E45 Vibrating Alert Bracelet

Final Report

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Executive Summary

The Vibrating Alert Bracelet (VAB) is an IoT-connected wearable device intended for usage by elderly, hearing-impaired individuals residing in retirement homes and assisted-living facilities. The goal of the VAB is to provide an alternative paradigm by which to warn such individuals of an emergency by providing a firm vibrating pulse coupled with a bright visual signal.

The VAB is comprised of a three-part system: the bracelet itself, an Android app, and a backend server that enables communication between the bracelet and phone app. While the bracelet is capable of sending a call-for-help signal to the app at the push of a button, the app is used to monitor the status of and push alerts to all connected bracelets. The server functions as a middleman between the app and the bracelets, facilitating communication through WiFi protocol. The server also contains all the information about each of the bracelets, such as their MAC addresses. The bracelet serves as the way of communication between the wearer and the administration of the facility. As the end user product, the VAB vibrates and flashes when it receives alerts from the app.

As per the project's hardware/software design validation, the VAB functions as intended by meeting all functional performance parameters and goals set for it. The VAB's system hallmarks are defined by confirming performance parameters via adhering to the electrical design limits, performing the intended functions of vibration and visual signalling when pinged, and maintaining two way from an app across a WiFi network. Tantamount to the performance parameters are the target specifications of remaining compact and ergonomic enough to comfortably be worn throughout the day, while also having the longevity for sustained usage in case of emergency - its intended purpose. Going forward, the major areas for improvement lie in reducing the size of the VAB even further while increasing battery life more than three-fold.

Overall, the VAB project has succeeded as a proof of concept, though it is not without notable flaws that can be improved significantly upon.

Project Overview

Elderly residents in retirement homes and assisted-living facilities are potentially at risk of missing an evacuation notice for a fire or other emergency particularly if the individual has a hearing impairment. Since existing alert systems such as fire alarms function on the basis of a loud, repetitive auditory tone a new alert paradigm was required for the hearing-impaired. In order to ensure that all individuals in an assisted living facility are notified of an imminent threat regardless of their disabilities the Vibrating Alert Bracelet (VAB) was proposed as an alternative solution to conventional alarm systems.

The goal of the VAB is to create an Internet-of-Things (IoT) wearable bracelet that can be worn by residents of assisted living centers. Its intended capabilities include both receiving emergency alerts from the administrator and sending calls for help from the user. Emergency alerts are to be communicated to the user via both haptic and visual sensation. This is achieved with a pager motor and flashing LED. The communication over WiFi requires a client that communicates with a Raspberry Pi back-end server. This server functions as a middleman between the bracelet and the Android app. The system must handle the administration and deployment of all VABs by acting as a relay for emergency warnings. An android app allows the administrator to interface with the server as they monitor users and send alerts.

Design verification tests have proven that the Vibrating Alert Bracelet fulfills the base design goals. It fulfills the goal of being an IoT-enabled wearable device that sends tactile and visual alerts to the user wearing it upon command from the Android app over WiFi connection. The bracelet also meets the requirement of being able to communicate user calls for help to the Android app. The device is compact and ergonomic enough to be worn on most wrist sizes. While the VAB hasn't been deployed in the field at nursing homes, the current design is a proof of concept that represents a fully-functioning device.

Project Design

Hardware: Electrical Design

Hardware design of the VAB primarily revolved around the selected system communication protocol and alert system method, while power delivery and energy storage in the form of a conventionally USB charged battery was an absolute given in accordance with the project scope. Hardware design feasibility required an examination of the estimated workloads, possible vendors, purchase options and needed equipment. Knowing how the user will interact with the product allows for a better grasp on what hardware would be best for a specific use case scenario. The vibration alert bracelet is intended to be worn by elderly people and only used in emergencies or when a patient is in need of help. Therefore, the hardware design must keep longevity, reliability, ergonomics, and wearability in mind.

Functionality to connect to a WiFi access point and communicate via TCP/IP to an on-board microcontroller is required for the bracelet to function. The microcontroller that was chosen in this design is the ESP8266 from Espressif Systems. This microcontroller was chosen primarily for its included WiFi radio. This choice greatly reduces complexity of the design as well as size, because choosing a microcontroller without an integrated WiFi radio requires that an external radio be included, thereby wasting precious space. It is required that the bracelet be able to perform three tasks: communicate over WiFi with a management application running on a smartphone, vibrate on command from the management application, and communicate a call for help from the user to management via the bracelet's emergency button. The ESP8266 serves all of these needs since it has a WiFi radio and a sufficient amount of GPIO pins. A USB to serial converter chip is also included in the design as a means of programming the microcontroller over USB, making development significantly easier. This is especially convenient as the device is to be charged via USB regardless.

