Child Location Monitoring Device

Group 9

Create-X Capstone

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II. Executive Summary

Parents have a keen interest in knowing where their children are physically located. This is evident with the rise in popularity of applications such as "Life360", where anyone with a phone can know other trusted members' locations. However, without the benefit of a phone, parents do not have a great solution for keeping tabs on their younger children. There are few products on the market aimed at solving this problem for families, though they lack performance in three key areas: durability, battery life, and ability to stay with the child. Specifically, children three to ten years old are rough with what they are wearing, parents want batteries to last for at least a few days, and kids try to take things off themselves all the time. Current products are simply not engineered to stand up to the wear and tear of daily childhood existence while also delivering the location tracking services parents want in an affordable, comfortable form factor.

To prove out a design concept to meet these goals, the team gathered requirements from parents. These are translated into functional requirements that the engineering team can put towards a realizable design. With requirements nailed down, the engineering team uses a handful of ideation and selection methods to determine the most important aspects of the design for a prototype.

These design tools inform the desired functionality of the device, but before the team dives into specific implementation, a patent search is conducted to understand prior art and to avoid (or be aware of) patent infringement. To this end, six patents are found that pose a risk of infringement, and the team works to produce clever ways of navigating them.

With all design work prepared, the software team prototypes with some off-the-shelf BLE, Cellular, and GPS development boards to integrate with a smartphone application. In parallel, the electrical and mechanical teams work on the physical device – PCB layouts are generated and designed to fit into custom enclosures designed by the mechanical team. The mechanical team designs a custom latching mechanism that is easy to fasten but difficult to un-fasten by a child and 3D-prints a custom band for form-factor visualization.

To understand how this prototype compares to existing products, the team conducts tests: the software team creates a simple smartphone app to test the Bluetooth functionality and range compared to a competitor's product. Preliminary results show that the team's low-fidelity prototype comes within 70% or meets the competitor's product, while still well exceeding consumer requirements. Similar experiments around mechanical life of the proposed latching mechanism are also performed using Finite Element Analysis.

With a functional device in hand, the team examines manufacturing feasibility, looking to move towards injection molding and PCBs in the future. The team also considers the environmental, societal, ethical, and sustainability concerns associated with full-blown production of the product as the team moves forwards with getting seed funding and participating in an incubation program.

III. Nomenclature

PCB (Printed Circuit Board) -- a thin board made of fiberglass, composite epoxy, or other laminate material through which conductive pathways are etched or "printed" onto board, connecting different components.

UWB (Ultra-Wide Band) – a low-energy radio communication technology for short-range, high bandwidth device to device communication.

BLE (Bluetooth Low Energy) – a low-energy variant of Bluetooth designed for low-bandwidth device to device communication.

GPS (Global Positioning System) – a navigation system which synchronizes localization, velocity, and altitude of a receiver by connecting to multiple satellites.

IoT (Internet of Things) – the interconnection of computing devices embedded in everyday objects via the internet.

MQTT (MQ Telemetry Transport) – a lightweight publish-subscribe network protocol which transports messages between devices. Designed for IoT devices.

1. Introduction and Background

In general, parents are concerned for their child or children's safety. This protective instinct is useful in many ways, though the constant mental load associated with worrying over children can eventually have negative effects that out-weigh the positives. One such worry is knowing where their child is during the day, especially when the child is going to a new location or somewhere with lower levels of adult supervision than the parent is traditionally comfortable with. Currently, in most of these situations, parents are helpless, relying on good-word or blind trust in those that are responsible for their child. And while most caregivers are worth trusting, the incidences that keep parents up at night are the instances where there is a lapse in attention or judgement of a caregiver (or the child), leaving the child stranded or abducted. Few parents can imagine a worse scenario for their child. In fact, after interviewing over sixty parents of kids between the ages of three and ten years old, the fear of losing a child or child abduction rates in most parents' top five fears with their children, especially when they're not under their parents' watchful eye.

