3. DESIGN APPROACH

In this section, the approach to the project is explored, targeting the development of an innovative alarm system designed to awaken individuals with hearing impairments or deep sleepers during nighttime emergencies. To navigate this phase of the design, AlertSense has organized the content into three primary components: Design Options, System Overview, and Subsystem Descriptions. Within these sections, vital elements are outlined that inform the approach. In line with a commitment to delivering a user-centric solution, AlertSense prioritizes critical requirements, constraints, and standards that include ensuring user safety through timely alerts, complying with accessibility guidelines for individuals with hearing impairments, and delivering non-auditory sensory cues to communicate vital information.

3.1. Design Options

When developing a system that is designed for individuals with hearing impairments, it is imperative to explore various design options to ensure that the final solution is not only effective but also innovative and user-friendly. This section describes design alternatives and choices that were considered during the planning phase. Each design option represents a unique path to achieving AlertSense's project goals, and the selection of the most appropriate approach was driven by the careful evaluation of factors such as technology, materials, user experience, and accessibility. By assessing these design options, AlertSense aims to ensure that the resulting alarm system is not just functional but optimal to meet the specific needs of its target users, providing them with a heightened sense of safety and security during the night.

3.1.1. Design Option 1

The first design option proposed by AlertSense was utilizing multiple vibrational motors strategically integrated into the mattress itself, providing a direct means of alerting the user. These motors were synchronized with a dimming light source located overhead, which was designed to provide a visual component to the alert system. To coordinate these components, a control box was incorporated into the system. This control box housed an array of sensors for detecting potential hazards, a microcontroller for controlling the system, and a backup power source to ensure the system's reliability even in the event of a power outage. This design keeps the motors away from the user and uses fewer materials, keeping the price economical. The downside of this design was that there was less reliability from the motors. The only solution to this problem would have been to increase the vibrational power, which in turn would have decreased the integrity of the bed frame.

3.1.2. Design Option 2

The second design option, similar in many aspects to the first design, introduced a different method of implementing the vibrational alert system. In this iteration, multiple vibrational motors were placed within a nonconductive sheeting, designed to be both shock and fireproof, ensuring the user's safety during emergencies. This sheeting served as the surface upon which the user sleeps. To enhance the precision and effectiveness of the vibrational alerts, the motors were divided into sections within the sheeting. This sectionalization allowed for specific patterns and locations of vibrations, which were programmed to convey different alerts. Implementing the motors in this design increased the reliability of the motors while simultaneously not affecting the integrity of the bed frame. The downside is that this requires a more direct approach, which poses more risks and increases the budget to maintain safety. AlertSense opted for this choice because it provides a tactile sensation that users can feel without the need to alter or damage the bed frame.

3.2. System Overview

The system overview provides a comprehensive perspective on the design, functionality, and key elements of the alarm system. This section presents the high-level architecture through Level 0 and Level 1 diagrams, along with an in-depth exploration of the core microcontroller that governs the system's operations.

In Figure 3-1, the Control Module serves as the core of the alarm system. This Control Module acts as the control hub for all system functions and interfaces directly with the user. The user is the primary external entity, representing the end users who interact with the system. The Control Module receives input from the Detection Sensors, which include sensors for intruder detection and fire monitoring. The Control Module processes the sensor data and, based on its analysis, triggers the appropriate responses in the User Alert Interface.

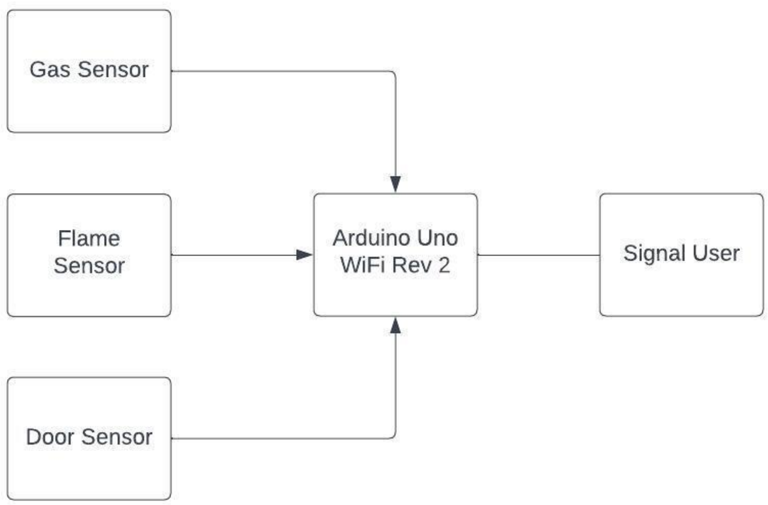

Fig. 3-1: AlertSense at a Glance (Level 0) [15]