Making sure that the battery is properly be charged is of utmost importance to the bracelet's effectiveness in the field. Minimizing the downtime is vital as the bracelet is ideally meant to be worn at all times and only used in the event of emergencies. The chosen charging IC was then selected due to its high output current. Based on data collected it was found that the battery takes seventy-five minutes to fully charge from a completely discharged state.

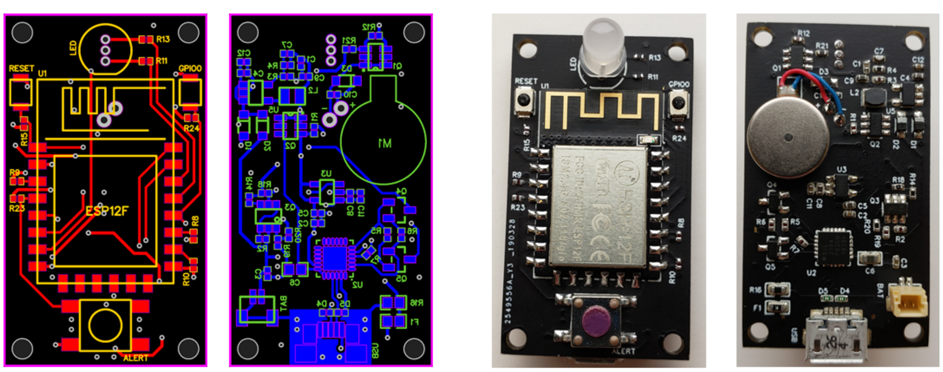
As this is a battery powered device a means of providing a regulated voltage source is required. A buck converter IC with switching diodes to handle power handoff between USB and battery power is included in the design to meet this need. The chosen buck converter must be able to provide a consistent 3.3 volts to the microcontroller, pager motor, and LED. It must also be able to source enough current from the battery to run everything simultaneously. The total current draw of the device is projected to be approximately 280 mA. This estimation was calculated by adding up the maximum current draws of the ESP8266 (170 mA), pager motor (90 mA), and the LED (20 mA).

The bracelet design is intended to alarm hearing impaired individuals, meaning the motor must generate great enough force to wake someone, even from a deep sleep. The RPM, size, operating voltage, and power consumption were all considered in during the selection process. Ultimately, the Parallax 28821 pager motor proved to be ideal for this project's purposes as it has an operating voltage of 3VDC, which maintained consistency with the other components operating voltage. Its rated current of 90mA results in small power consumption, optimizing battery life. Finally, its acceleration of 9000 RPM and small diameter finalized the decision, being efficient enough to wake someone and small enough to fit in the bracelet design.

The LED and button are general components which do not have many specifications that were stressed in their decision. The LED was chosen based on bi-color functionality, current rating, through-hole configuration for easy production mounting, and order quantity.

The battery used in the design is a 290 mAh lithium ion polymer battery. This battery was chosen with two primary motivations in mind: it's small size, and its built-in protection circuitry. Battery size is a primary concern because one of primary motivators behind the design of the bracelet is the necessity for it to be small enough and light enough to be worn on the wrist. The protection circuitry that is included with the battery is also a necessity because of the challenges in dealing with a lithium ion polymer battery. Without protection circuitry there is the possibility of catastrophic failure that would result in the user being harmed. The main trade off in battery choice is that of size versus capacity. The goal of the design is for the battery life of the bracelet to exceed a day, and ideally exceed a week. We intend to make this possible with the use of the ESP8266's advanced power states. The datasheet of the ESP8266 specifies that the microcontroller can enter a low power state where it will consume less than 1 mA of current and maintain a connection to a WiFi access point. The device itself only needs to be active when an emergency situation is present, so assuming emergency situations are very infrequent the device will be able to remain in the low power state for well over 99% of the time.

The following images show the completed electrical design of the VAB:



Top Bottom

(a)

Top Bottom

(b)

Figure 1: 3D CAD model of case.