In parallel, several successful companies have built out tracking options to help people find things. Notable products/companies include Life360, Apple Air Tags, Tile, Apple Find My, and Samsung Find My Mobile. The democratization of these products has laid the groundwork for other types of tracking products to hit the market, making integrating a GPS, Bluetooth, Cellular, etc. a straightforward proposition. As such, a couple of products have heard the cry of parents and are aiming to solve some of these issues. Most notable in this category are Jiobit by Life360, Angel Sense, and Gizmo Watch 2 by Verizon. Each of these incorporates GPS tracking into a physical device with a mobile app. However, none of these options seems to have captured a substantial share of the potential market, and most are poorly reviewed by consumers. Many parents reported having considered these options but did not purchase them for various reasons including concerns over battery life, durability, and ability to stay with the child.

2. Existing Products, Prior Art, and Applicable Patents

There exist a handful of existing products aimed at meeting this need – some products have been discontinued since the middle of the pandemic, citing chip shortages as a primary reason. Fundamentally, most of the products are not built well for young kids. Most lack the robustness and durability parents long for inside a package that will stay on their child without their worry.

2.1 Toddler Proximity Sensing Devices:

Gizmo Watch 2 – $99 plus activation cost and monthly fee - The Gizmo watch is a device designed for children to wear around their wrist, with text and call capability. Many of the reviews claim that the watch has a poor build quality, does not charge, and that the battery dies very quickly.

Jiobit - $90 + $9/month fee – The Jiobit is a clip-on GPS tracking tool marketed at kids, pets, and seniors. saves power by using Bluetooth Low Energy when in-range. This is the highest rated and recommended tracking device, though it has little promise of staying on young kids.

Angel Sense - $59 + $33.33/month fee – The Angel Sense is a small wearable GPS tracker and 2-way communication device marketed at parents of kids with special needs and elderly people with memory problems. The Angel Sense does not have the capability to use Bluetooth which limits its battery life substantially.

2.2 Applicable Patents

The information disclosure statement in Appendix 1 gives a list of all applicable patents that the device could infringe upon. The disclosure contains both utility and method patents; this list is not exhaustive.

In 2016, Christopher DePascale patented a wearable personal locator device with a removal indicator [1]. Christopher identified that guardians want to know if the wristband of the device has been removed. Our device will also perform this action, but instead of using a frangible circuit placed on adhesive on the back of the device (as the patent does), our device will use a circuit running through the band.

Other prior art includes a wearable that contains electronics in both the display and the band of the wearable that communicates when the two components are connected [2]. There is also a utility patent on a wearable that integrates its battery into its band to conserve space in the top of the device [3]. Also included is a wearable device that comprises biometric and environmental sensors, which could be relevant in a future version of our device [4]. Overall, the Pomdot device will have a combination of features, some unique, that no one patent includes and will therefore avoid infringement. Licensing from companies who own the patent to certain features might be needed if commercialization is pursued.

Since most of the functionality of this device comes from the design of the software and electronics, it is important that investigation any prior art in this area as well. Two patents by Jiobit claim a method of selecting a location tracking category and communicating this information to the parent [5, 6]. Their patents include a device that contains up to three location tracking categories. The method used to select between Bluetooth and cellular location categories could infringe on this patent.

3. Customer Requirements and Engineering Design Specifications

3.1 Customer Requirements

Parents want a reliable, durable device with a long battery life that stays on their child and can let them locate their child instantly and effortlessly. To this end, Appendix A1.1 shows the functional requirements developed to meet this goal. These functional requirements mesh well with the House of Quality shown in Appendix A1.2, which takes those requirements and passes them through an importance filter, to yield the areas of the product most crucial to implement optimally.

As seen in Appendix A1.1, the most important functional requirements revolve around child safety – parents want to feel confident that this device will never cause their child distress or harm. Therefore, requirements such as “non-choking”, “does not burn child”, and “child proof” are considered immensely important.

These requirements begin to outline some fundamental constraints on the solution set. Appendix A1.1 lists these constraints. The constraints largely fall under two main categories, physical and technological. Physical constraints focus on the customer-facing requirements; for instance, many children are allergic to nickel and cannot wear something that would irritate their skin, while technological constraints are more closely tied to the state-of-the-art and underlying physics; for instance, there is currently not a cost-effective method of communicating GPS data over large distances (> 2 miles) other than using existing cellular networks. This is a fundamental constraint on solving the technical portion of this product.