In Figure 3-2, the Control Module serves as the central hub, controlling communication with the various subsystems. This diagram highlights the interconnections between the Control Module and each subsystem, including the Safety System, Vibrational System, Lighting System, and Application. It visually conveys how the Control Module is the main component responsible for managing the data flow, commands, and responses between these subsystems, ensuring the effective operation of the entire alarm system.

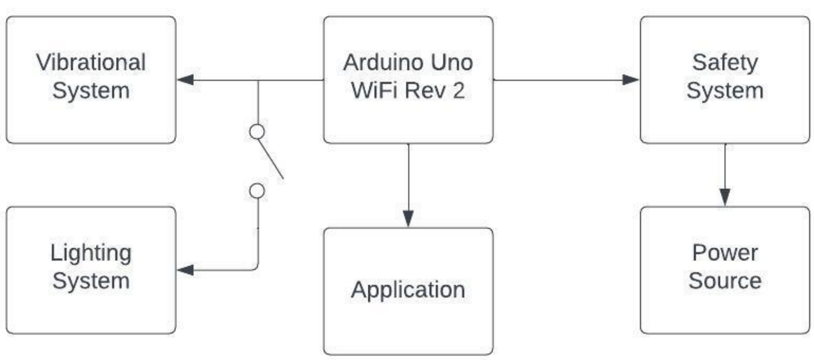

Fig. 3-2: AlertSense Functionality (Level 1) [15]

3.2.1. Microcontroller

The central processing unit for AlertSense is the Arduino Uno Rev 2, responsible for overseeing all subsystem connections and instructions. This microcontroller, showcased in Figure 3-3, was chosen for its robust processing capabilities, extensive connectivity options, and cost-effectiveness. While the ESP32 was considered for its impressive capabilities, it was ruled out due to its lack of embedded libraries and coding complexity. Similarly, the Raspberry Pi, with its substantial processing power and alignment with most criteria, was not chosen because of its steep learning curve in coding and higher cost. Table 3-1 is a comparative table of the microprocessors considered.

Table 3-1 Microcontroller Alternatives

Product Name	Operating Voltage (V)	I/O Pins	Wi-Fi/Bluetooth	Price ($)
Requirements	>3	>6	YES	<100
Arduino Rev 2 [6]	6-20	20	YES	58
Raspberry Pi [7]	5.1	14	NO	80
ESP32 WROOM-32E [8]	3-3.6	34	YES	59

Fig 3-3: Arduino Uno Rev 2 [6]

In summary, the System Overview section offers a comprehensive insight into the AlertSense alarm system. The Level 0 diagram simplifies the representation of core system elements, underscoring the significance of the Control Module and User Alert Interface. In the Level 1 design, the integration between the Control Module and subsystems, including the Lighting System, Vibrational System, Safety System, and Application, is explored in detail, with a focus on the central role of the microprocessor in system control.

3.3. Subsystem Descriptions

The prototype for AlertSense comprises five subsystems. Subsystem 1 is the Control Module, housing the Arduino unit that orchestrates the operation of all other subsystems, as well as the Bluetooth module for external connectivity. Subsystem 2, the Lighting System, features a dimmable light source that shines directly in the user's face, providing a visual alert in response to a safety system trigger. Subsystem 3, the Vibrational System, employs motors to deliver bed vibrations when the Safety System detects a threat, awakening the user discreetly. Subsystem 4 encompasses the Safety System, equipped with carbon monoxide, air quality, and door sensors, which collectively monitor environmental conditions and potential intrusion or danger. Finally, Subsystem 5, known as the Application and Website system, includes both a user-friendly interface and a website. The application serves as the central control hub, connecting to the Arduino and facilitating user interaction with the alarm system. Simultaneously, the website complements the application by providing users with an online platform where they can access further resources, updates, and support from AlertSense.