The following schematic highlights the electrical design's details:

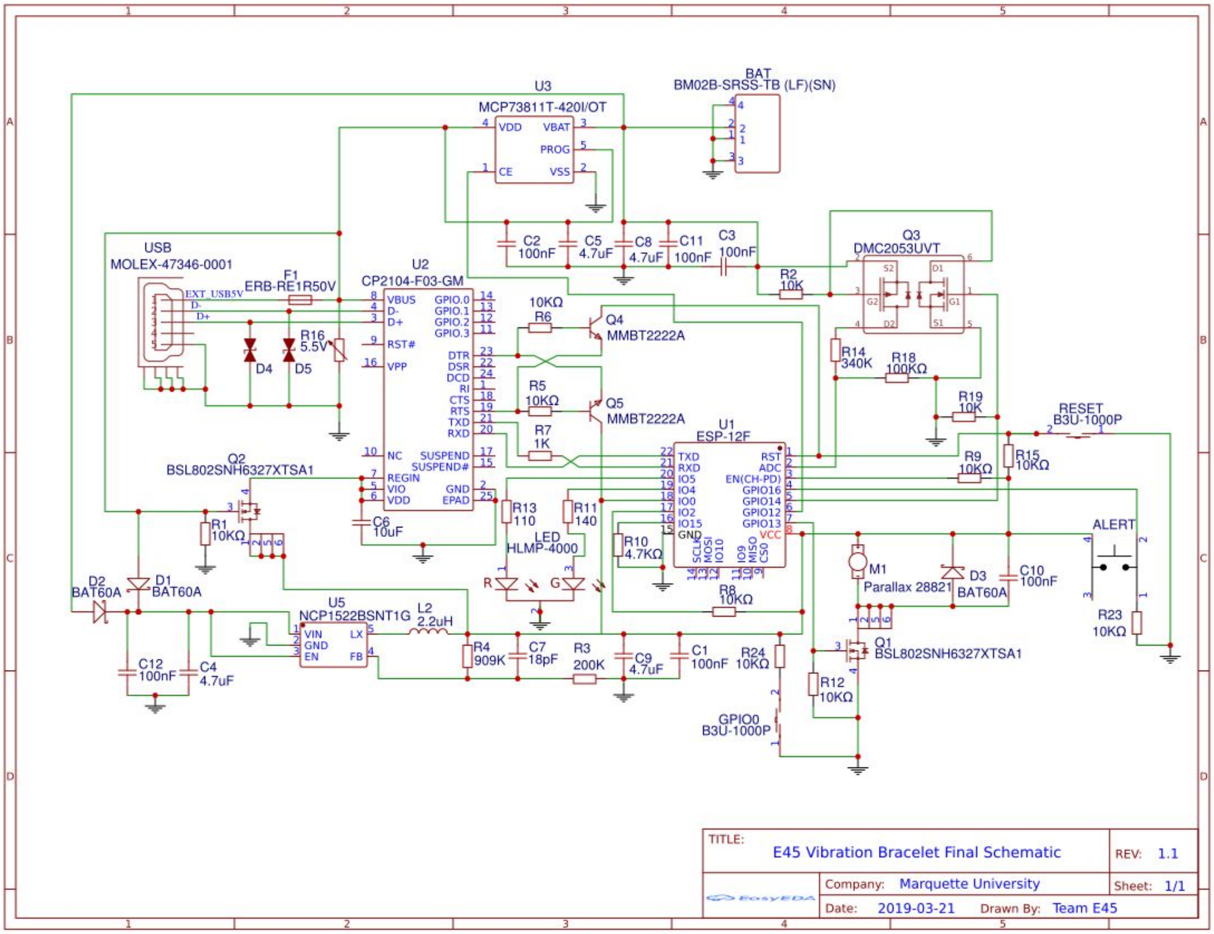


Figure 2: VAB Schematic.

<u>Hardware: Case Design</u>

The vibration bracelet is cased inside a 3D printed enclosure, designed to be ergonomic and to be able to attach and wear on a wrist using a NATO style watch strap. The enclosure is 65mm long, 31mm wide and 14mm high. There are two holes on the top for the LED and the button to be accessible. The button is recessed so that it can no be accidently pushed. The tolerances of the case are precise enough for the top to secure to the bottom and for both the board and battery to stay put without movement in the case. The 3D CAD model of the enclosure is shown in Fig. 1.

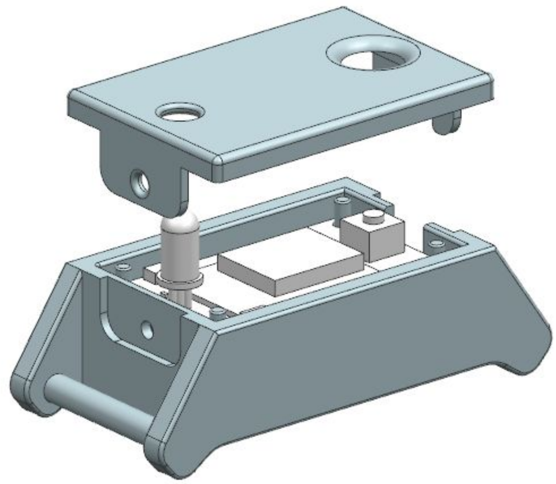


Figure 3: 3D CAD model of case.