3.2 Design Concept Ideation

After determining the customer requirements, the mechanical design team began ideating potential avenues to solve the problems presented. These ideas are represented in Appendix A2.1 in the mechanical design space. When looking at ways to make the device adjustable to fit a growing child, the team considered a strap with discrete intervals that would adjust to fit the child. Alternatively, bands could be replaced as the child grew. Adjustable straps are also considered to provide continuous adjustability.

Keeping the device on the child and deterring or making it impossible for the child to remove the device is imperative. A magnetic lock that could be powered on and off by only the parent or authorized guardian is considered. In a similar vein, a lock mechanism is considered where a physical key is required to remove the device. Alternatively, the doffing process can be made torturous for the child. Similarly, making the doffing mechanism require two or more hands to remove would also increase the difficulty of removal.

To keep the device "hidden in plain sight" and seamlessly integrated into the child's life and clothing, designing the device to be a common accessory or clothing article that children wear is the prevailing design theory. Working removal detection into the overall design is also very important, such as a continuous wire that would detect if the device has been cut.

4. Market Research

4.1 Target Market

The target market of the wearable is parents of children aged 3-10. ChildStats.gov places the number of children in the 3-10 age group around 28,500,000 [12]. This group will experience turnover (new children turning 3 years old) approximately equal with the birth rate, of 3,750,000 children per year [3]. Based on the fact that roughly 1/3 of parents track their children's location, at least 1/3 of parents would reasonably be expected to show interest in our product. With this factor, the total addressable market is sized at 9,480,000 parents, with a turnover rate of 1,250,000 parents/year. Assuming a product price range of $90-110, the total market size is $948 million to $1.04 billion, but with a yearly turnover of $113 million to $137.5 million. Both analyses can be fine-tuned as the team conducts more quantitative customer interviews, to gauge interest more directly in the exact products hypothesized.

4.2 Major Competitors

Ranging from purely proximity detection at $35 in the My Buddy Tag up to $99 plus a $30+ monthly fee for GPS tracking and messaging capabilities in the Gizmo Watch 2, products in this space span a fair amount. To be competitive, the team's device comes in at a sub-$100 price range with a minimal monthly cost (< $10/month).

There are many existing products on the market that claim to solve these problems, although the products that currently exist tend to be poorly made, unreliable, and of poor build quality. Another chief complaint is battery life (or lack thereof) for most of these devices. See "Existing Products, Prior Art, and Applicable Patents" above for a detailed list of competing devices.

5. Final Design Overview and Justification

Appendix A2.2 shows a morphological chart of different system designs and design options. The three main concerns for system design are Method of Local Wireless Communication, Method of Global Wireless Communication, and Method of Locating the Device. For each, there exist several well-established protocols and supporting hardware. Most smartphones are well equipped to deal with the Bluetooth Classic, Bluetooth Low Energy (BLE), and Wi-Fi protocols out of the box, ruling out methods which do not take advantage of these protocols. Bluetooth Classic requires more power and a larger software stack to implement on an embedded device, making BLE an attractive option since it requires minimal code, very little power, and can be run in the background on most phone operating systems. Wi-Fi meets some of these criteria, but Wi-Fi consumes much more power than BLE[7]. For global communication, the only protocol/interface that most smartphones implement is cellular, therefore that decision is straight-forward.

Most phones have a few reasonable localization options available but are constrained by topology. GPS works close to everywhere in the world, since it relies on satellites which orbit the earth. Ultra-Wide Band (UWB) and BLE require other UWB or BLE enabled devices to act as "anchors" to localize objects, functioning well in crowded areas, but infeasible in more remote areas. GPS makes the most sense.

The selected design for adjustability is a watch-strap system with a series of pegs on the underside of the electronics package corresponding to a series of holes in the watch band. This design integrates well with a removal detection circuit. Childproofing the device is designed around making the unclipping mechanism difficult to remove. Ideally, the parent or guardian can easily put on and remove the device with relative ease. Ultimately, creating a clip mechanism that can only be removed using two hands was selected for its balance of low-profile implementation, tool-less application and removal, and intuitive operation.