3.3.1. Control Module

The control box serves as the secure enclosure for housing sensitive and potentially hazardous equipment within the system. It is designed with dimensions of 6 in L x 9 in W x 9 in H, providing ample space to house critical components, including backup batteries and processors for various subsystems. For safety and early detection, fire and gas sensors are seamlessly integrated into the sides of the control box. Additionally, air vents have been thoughtfully included to ensure proper ventilation and prevent overheating, guaranteeing the reliability and safety of the system even in challenging conditions.

To ensure uninterrupted operation during power outages, an emergency battery plays a vital role in supplying continuous power to the sensors and motors. The control box is designed to accommodate the battery pack while also featuring an automatic charging mechanism. This design allows the system to remain functional without manual intervention. The sensors are required to maintain activity for a minimum of 24 hours, crucial for reliability during emergencies such as fires or intrusions. While in standby mode, the sensors consume a minimal amount of power. Consequently, the battery possesses sufficient capacity to sustain both the standby mode of the sensors and power the motors [4]. It is essential that the dimensions of the battery align with the constraints of the control box and do not exceed the specified weight limit to ensure seamless integration and optimal performance. Finally, the cost minimum cost is simply decided by how much budget is left. Table 3-2 describes the battery options considered by AlertSense.

Table 3-2 Battery Options

Product	Power Capacity (mAh)	Power (W)	Weight (lb)	Dimensions (in) (LxWxH)	Cost ($)
Requirements	>500	-	< 20	-	<400
ZeroKor Portable Power Bank [10]	24000	65	1.6	6.8 x 3.8 x 1.8	66.98
DenGaWah Portable Power Bank [9]	67500	250	5.1	8.5 x 6.7 x 4.1	139.99
Mormluck Portable Power Bank [5]	24000	127	2.3	6.7 x 3 x 4	119.99

For the backup power source, AlertSense has opted for the Mormluck battery, as depicted in Table 3-2. This battery is selected based on its capacity to provide steady power, sustaining multiple sensors for a minimum of 24 hours. Additionally, it can deliver a substantial voltage boost, sufficient to activate the motors for no more than 1 minute. During standby mode, the combined power consumption of all sensors is calculated to be at least 13mAh. Figure 3-4 shows the method used to determine the minimum current. The Mormluck battery, containing a capacity of 24000mAh, exceeds this requirement, ensuring extended sensor activity for over 24 hours [4]. Importantly, this battery can be connected to a constant power source through an outlet for continuous replenishment. The Mormluck battery emerges as a highly favorable option as it fulfills all specified requirements and budget considerations.

$$\text{Power (Watts)} = \text{Voltage (Volts)} \times \text{Current (Amps)}$$

$$\text{Current (Amps)} = \frac{\text{Power (Watts)}}{\text{Voltage (Volts)}}$$

$$\text{Battery Capacity (Ah)} = \left[\frac{\text{Power (Watts)}}{\text{Voltage (Volts)}}\right] \times \text{Time (Hours)}$$

Fig. 3-4: Calculations and Mormluck Battery [5]

The straightforward formula shown above was employed to calculate the required battery capacity to maintain AlertSense in standby mode for a minimum of 24 hours. The system comprises multiple sensors that draw only minimal current in micro-amps. Consequently, each battery option considered fulfills the requirement to sustain the system's operation for extended periods, ensuring reliable functionality.

3.3.2. Lighting System

The Lighting System collaborates with the Vibrational System to offer an extra means of alerting the user during emergencies. It is seamlessly linked to the control box, enabling immediate activation of the light when a threat is detected. For user convenience, a wall mount with simple installation is included to position the light directly above the user, featuring a low-wattage, eye-friendly light source. The available light options are outlined in Table 3-3 for reference.

Table 3-3: Lighting Options

Product	Wattage (W)	Rated Lifetime (hours)	Cost ($)
Requirements	< 21	-	< 50
Philips LED Bulb (Dimmable) [16]	12.2	15,000	9.99
LAIFUNI Dimmable Under Cabinet Light Bar [17]	15	54,000	46.89
American Lighting LED BRIO 5CCT 6” [18]	12	50,000	27.72

AlertSense incorporates the Philips LED Bulb shown in Figure 3-5 for its lighting needs, primarily selected for its cost-effectiveness and eye-friendly design. The dimmable feature serves to reduce the potential for eye strain. While this bulb may have a slightly shorter rated lifetime compared to alternative options, its affordability and ease of replacement make it a practical choice.

