is already on, keeping the potentiometer in this point will not affect the device.
- Turn the potentiometer counterclockwise to decrease the brightness of the LED indicators. Rotating it fully counterclockwise turns the system off. To turn the system back on, reconnect it to the power source or rotate the potentiometer fully clockwise.

- Adjust the brightness until the visual alerts can be clearly seen under the lighting conditions.

Figure 11. The curved arrows are on the system's Potentiometer. It is used for adjusting the LED's brightness and turns ON/OFF the system when rotated fully in the respective direction.

Normal Operation

- Keep the device connected to power during use.
- Allow the sound sensor to continuously monitor surrounding sounds.
- When an emergency or warning sound is detected, observe the corresponding LED indicator.
- Use the pictogram and LED color together to identify the type of alert (**Page 6**).
- Respond according to the surrounding situation.

If the Device does not respond as expected

- Check that the device is still connected to USB power.
- Confirm that the Red ON LED is still illuminated.
- Inspect the sensor area for obstructions.

- Verify that the device mount has not shifted position.
- Restart the system by disconnecting and reconnecting the USB cable if necessary.

Turning the Device OFF

- Disconnecting the system from the power source turns OFF the system. Additionally, rotating fully the Potentiometer (**Figure 11**) **counterclockwise** also turns OFF the system.
- Confirm that the Red ON LED turns off.
- Store the device safely if it is not used again immediately.

Figure 12. The red arrow points to the system's ON LED indicator. When OFF, it does not glow

5. MOUNTING RECOMMENDATIONS

The device should be mounted in a position where the user can easily see the LED indicators without interfering with safe vehicle operation. Examples of these mountings can be seen in **Figure 7** and more general examples on **Page 17**

Mounting Orientation

The device may be installed in either **vertical** or **horizontal** orientation according to the user's preference. Both orientations provide full functionality and do not affect the performance of the emergency alert system.

Recommended Mount

A **car phone holder mount** is the recommended mounting method for this prototype. This type of mount helps keep the device stable, visible, and easy to position inside the vehicle. The recommended mount for this system is the **RAM® Finger-Grip™ Universal GPS and Radio Holder, model RAM-HOL-UN4U (Figure 13)**. This mount is suitable because, when configured with the long arm side clamps, it can accommodate devices up to approximately **3.5 inches wide** and **1.6 inches deep**. Since the system is approximately **2.56 inches wide** and **1.57 inches thick**, the mount can hold the current casing dimensions.

Figure 13. RAM® Finger-Grip™ Universal GPS and Radio Holder model RAM-HOL-UN4U

Mounting Guidelines

- Mount the device in a location visible to the driver.
- Do not place the device where it blocks the road view, mirrors, dashboard controls, or airbags.
- Make sure the mount holds the device securely during vehicle movement.
- Position the device so the sound sensor remains exposed to the surrounding environment.
- Confirm that the LED indicators and pictograms are clearly visible after mounting.

Examples of Mounting

Figure 14.

Figure 15.

Figure 16.

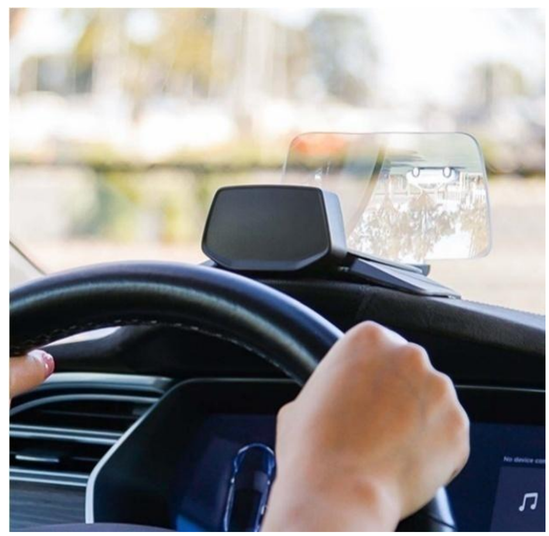


Figure 17. Dashboard-mounted heads-up display (HUD) phone holder

NOTICE

An average smartphone measures approximately 145-160 mm × 70-80 mm × 7-9 mm, while the proposed system measures 120 mm × 65 mm × 40 mm. Although the system is thicker than a typical phone, its overall height and width are relatively comparable. For this reason, the phone mount should be capable of supporting a device thickness of up to 40 mm.

6. MAINTENANCE

General Maintenance

The device should be inspected regularly for dust buildup, or signs of wear. The user should verify that the LED alert indicators, sound sensor, and power connection are functioning properly before use.

The internal electronics are enclosed inside the protective housing and should not be tampered with during normal operation.

Cleaning the Device

The outer housing should be cleaned using a **soft dry cloth** or slightly **damp microfiber cloth**. Do not allow water or other liquids to enter the device. The sound sensor area (**Figure 18**) should be kept free of dust and debris to ensure accurate sound detection.

The recommended cleaning method is to gently wipe the outer case and sensor openings without applying excessive pressure.

Figure 18. The red arrow points to the system's Sound Sensor

Chemicals to Avoid

To prevent damage to the device housing and internal electronics, do **not** use harsh cleaning chemicals or solvents. Keep the device away from:

- Acetone
- Bleach
- Ammonia-based cleaners
- Alcohol in high concentrations
- Paint thinner
- Gasoline or petroleum-based solvents
- Abrasive cleaning powders or pads

These substances may damage the protective case, remove labels or pictograms, or affect the electronic components.

Periodic Inspection

The system should be inspected periodically to confirm that:

- The LED indicators are operating correctly
- The pictogram labels are visible and undamaged
- The sound sensor is clean
- The mounting system is secure
- The wiring is intact
- The protective case is not cracked or loose.

If any component appears damaged, loose, or nonfunctional, the device should not be used until it has been inspected by the project designer or instructor.