While several form factors were considered, the most seamless integration choice was a bracelet. Bracelets are gender neutral and screenless. They also only allow one hand of the wearer to be involved in taking it off, matching the selected childproofing method. However, the electronics package would ideally be translatable into necklaces, scrunchies, belt buckles, and anklets as well.

Some of the expected electrical design difficulties as the concept is moved towards commercialization include miniaturization, FCC approval of antennas, and power consumption. The current PCB layout is designed to be the size of an evaluation board. Further miniaturization will be accomplished primarily by upgrading the design from a two-layer board to a multi-layer board such that the small surface mount devices such as capacitors, inductors, and resistors can be placed very close to each other and be packed together. Further reduction in size can be done by replacing the chip antennas with surface mount antennas located within the wristband. Design of these antennas can be time consuming and requires FCC approval.

6. Industrial Design

The biggest industrial design consideration for the device was the overall size of the device. A major complaint for parents who used competitor products was that the device was very bulky, and some parents also complained about the inclusion of a screen in competitor products as it serves as a distraction and structural failure point. The device's size is minimized to house the electronics and seamlessly fit into the child's fashion with a sleeker, minimalist look. There is a slight design focus on making the device aesthetically pleasing to the child as well. The theory behind this thought is that if the child enjoys wearing this device and likes showing it off to their friends, they will have less incentive to attempt to remove the device, leading to less unauthorized removals. Introducing bands with designs that appeal to the children in the targeted age group and adding designs on top of the electronics package are also potential avenues to improving the appeal of the device to the child. Forgoing a screen also helped miniaturization. Certain devices show a diagram that can inform people of which allergies a child has where a screen would normally be. For example, a child with a peanut allergy would wear a Pomdot with an embossed peanut and the text "PEANUT ALLERGY" on the electronics housing package, which would be colored tan/brown as well. An example of this device with these types of designs is shown in Appendix 3.1.

7. Detailed Technical Analyses, Experimentation, and Design Performance Prediction

7.1 Sizing

The desired user of this product will be children aging 3-10 years of age. Because this is an age group that has a wide range of wrist sizes, the adjustability of this device is a crucial functional requirement. After looking at statistics for children in this age range, it has been determined that the circumference of the band needs to be able to adjust for a wrist circumference between 5 in and 6.5 in. It can be assumed that the overall shape of the wrist scales uniformly, but some accounting for irregular wrist shapes must be done. Wrist size will also play a role in the design of the electronics package as well as the clip mechanism. Since the curvature of the wrist will change as it gets bigger, it is important to design these components to account for this. Luckily, the top of the wrist is relatively flat compared the sides, so if the curvature of the electronics package meets the average curvature of our customers, it should affect comfort.

7.2 Material Testing – Fatigue Analysis

For the purposes of a low fidelity prototype, the components are 3D printed in different photopolymer resins on Form Labs Form3 printers. The band is printed in Flexible 80A resin, which has an ultimate tensile strength of 1290 psi, can be elongated 120% before breaking [8]. Furthermore, this resin is soft to the touch and comfortable to wear, making it a viable lo-fi prototyping material for developing the band. The electronics package is encapsulated in Tough 1500 resin which has an Elastic Modulus of 218 ksi. Tough 1500 is meant for parts to be printed that will be withstanding high impacts and rugged use, thus making it great to use when simulating a child's activities' effects on its ability to withstand impacts [9]. The final materials used in the manufacture of the device have yet to be finalized, but for the purposes of rapid prototyping, these materials will provide a good alternative.

7.3 Power Analysis

On the electrical side, power analysis was performed to determine the average power consumption of the device, specify the required battery size and estimate device run time. The device's major power consumption components typical current draw, operating voltage, and duty cycle are tabulated from manufacturer datasheets, shown in Appendix A4. The estimated average power draw for this device is 25 milliwatts. Using a 1.1 Wh battery, then the run time would be nearly 44 hours, short of the design specification. However, methods such as eDRX and PSM can be used to reduce the operating frequency of cellular connectivity; an accelerometer can be used to determine whether the child is in motion, strategically putting the device to sleep when the child is not in motion. A full power analysis will need to be performed on the physical device once the high-fidelity prototype is realized.