Fig 3-5: Philips LED Bulb (Dimmable) [16]

The light necessitates a wall mount for optimal positioning directly above the user, enhancing its effectiveness in waking the user during emergencies. The provided wall mount is designed for easy installation and extends adequately to ensure precise light placement. Table 3-4 provides an overview of the various wall mounts evaluated by AlertSense.

Table 3-4: Wall Mount Options

Product	Arm Length (in)	Rated Wattage (W)	Material	Cost ($)
Requirements	> 12	> 12	-	< 50
TRLIFE Wall Sconce [19]	22	60	Metal	31.99
VONLUCE Modern Swing Arm Wall Mount Light [20]	14.2	40	Metal	39.99
PULLCU Swing Arm Wall Lamp [21]	18	60	Metal	49.99

The wall mount solution selected for AlertSense is the PULLCU Swing Arm Wall Lamp depicted in Figure 3-6. This choice extends up to 18 inches, guaranteeing that the light is optimally positioned beyond the bed frame and directly above the user. It is also perfectly compatible with the dimmable LED bulb, featuring a wattage rating that comfortably exceeds the bulb's requirements. Additionally, it comes with a lamp shade, which serves to direct the light and reduce the risk of eye strain or damage.

Fig 3-6: PULLCU Swing Arm Wall Lamp [21]

In essence, the Lighting System in AlertSense complements the Vibrational System for user alerting during emergencies. It utilizes the Philips LED Bulb for gentle, dimmable lighting and is efficiently positioned by the PULLCU Swing Arm Wall Lamp. This combination enhances user safety without compromising eye comfort.

3.3.3. Vibrational Subsystem

The Vibrational subsystem plays a vital role in the AlertSense system, consisting of a series of identical motors controlled by the central module. Its primary purpose is to offer an innovative alternative to traditional sound-based wake-up alarms by delivering gentle vibrations to the user's bed. To ensure an even and effective distribution of vibrations, these motors are strategically placed beneath the bed, and a protective cover is used to prevent damage to both the bed and the motors. Table 3-4 provides an overview of the motor options that best align with AlertSense's requirements and overall suitability for the device.

Table 3-4: Motor Options

Product	Operating Voltage (V)	Dimensions (mm)	Material	Cost ($)
Requirements	>= 3	-	-	< 15
Tatoko DC 3V 12000RPM Vibration Motor [22]	3	10 x 3	Stainless Steel	6.99
Tatoko DC Coreless Motor [23]	3	7 x 25	Stainless Steel	9.99
Bojack N20 DC Vibration Motor [24]	3	16 x 12	Metal	8.99

AlertSense opted for the Tatoko DC Coreless Motor shown in Figure 3-7 to serve as the primary mechanism for inducing vibrations in the user's bed. This motor is seamlessly integrated with the control module to streamline its operation. With a voltage range spanning from 1.5 to 3 volts, it offers users the versatility to fine-tune vibration intensity to suit their preferences. Notably, its waterproof design adds an extra layer of durability, ensuring its functionality remains unimpeded even in the presence of moisture. The Tatoko motor emerged as the best choice due to its sturdy build, promising a tactile yet comfortable vibration experience. Furthermore, it presents a cost-effective solution, and when multiple motors are deployed in unison, they collectively possess the strength to effectively rouse a sleeper from slumber.

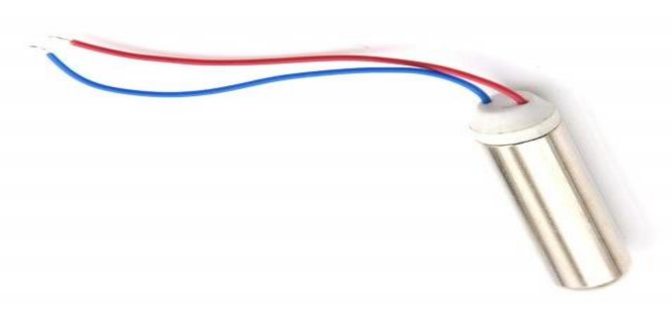

Figure 3-7: Tatoko DC Coreless Motor [23]

Thus, the Vibrational Subsystem is a key component of AlertSense, offering an inventive alternative to sound-based alarms through carefully selected Tatoko DC Coreless Motors. The even motor distribution under the bed, combined with protective coverings, ensures durability and user comfort. This section highlights AlertSense’s commitment to providing a cost-effective, reliable, and user-centric solution.