Software: Android App

The design for the app includes two major areas of functionality. The first of these functions is to display a list of all clients who are currently registered with the system. This includes any bracelets that are not currently activated or are otherwise not functioning currently. This list includes the names of each of the bracelet holders, as well as their attached room number to allow for the staff members to easily locate the room that the alert originated from. The other important aspect of this list is the status icon associated with each entry. This image can swap between a green, gray, or red circle depending on the status of the bracelet's connection to the server. If the bracelet has connected to the server in the last two minutes, the icon appears green to indicate that the connection is still viable. In the event that the bracelet has not contacted the server in the last 2 minutes, the icon switches to a grey disconnected icon. Finally, a red icon is shown if the bracelet has sent an alert to the app. In the event an alert is received a notification is sent to the device, which means that the phone will vibrate and notify the user that a client is in need of assistance.

The second primary function of the app is to mass alert bracelets of any potential emergencies. This is done through a screen with a button to issue notifications to the server. Alerts issued to the server stay active indefinitely until canceled by an app, and cancellations can be issued from any app to the main server. Currently, alerts are sent en masse to all bracelets connected to the server, which receive the alert at their next contact.

Software: Server & Back-end

The server has two primary functions: Relaying communications between the app and the bracelets and keeping track of the status of each client. The relaying of communications happens in a number of different forms. App connections are made periodically, during which the server passes on the current status of all the bracelets, as well as the alert and connection status of each. This allows the app to keep its list of clients consistently updated, providing the user with an accurate readout of the status of all connected bracelets. Bracelet connections are made more infrequently due to battery life concerns, and are less complicated due to that. The connecting bracelet identifies itself with a MAC address, which is then used to check the list of known MAC addresses so that the client can be determined. After confirming the identity, the check-in time of that client is updated and the server informs the bracelet if an app has issued an alert.

The second functionality of the server is to keep track of the status of each individual client. These statuses are updated any time a client connects and requests information. For instance, the check-in time is stored for that particular client whenever a bracelet connects. Then, whenever an app connects, the status is calculated by finding the difference between the current time and saved time. In the event that an alert has been sent, that status would override any others for the ten minutes that that alert would remain active.

Software: Bracelet Firmware

The bracelet's primary function is to provide the wearer with an easy way to communicate with the administration of the care facility. The bracelet uses the ESP8266 to perform a set of instructions that allow it to carry out the necessary functions of the system. The bracelet begins its operation by initializing all of the different GPIO pins and enabling serial monitoring if that option has been enabled. There are a total of seven GPIO pins used with five of them be used for output and two for inputs. The outputs are used for controlling the LED, pager motor, and battery control. The inputs are used for the button and providing information on battery charge. Following the initialization of the pins, the bracelet then enters a loop where the operation of the system. The bracelet first connects to a set WiFi network and then checks the current status of the battery. Following these instructions, the bracelet will then connect to the central server. A check in message is sent from the bracelet to the server containing information on whether the alert button on the bracelet has been pressed or not. The bracelet will then send its Mac Address as a follow up message which the server will use to identify the wearer. A message is then received from the server that will tell the bracelet if an alert has been sent from the administration. If an alert has been received a ticker function is used to activate the pager motor to vibrate. Once the communication between the server and the bracelet is completed, the bracelet will disconnect from the server and the WiFi network. The bracelet then uses the

ESP8266's light sleep function to conserve the battery life of the system. The bracelet will wake up every few seconds during sleep to check if the button has been pressed. If the button has been pressed, then the bracelet will break out of its sleep cycle and send the alert to the server. If the button is not pressed during this time it will continue its sleep cycle until the thirty second timer is completed. Once it exits sleep cycle it will go back to the beginning of the loop and start it functions again.

Functionality Requirements & Considerations

The Vibrating Alert Bracelet (VAB) has a set of target specifications that must be met in order to ensure proper operation and full functionality of the device. Due to the nature of the VAB, there are two main focus areas which require experimental verification: hardware design/physical construction and software implementation.