In the future, antenna analysis will need to be performed to ensure the antennas are receiving and transmitting signals as intended along with impedance analysis to get the proper antenna matching circuitry; the antennas being used for BLE, cellular, and GPS all have an inherent impedance of 50 Ohms, and to avoid signal reflections, the total impedance between the cellular chipset and each of the antennas must also be 50 Ohms. Keysight's Advanced Design System software will be used to analyze the impedances from the PCB traces, vias, and the antenna switches. The necessary capacitors and inductors will be added into the circuit for the remaining impedance matching.

7.4 Medium Fidelity Electronics Prototype Testing

The medium fidelity electronics prototype was tested for GPS accuracy, BLE range and penetration, and cellular connectivity. These numbers ensured that the right communication protocols and location methods were chosen but are not necessarily reflective of the final device due to different components being used in the miniaturized version of the device. To test GPS accuracy, the GPS unit on the smartphone was taken as ground truth, and the location determined by the GPS was measured relative to this, when the prototype was held vertically over the phone. Distance was computed between the two GPS locations using google maps, and the results are tabulated in Appendix 3.18. For BLE range testing, the prototype and a connected smartphone were slowly moved apart until a disconnection event was registered. The distance between resulting locations were measured with a construction-reel tape measure. Results are tabulated in Appendix 3.19. Lastly, cellular connectivity was tested in several places on Georgia Tech Campus. The entire campus is mostly covered, with a few small dead-zones where cell reception would be routinely and predictably lost. Of the locations tested, 98% of them repeatably held cell reception.

8. Final Design, Mockup and Prototype

8.1 Electronics Package

Given the requirements of size and weight restrictions and modularity, the initial proposed electronics packaging and layout, as seen in Appendix A3.3, was three separate PCBs that are stacked vertically to reduce the surface area of the device. A 3D model of the PCB stack and electronics package is shown in Appendix A3.4. After starting PCB layout, it was realized that the electronics can likely be packaged within a single PCB. As seen in Appendix A3.12. development PCB has been designed which combines most of the elements that go on the final product within a medium fidelity prototype. This PCB is to prove that the components can be fit within a relatively small sized board and the packaging can be further miniaturized. The electrical schematic for this board is shown in Appendix A3.13. An initial bill of materials has been created, as seen in Appendix A5, and the current single unit cost for the required electronics is approximately $65; this drops to $38 at scale.

8.2 Band

The current band is designed to be slim and comfortable. The current prototype rendering is shown in Appendix A3.2 and actual prototype in Appendix A3.16. The method of attaching the band to the clip mechanism is also an important component. The design for this prototype consists of an interlocking feature where the band has a bulb shape that the clip slides around. One side connects to the clip, and the other side ends in several holes to attach onto the pegs on the bottom of the electronics housing. The band slides through inlets on either side of the housing and securely connects into the pegs like a watch band or similar adjusting mechanism found on other wearables. However, this implementation under the electronics housing is a way of adding in adjustability to the device while keeping it childproof. The child cannot undo the device through the adjusting mechanism without removing the device completely, which is outlined in the section detailing the clipping mechanism.

Another main feature of this device is removal and tamper detection. This is achieved by running a small copper wire through the band and clip of the device. An image of this system is shown in Appendix A3.9. The wire runs through a small groove in the center of the band for the prototype, but in mass production it is likely that the band material would be molded around the wire. This system maintains its conductivity through the clip and electronics package transitions by having thin copper sheets that contact each other at each of the interfaces of the band. The copper sheet on the electronics band can be seen in Appendix A3.6.

8.3 Clip Mechanism

There are currently clip designs for both a child proof and non-child proof mechanism that are being implemented into the first prototype. The childproof design is included in the initial drawings in Appendix A3.7 showing a locked clip, and Appendix A3.8 showing an unlocked clip. The first, a child proof design, is a two-part design that contains a latch mechanism that is like what one would see in a common side release buckle but is opened by moving the arms of the buckle outward rather than pinching them inwards. This will make it very difficult for the child to open the clip with only one hand and will therefore require a second person to take it off. The design utilizes a compliant mechanism in both arms, and therefore must be made of a material that can withstand a high amount of fatigue. The mechanism snaps together with ease, requiring little effort by the parent of the child that is putting on the device.