3.3.4. Safety System

Within the safety subsystem, three distinct functions are incorporated, consisting of a door sensor, a fire alarm, and an air quality alarm. The door sensor employs a magnetometer due to its simplicity and user-friendliness. Positioned on the door frame, a magnet is affixed to the door. When the door is opened, the magnet shifts away from the sensor, leading to an alteration in the magnetic field, thus activating the sensor. The magnetometer swiftly detects this change and transmits a signal to the processing unit. Table 3-5 outlines the different magnetometer options.

Table 3-5: Magnetometer Options

Product	Operational Voltage (V)	Mount Type	Dimensions (In) (WxH)	Weight (g)	Cost ($)
Requirements	3-9	-	-	-	< 40
HiLetgo GY-271 HMC5883L [1]	3.3	PCB Mount	0.55 x 0.16	13.9	6.69
HiLetgo Mpu9250 GY-9250 [7]	5	PCB Mount	0.59 x 0.98	17.9	14.99
WitMotion WT901 [8]	3.3-5	Surface Mount	2.95 x 0.83	18	33.90

The HiLetgo GY-271 HMC5883L Magnetometer, as depicted in Figure 3-9, was selected for magnetic field detection. This magnetometer provides data representing the strength of the magnetic field, measured in gauss (G) or unit tesla (T). By assessing the magnet's proximity to the magnetometer, the position of the door can be determined, establishing a straightforward door sensor. This magnetometer stands out due to its affordability, compatibility with Arduino systems, and its low operating voltage. These specifications align perfectly with the project's requirements, making it a logical and cost-effective choice for the door sensor application.

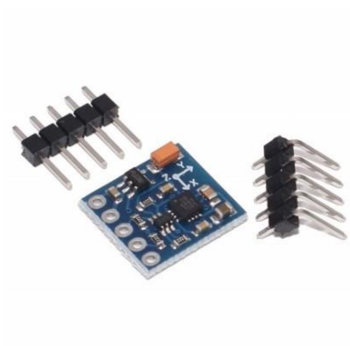

Figure 3-9: HiLetGo GY-271 HMC5883L Magnetometer [1]

As depicted in Figure 3-9, the magnetometer is equipped with extra mounts suitable for PCB usage, facilitating testing with a breadboard setup.

To address fire detection, a specialized fire sensor was selected. This component operates by detecting fire through the assessment of infrared radiation. It achieves this by employing an infrared radiation photodiode to measure levels of infrared radiation, subsequently comparing these levels with a predefined threshold to determine the presence of a fire. Notably, the fire sensor is housed in a separate enclosure, distinct from the primary module, ensuring dedicated functionality and efficient response in fire detection scenarios. Table 3-6 showcases the different flame sensor options.

Table 3-6: Flame Sensor Options

Product	Operational Voltage (V)	Temperature Rating (C)	Dimensions (In)	Weight (g)	Cost ($)
Requirements	3-9	-	-	-	< 30
Oiyagai 5pcs IR Flame Sensor Module [2]	3-5	60	2 L x 0.59 W x 0.59 H	5	10.60
KY-026 3pcs Flame Sensor [11]	0-15	60	1.41 W x 0.63 H	9	7.00
LM393 4 Pin IR Flame Detection Sensor Module [12]	3.3-5	60	3.94 W x 1.18 H	74.6	26.03

The Oiyagai Flame Sensor Module, as featured in Figure 3-10, was integrated for fire detection within the system. The selection of the Oiyagai Flame Sensor Module was due to its price and low operating voltage. While considering alternative options, the KY-026 sensor almost met the specifications; however, it lacked clarity on its operating voltage requirements. In contrast, the LM393 sensor fulfilled the criteria for temperature, voltage, and dimensions but was heavy, making the Oiyagai Flame Sensor Module a more suitable choice for the specific application.

Figure 3-10: Oiyagai IR Flame Sensor Module [2]

In Figure 3-10, the flame sensor shows a slim design that lowers the overall weight and has an extruding IR photodiode that collects IR radiation data.

To address air quality concerns, an air quality sensor was incorporated into the system. This sensor is designed to monitor the air for harmful gases or unfavorable air conditions. It operates by assessing air quality parameters and promptly transmitting a signal to the processing unit if it detects any concerning problems. The air sensor is positioned at the top of the subsystem box, ensuring efficient monitoring of the surrounding air quality.