The hardware design of the VAB includes several aspects which require consideration. Chief among these is the electrical design and implementation of devices such as the microcontroller, FETs, diodes, and USB protocols in respect to each other. In addition, the PCB layout and board design must also be taken into account, as improper component placement and routing can lead to improper functionality. It is imperative for the signal integrity of subcircuits within the design to be verified in order to ensure that the device performs its intended functions holistically. Another key focal point of hardware is the physical construction of the VAB, which must be compact and rigid, while adhering to PCB-specific tolerances to house the VAB's circuitry securely and properly..

The second focus area which requires its own experimental verification is software implementation for the VAB. This aspect of testing is required to confirm the connectivity and functionality of the device in service. In other words, the app functionality, WiFi operation and connectivity between the phone/server/bracelet, button input registration, LED toggling, and battery life must all perform their intended functions in order for the device to work as advertised. Due to the IoT-connected nature of the VAB's operation, software must be tightly integrated with hardware, so many of the tests required to verify software optimization and functionality overlap with hardware tests. For example, the battery life is both an electrical constraint and a software one. Lengthening battery life requires proper circuit design with minimal variation in voltage and current, but it also requires optimization of the ESP2866's power consumption in low-current modes. In this regard, design verification requires coordination from both hardware and software teams to adequately test, measure, and verify battery functionality.

Validation of all the above aforementioned aspects will confirm effectiveness of the Vibrating Alert Bracelet both independently as a device and when deployed throughout nursing homes.

Design Verification and Experimental Validation

Signal Integrity & Hardware

The two most important aspects of the design are its voltage values at certain nodes and its signal integrity, the latter of which is a byproduct of design and PCB layout. Testing the electrical noise on key nodes within the circuit and monitoring ripple was paramount to maintaining a high quality signal for stable operation, even in a low-power device like the VAB. Furthermore, probing at these same select nodes enables verification of node voltages in accordance with their specifications. For example, VBAT must supply 3.9-4.2V when charged to full capacity, VBAT_SCALED must comply with the ADC input parameters and be under 0.966V, USB5V must be ~5V, USB3.3V must be 3.3V, and there must be negligible voltage ripple or electrical noise throughout the circuit when operating. In order to test the signal integrity of the production board, key nodes in the circuit with respect to the schematic had to be tested. These included the following voltage nodes: USB5V, USB3.3V, Vcc, VBAT, VBAT_SCALED, CHARGE_EN, and BAT_CHECK.

The following results confirm proper operation of all major voltage rails and current loops within the VAB's circuitry while adhering to the device specifications for each component used in the design.

Testpoint	Voltage (V)	Current (mA)	Within Specification?
USB5V	5.04	-	Yes
USB3.3V	3.5	-	Yes
VCC (USB power)	3.46	-	Yes
VBAT	4.14	-	Yes, within 3.9-4.2V
VBAT_SCALED	0.932	-	Yes, under 0.966V max
BAT_CHECK	3.36V	-	Yes

RLED	-	66.53	Yes
GLED	-	66.9	Yes
R+GLED	-	73.8	Yes
Base Current	-	61.8	Yes
Motor	-	110.2	Yes

Table 1: Table of circuit test points for voltage and current.

Battery Life & Charging

One of the main considerations of the VAB is the battery life while in use. Given that the VAB is intended as a wearable alert system that is constantly worn, battery life is expected to last at least 24 hours on a single charge through normal usage with minimal charging downtime. To limit this downtime two measurements must be observed, the time for the battery to discharge and the time to charge as this controls the frequency of the downtime and its duration. Battery life testing is done through an automated script that allows for a higher sampling frequency and greater consistency than if a person were to manually run the tests. The script runs the device at full power and every five seconds it reports the voltage across the battery.

The following battery life data was collected for 15 second, 30 second, and 60 second wake/sleep interval cycles:

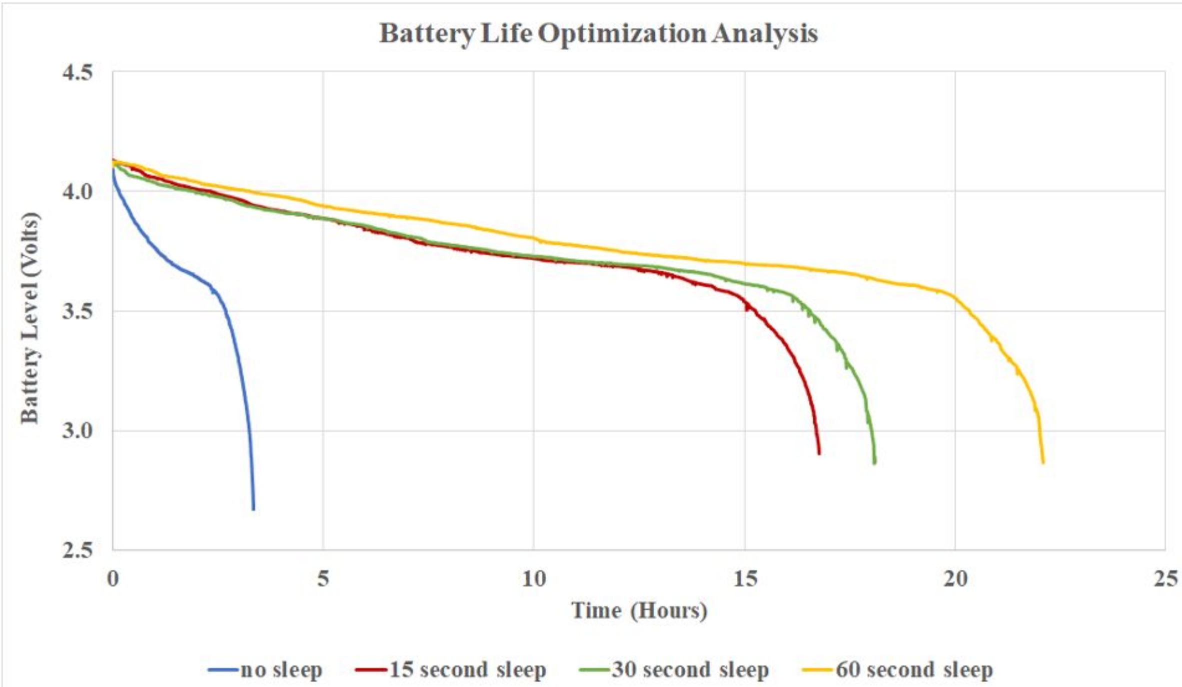


Figure 4: Comparison of battery longevity between 0, 15, 30, and 60 second sleep cycles.

In order to test the battery charging process, measuring supplied current proves more useful than voltage charge due to the charge methodology applied to lithium ion battery technology.

The following data is representative of the battery's charge time for current:

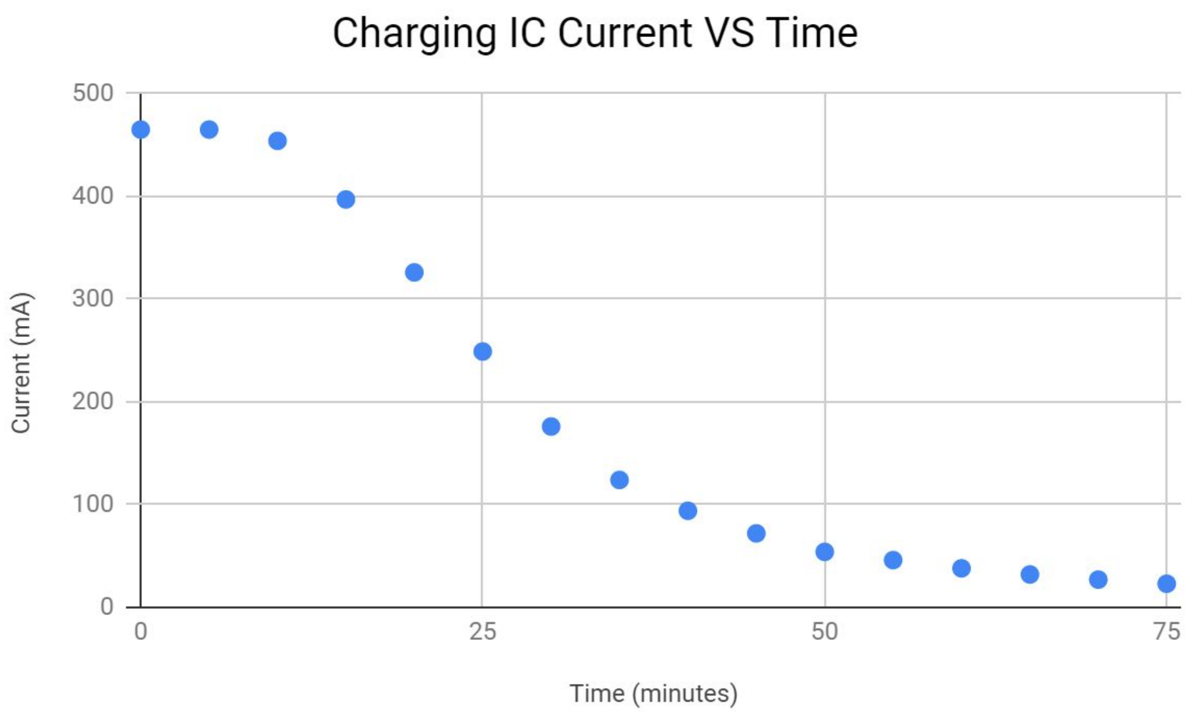


Figure 5: Graph of battery charge time to full capacity.