8.4 Companion Application

The companion application uses a three-paned app flow, shown in Appendix A3.8. On initial launch, the user's location is shown on the map. Switching to the Devices tab via the bottom menu bar takes the user to a screen where they can scan for their Pomdot device and connect to it over BLE. Once connected, the Map tab will show the location of both the phone and the Pomdot device. When the Pomdot moves out of BLE connection range the device will transition to communicating over cellular data. The device will reconnect automatically upon returning to Bluetooth range. Finally, if the device is removed, a notification will be pushed to the user's phone, alerting them of an unauthorized removal, as shown in the last image of the app flow in Appendix A3.8. The application was developed in Java using Android Studio.

8.5 Medium Fidelity Electronics Prototype

To prove out the communication protocols, data flows, and application functionality a medium fidelity electronics prototype was developed, and encapsulates the major functionality of the device. The prototype, pictured in Appendix A3.9, uses breakout boards and large antennae, and is significantly oversized, measuring roughly $2.3x5x1.5in$. For cellular communication and GPS localization, the prototype uses the Sara-R5 breakout board, which communicates with an EPS32 over UART. The ESP hosts the BLE Gatt server which connects to the companion app on the smartphone, as well as commanding the Sara-R5 chip to read GPS location and send data over cellular network when necessary. ThingSpeak server is used to publish and read data of the cellular network. Finally, a button is wired to the ESP32, pressing of which is used to simulate the opening of the device removal detection circuit, triggering a device removed warning. The breakout boards are both powered from a battery bank via USB connectors. The bill of materials for the electronics prototype is given in Appendix A3.17.

9. Manufacturing

9.1 Electrical Packaging and Assembly

The manufacturing process on the electrical side will primarily comprise of three major steps: PCB manufacturing, component placement, and testing. The PCB manufacturing process is fairly complex but has been highly studied and replicated. At the mockup and prototype stages, PCB manufacturing will be done by vendors while it will be custom made for the mass production stage. Once the PCB itself has been created, components can be placed and soldered using modern automated processes at the mass production scale while being done manually by hand for mockups and prototypes. Similarly, testing on the mass production version of the products will be done using a series of test points that are checked using automated systems, whereas the mockups and prototypes will be tested by hand.

9.2 Mechanical Parts Manufacturing

The mechanical components will be injection molded. These include the band, clip, and electronics housing package. Design considerations will have to be taken when switching manufacturing methods as well to make the product viable for injection molding. A benefit of introducing injection molding is the ability to mold the plastic around metal parts, which would help hide and safekeep the copper loop that is used for removal detection. Also, it provides an overall cleaner aesthetic design in the final product.

The overall manufacturing and assembly will likely take place outside of the United States as labor costs are typically cited as being high. Other watch manufacturers such as Fitbit have a complete manufacturing and assembly setup within a single plant in countries such as South Korea, Taiwan, and Vietnam.

10. Codes and Standards

Given that most of the product’s useful life will be spent in contact with a child, certain safety and durability metrics will need to be met to empirically prove that the device is rugged and safe enough for everyday use. The standard to achieve will be UL certification. ULI Industries conducts testing and certification for a variety of products, including wearables. The standards for ULI certification are outlined Appendix A6.

11. Societal, Environmental and Sustainability Considerations

Some of the societal considerations with the Pomdot wearable are related to electrical safety with the battery and its management. Poorly designed electronics can explode and cause injury and thus making sure the product works seamlessly without any issues is a priority. This can be mitigated by utilizing proven and reliable power management techniques and components. Additionally, keeping the power draw low and having quality heat management are important to ensure that any user doesn’t get burned from the device. An environmental consideration with the device has to do with electronic waste. E-waste is a rapidly growing issue as electronics and batteries contain various dangerous chemicals which can easily find their way into the environment and society when thrown away. This issue can be mitigated by potentially having a recycling program for Pomdot devices once a child has grown old enough to no longer need one.