Table 3-7: Air Quality Sensor Options

Product	Operational Voltage (V)	Operating Humidity (%)	Dimensions (In)	Weight (g)	Cost ($)
Requirements	3-9	-	-	-	< 20
MQ – 5 Methane LPG Natural Gas Propane Sensor Detector Module [3]	5	95	1.25 L x 0.8 W x 1.1 H	7	5.69
Ximimark MQ 135 Air Quality Sensor [13]	5	95	5.71 L x 3.58 W x 1.06 H	17.9	8.99
MS1100 Gas Sensor [14]	2.6-5	90	6.22 L x 4.25 W x 0.83 H	58.9	12.99

For the detection of harmful gases, AlertSense used the MQ-5 Methane LPG Natural Gas Propane Sensor Detector Module, displayed in Figure 3-11. These MQ series air quality sensors incorporate a small heating element and an electrochemical sensor to identify the presence of noxious gases. The heating element warms the electrode's coating, rendering it more reactive. As a result, the resistance measurement fluctuates when gas is present, triggering the sensor and sending a signal to the processing unit. The choice of the MQ-5 sensor is due to its favorable attributes, including price, lightweight construction, and alignment with the AlertSense system's operating voltage requirements.

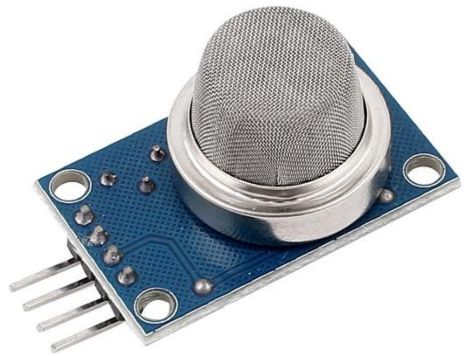

Fig. 3-11: MQ-5 LPG Natural Gas Propane Sensor Detector Module [3]

In Fig. 3-11, the gas detector module is made up of an electrode dome surface which contains a small heater and an electro-chemical sensor inside.

Thus, the safety subsystem section has provided an in-depth understanding of the components that contribute to the security and well-being of its users. The door sensor, fire alarm, and air quality alarm have each been carefully selected and integrated to ensure an efficient safety system. These components, along with the Oiyagai Flame Sensor Module and the MQ-5 Methane LPG Natural Gas Propane Sensor Detector Module, are vital in detecting potential threats such as intruders, fires, and harmful gases.

3.3.5. Application and Website

The Application Subsystem plays a pivotal role in AlertSense, acting as the central control point that facilitates user interaction. To meet its functional requirements, the application is designed for smartphones and tablets, ensuring broad accessibility. It utilizes Bluetooth Low Energy (BLE) for efficient communication with the Arduino control module, providing a reliable and energy-efficient link between the user and the alarm system. To ensure compatibility with both iOS and Android devices, the application is cross-platform, using React. In parallel, the website component is hosted on a dedicated web server, offering users resources, frequently asked questions, and support contact options. The website is constructed using modern web development technologies, including HTML, CSS, and JavaScript, guaranteeing easy updates and maintenance for long-term support. Data exchange with the Arduino relies on the Bluetooth Serial Communication (RFCOMM) protocol. This approach balances efficiency, cross-platform accessibility, and scalability, addressing the diverse needs of AlertSense's users.

HTML, CSS, and JavaScript are the optimal choices for developing a web app that communicates with an Arduino for various compelling reasons. First and foremost, these technologies offer cross-platform compatibility, ensuring that the AlertSense web app can run seamlessly on a wide array of web browsers and operating systems, thus reaching a broad user base. JavaScript, in particular, excels as a scripting language tailored for web applications, allowing AlertSense to create interactive and dynamic web pages that are ideal for real-time communication with external devices like the Arduino Uno via the web.

Moreover, HTML and CSS provide the foundational structure and styling for a web app, while JavaScript adds functionality without introducing significant overhead. This ensures that the web app remains responsive and efficient. The lightweight nature of these technologies is particularly advantageous. Additionally, JavaScript boasts a rich ecosystem of libraries and APIs that simplify web-based communication, making it easier to establish connections with Arduino devices, and facilitating the exchange of signals and data. Figure 3-12 outlines the overall design of the web application.