Case Design

When designing the 3D model to contain the VAB's circuit board, the case had to be compact enough to wear comfortably on an average-sized wrist, rigid enough to stand up to the rigors of daily use, and be simple enough to operate. After initial prototyping, validation was required to address form-fit and accessibility concerns. The following objectives were aimed for and verified after the model was printed. If they were not met, changes were made to provide these attributes for the final prototype.

Checking design constraints and prototype quality yields satisfying results, thus fulfilling all the above benchmarks.

Figure 6: VAB case fitment.

Bracelet Firmware

The bracelets current code is able to satisfy most of the necessary requirements of the system with the possibility of minor improvements and optimizations. The bracelet is able to send an alert to the server once the button has been pressed. The button can also be pressed at any time during the operation of the bracelet by an interrupt. The bracelet is also able to receive messages from the server once connected and interpret the messages and perform necessary functions such as activating the pager motor. Improvements can be made to the user setup of the device. While this functionality may be added later in the project, it seemed that this was less important than the bracelet's primary functionality.

App Functionality

The app currently fulfills each of the test cases that it was designed around. The test cases cover the full intended functionality of the app, and thus the program is able to handle everything needed for the scope of the project. As written above, the app is able to effectively connect to the server, receive client information, and present it to the user on an updating interval. The app is also able to properly send notifications to the user's phone to alert them of requests for help sent by bracelets.

Server Functionality

The server's test results with the test cases listed in the previous section are all favorable. The server is able to handle all the required cases specified previously. As such, the server program implements all the functionality needed for this project. This includes handling connections with properly functioning threaded sockets, as well as handling multiple consecutive messages from one socket. The program is also able to correctly create and pass on the client information stored on the device.

Conclusions From Experimental Verification Testing

As described in the aforementioned design verification sections, the VAB functions as intentend, meeting all functional performance parameters by adhering to the electrical design's limits, performing the intended actions of vibration and visual signalling when pinged from an app across a WiFi network, and remaining compact and ergonomic enough to comfortably be worn throughout the day.

Testing has shown that even on the optimum 60-second sleep cycle, battery life is under a day, and with more realistic, frequent polling every 30 seconds, battery life decreases even further to ~20 hours. Therefore, battery life remains an area where significant improvement can be done. Comparison against targeted performance parameters has also shown that there is room for improvement in making the device smaller and physically more compact.

Economic Viability

The VAB is an open source project designed as a proof of concept, this means that it is not meant to be mass produced, therefore most economic considerations were not made for a manufacturing scale. Small scale batches of the device in limited quantities means that labor and tooling costs are neglected, therefore the driving economic factor is part costs.With this being an open source project and not a medical device there is no set of standards that this project can directly follow.

Legal Concerns, Standards, & Regulations

Since the VAB was intended as a design study and a proof of concept, the project specifications explicitly stated that existing standards and regulations need not be followed. Due to the open-source nature of the VAB's electrical design and software implementation, there are no intellectual property concerns either with no legal infringement.

Risk Analysis

Current Concerns

One of the current challenges faced with the design is the enclosure durability. With the PCB being small, the enclosure required small posts that were difficult to to keep from breaking. The enclosure tolerances were precise enough to where the posts were not needed to keep the board in place, however, posts to hold the board in each corner would have better supported the board and enhanced the vibration it produces.

The other major challenge we faced was battery life. The battery lasted only around 3 hours with no sleep function implemented, which does not meet battery life's specifications. One way to overcome this issue would be to use a bigger battery. However, increasing the battery not only increases the battery life but also increases the dimensions of our enclosure. The best way to increase the battery life without having to change aspects of the enclosure was to implement a sleep function. This would decrease the power used, but increase the latency of the device, waking up every 60 seconds. Battery life was found to be more important to the design than the latency due to the use of the device.

Future Considerations

Future iterations of the VAB have several different possible changes possible. The first change that could be done, which would likely have the most significant impact, would be to change the wireless communication system used. If the system was changed to a Bluetooth Low Energy (BLE) or a different system it would increase the battery life; but this would require a significant redesign of how the VAB bracelet connects to the server. At minimum a intermediary between the bracelet and the server would be required, this would mean that the system would need a base station for the bracelet to connect to which could then interface with the server. By adding this it requires an entirely new hardware to be designed, tested and have firmware created for. This would greatly increase the scope of project which means that more personnel would be needed.