12. Risk Assessment, Ethical Considerations, Safety and Liability

Given the use case of the device, safety and the ethics of the product must be given due thought and consideration. An important distinction needs to be made that Pomdot does not prevent abductions, but instead informs parents of unauthorized removal immediately and the last known location of the device. This is important from a liability standpoint as the product cannot be held accountable for kidnapping or abduction, but its capabilities are an excellent asset in helping to save a child in a potentially dangerous situation. Furthermore, the data collected, and the app will be employed with the best security measures to make hacking into the device and app extremely difficult from a malicious actor. Keeping the information out of the wrong hands is a priority and something to implement in its fullest capacity when the product goes to market and parents rely on the device for to make sure their child is safe.

In addition, the materials used to manufacture the device have to be completely non-toxic to the child who wears it. The final materials that will be used are silicon for the band and ABS plastic for the electronics housing package and clip. Both materials have seen a high usage in the manufacture of wearables and are well known to be non-toxic to the wearer. However, making sure that the band is free of Latex and other elastomer allergens is important to consider as well to avoid irritation, rashes, or other allergic reactions that would make parents averse to using the product.

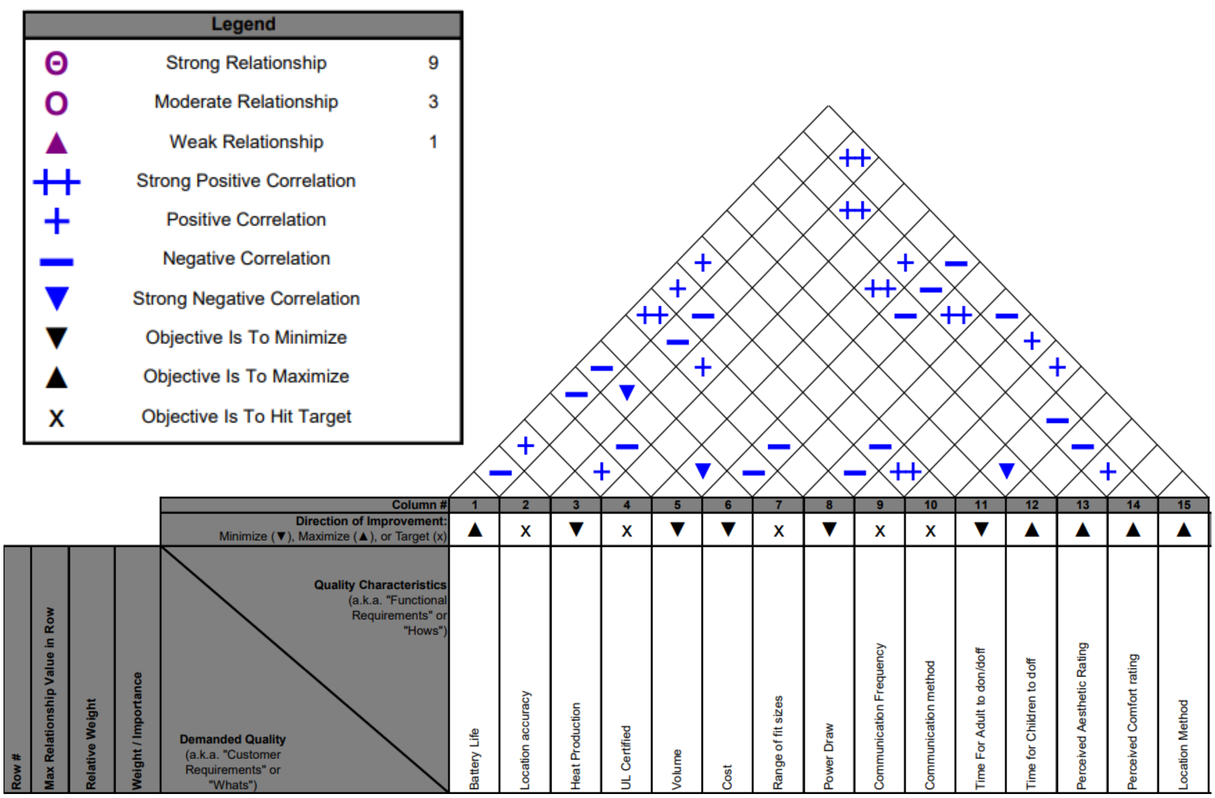
13. Future Directions

Over this past semester this team has gone through the stages of customer discovery, product ideation, and product development, eventually creating a device that ensures peace of mind from parents and guardians of young children. The goal of this project was to create a device that is more rugged than products that are currently on the market, has a longer battery life, and contains features that have never been seen before in a child wearable. Most, if not all the member of this team feels strongly about this being a problem that is worth solving, which is why many people in the target demographic have shown interest in this product and have said that they would