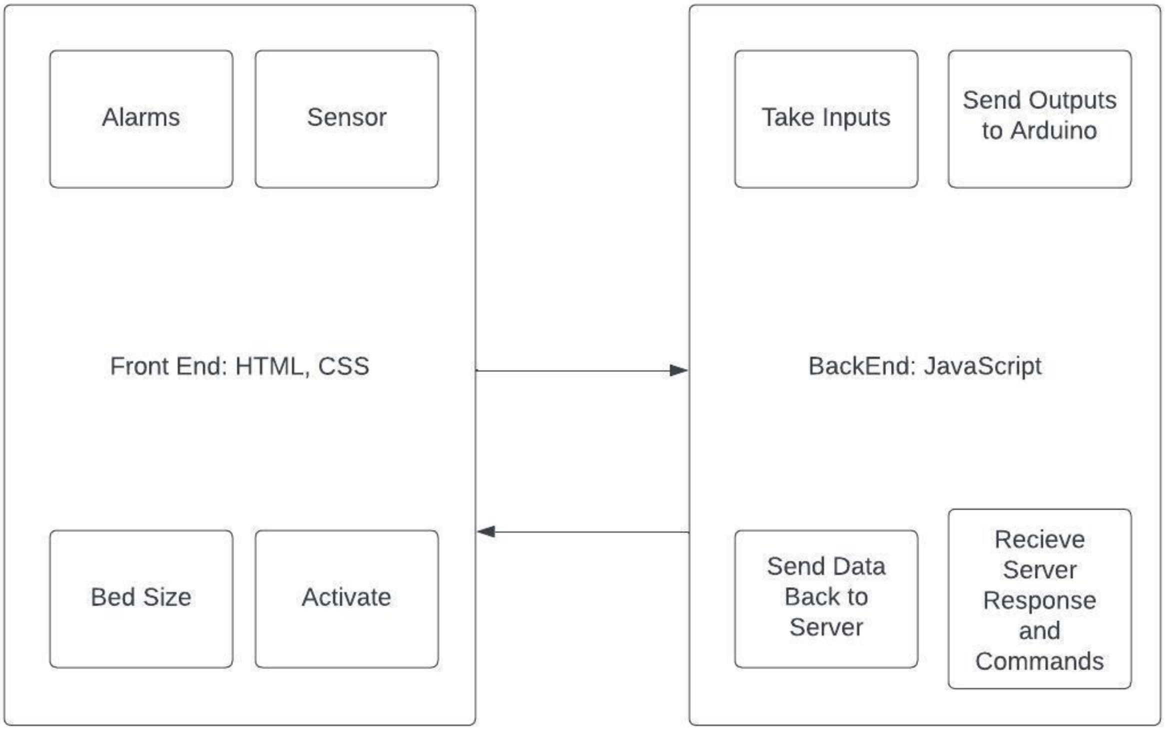

Figure 3-12: AlertSense Application Diagram [15]

On the front-end side in Figure 3-12, the application presents a user-friendly and intuitive interface for users to interact with the alarm system. The primary dashboard offers an at-a-glance view of the system's status, including active sensors and alarms. Within the application, users can fine-tune various settings, including bed size, sensor activation, and timing in which the sensors are activated. It also provides a dedicated section for managing sensor preferences, allowing users to enable or disable specific sensors based on their requirements. This aspect of the application design is written in HTML, CSS, and JavaScript.

The application communicates with the Control Module through Bluetooth technology due to the Arduino Uno having a built-in Bluetooth module. This data exchange facilitates the simplistic transmission of information related to sensor statuses, alarm settings, and user preferences.

Handling simultaneous events is crucial to ensure the application's responsiveness and reliability. The application utilizes event queue management and multitasking mechanisms. These mechanisms ensure that user-initiated commands, such as configuring alarms or adjusting sensor settings, do not disrupt the ongoing processing of sensor data. Effective error handling and asynchronous programming prevent potential problems like deadlock or livelock, guaranteeing that the application's code execution remains accurate and uninterrupted. This aspect of the application is written in JavaScript for data processing and signal transmission.

3.4. Level 2 Prototype Design

As AlertSense ventures into the next phase of its project in Design II, AlertSense's focus shifts towards transforming its comprehensive design specifications into a fully functional prototype. This stage marks a crucial transition from separated subsystems to a complete design. AlertSense intends to build a prototype that not only adheres to the specified design requirements but also exhibits the real-world reliability and user-friendliness that its target audience deserves. The AlertSense System involves precise assembly, thorough testing, and the refinement of user interfaces to ensure that the system not only meets but exceeds the expectations of those who rely on it for their safety. This section outlines strategies for the prototype's physical construction and testing.