Redesigning the enclosure of the system would further miniaturize the bracelet and allow for a larger battery. Possible issues with this would be increasing the weight of the device and harming the ergonomics of the bracelet. To avoid these issues prototyping the revised enclosure via 3D printing would be the recommended path, this would allow for rapid prototyping and testing of new possible models. With this the main issue then becomes dealing with the printing resolution, by designing over iterations any issues with print resolution could be dealt with.

In terms of software, there are a number of improvements that could be made for future versions of the project. The primary improvement would be to add the ability to create new clients for bracelets within the app. At the moment, adding new bracelet users to the server requires modification of the files that the source files for the server by a user. This functionality could be implemented within the app to allow for a much better overall user experience.

Project Legacy

Over the course of the last year working on this project several lessons were learned. From a hardware perspective the lessons learned were centered around learning the fundamentals of how to design a good pcb, how to choose the correct electronic components for the application, and how to an electrical design with minimum power consumption as the primary constraint. With respect to the software aspect of this project, there were many lessons learned regarding Android development and embedded C++.

As this project was the first PCB that any of the team members have created the entire process had to be learned from the very beginning. Seemingly simple tasks like finding the correct schematic and PCB footprint libraries for the components chosen were frustrating at times. Getting familiarized with the software to even begin the PCB design was also a challenge. While EasyEDA is very good for free software, the tutorials for it are lacking.

Choosing the correct electronic components was a challenge that was not expected to be challenging from the onset. Specifically, finding low voltage, small form factor, X7R series ceramic capacitors was a challenge. There were occasions where the design had to be adjusted as the capacitor that was called for in the design did not exist from any manufacturer.

Doing an electrical design with minimum power consumption as the main constraint was likely the biggest challenge encountered in this project. The bracelet's restrictive form factor also contributed to the difficulty of making the design as low power as possible. As the size of the battery was fixed at a constant size the power draw had to be minimized through more efficient circuit design.

Due to the team's lack of experience in developing for Android, creation of the app proved to be time consuming and difficult with some substantial redesigns done throughout the life of the project. A more advanced knowledge of the structure, terminology, and libraries involved with writing for Android would have shortened the development substantially. Before any work was able to be done, a significant amount of research was required to be able to work with Android's unique use cases and terminology. There are many different predefined views and functions created for developers, and utilizing them properly was a significant challenge.

Writing embedded C++ code for the ESP8266 was a challenge in and of itself. There were several difficulties encountered that persisted throughout the entire process. First and foremost was a lack of knowledge of how to write robust code for a microcontroller. Crashes and resets due to the ESP's watchdog timer triggering were shockingly common. Secondly was the unreliable nature of the Arduino codebase for the ESP8266. The two primary issues encountered were a memory leak on the TCP/IP client stack that would cause periodic crashes and the complete non-functionality of the microcontroller's Light Sleep function. The aforementioned issues were solved by modifying the client stack header file, and by using an old version of the codebase where Light Sleep still functioned.

References

[1] K. Conley, J. K. D'Souza, A. Foyer, P. Hara, T. Janik, and J. Reichard, "Abstract for Vibration Alert Bracelet ," in *Final Project Abstract*, Milwaukee, WI: Marquette University, 2019.

[2] K. Conley, J. K. D'Souza, A. Foyer, P. Hara, T. Janik, and J. Reichard, "Design Verification for E45 Vibration Alert Bracelet," Marquette University, Milwaukee, WI, rep., 2019.

[3] K. Conley, J. K. D'Souza, A. Foyer, P. Hara, T. Janik, and J. Reichard, "Experimental Verification Report for E45 Vibration Alert Bracelet," Marquette University, Milwaukee, WI, rep., 2019.

[4] K. Conley, J. K. D'Souza, A. Foyer, P. Hara, T. Janik, and J. Reichard, "Formal Proposal Report for E45 Vibration Alert Bracelet," Marquette University, Milwaukee, WI, rep., 2019.

[5] K. Conley, J. K. D'Souza, A. Foyer, P. Hara, T. Janik, and J. Reichard, "Project Definition for E45 Vibration Alert Bracelet," Marquette University, Milwaukee, WI, rep., 2019.

[6] K. Conley, J. K. D'Souza, A. Foyer, P. Hara, T. Janik, J. Reichard, and C. Ababei, "Open Source Vibration Bracelet for Notification of Visual/Hearing Impaired in Apartment Communities ," Marquette University, Milwaukee, WI, rep., 2019.