3.4.1 Level 2 Diagram

Figure 3-13 shows the prototype with all the subsystems integrated. At the heart of the system, the Arduino Uno assumes the role of the central control unit, orchestrating the functions of the Vibrational System, Lighting System, Safety System, and Application and Website System. The Vibrational System, with its motor components, is directly connected to the Arduino Uno, producing bed vibrations to awaken the user during emergencies. Likewise, the Lighting System, equipped with a dimmable light source, connects to the Arduino Uno and emits visual alerts under the control of the central unit. The Safety System comprises various sensors, including those for carbon monoxide, air quality, and entry detection, all of which feed data into the Arduino Uno. This critical data input triggers alarms and notifications in response to hazardous conditions. The Application, designed as a mobile app and website, establishes a user interface through which individuals can customize alarm settings, deactivate sensors, and receive notifications. This interface is achieved through the Arduino Uno's built-in Bluetooth module, facilitating seamless communication between the user and the system. The close interplay of these low-level components ensures that individuals with hearing impairments are not only alerted to potential dangers but also provided with a user-friendly means of customization, resulting in a comprehensive and accessible alarm system.

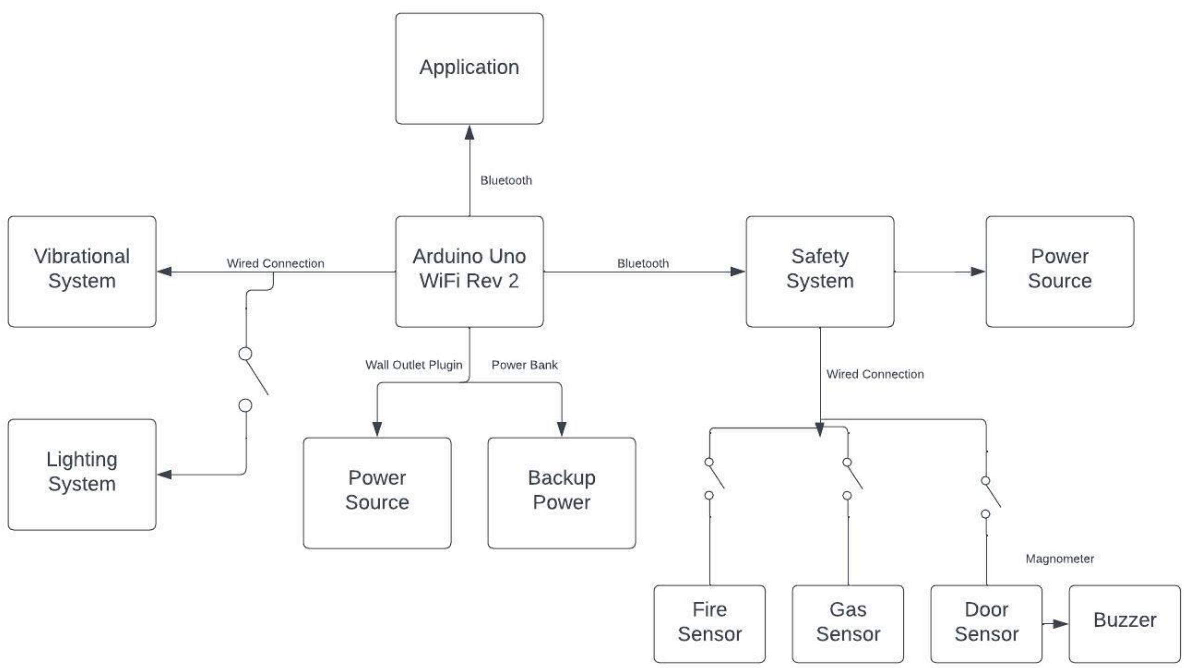

Fig. 3-13: Diagram for AlertSense (Level 2) [15]

AlertSense's commitment to adhering to industry standards, robust testing, and iterative user feedback positions AlertSense to develop a system that is both reliable and empathetic to the unique needs of its users. With the approach phase completed, the focus now shifts toward the testing phase, with the ultimate goal of enhancing the safety and well-being of those it serves.

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