love to see it on the market. There are several challenges that face the project in the upcoming steps, but there are avenues forward towards tackling them and the team believes in their capabilities to handle them. The next major milestone for this project would be to develop a successful miniaturized electronics package, which would forecast a successful product-to-market plan. From there, the path forward is unknown, but several team members are interested in working on this project in some capacity (full-time, part-time, or advisory) in the immediate future.

14. Appendix 1

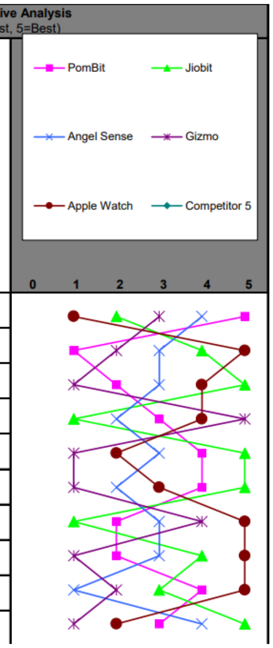
Customer Requirements	Constraints
Child Proof	Communicating GPS data
Comfortable	Form Factor
Easy to put on but difficult for child to take off	Battery Life
Tracks child	Interoperability with partner app
Does not burn child	Ability to use a charging dock
Minimum 5-day battery life	Non-toxic or irritating material
Non-Irritating / Non-Toxic	
Parent Interface	
Rugged	
Zero Risk of Strangulation or Choking	
Charging capability	

House of Quality:



Row #	Max Relationship Value in Row	Relative Weight	Weight / Importance	Demanded Quality (a.k.a. "Customer Requirements" or "Whats") \ Quality Characteristics (a.k.a. "Functional Requirements" or "Hows")	Battery Life	Location accuracy	Heat Production	UL Certified	Volume	Cost	Range of fit sizes	Power Draw	Communication Frequency	Communication method	Time For Adult to don/doff	Time for Children to doff	Perceived Aesthetic Rating	Perceived Comfort rating	Location Method
				Direction of Improvement: Minimize (▼), Maximize (▲), or Target (x)	▲	x	▼	x	▼	▼	x	▼	x	x	▼	▲	▲	▲	▲
1	9	7.8	5.0	Hard for Child for Remove						▲	▲				O	Θ	▲	▲	
2	9	6.3	4.0	Easy for Parent to Remove						▲	▲				Θ	O	▲	▲	
3	9	10.9	7.0	Comfortable			Θ		O	▲	Θ						▲	Θ	
4	3	15.6	10.0	Non-Choking				O	▲										
5	9	15.6	10.0	Safe to Wear			O	Θ		▲								▲	
6	3	10.9	7.0	Durable						O	▲						▲	▲	
7	9	14.1	9.0	Location Tracking	Θ	Θ				O		Θ	Θ						Θ
8	9	12.5	8.0	Easy access to data		▲							▲	Θ					▲
9	9	1.6	1.0	Aesthetically Pleasing	▲				Θ	O	O						Θ	▲	
10	9	4.7	3.0	Adjustability					▲		Θ				▲		O	Θ	
				Target or Limit Value	7 days	5 meters	Contact Temp under 75 degrees F	Certification	8 cm^3	$100	Ages 2-10	6 mW	Optimized	Optimized	< 5 seconds	> 30 minutes	> 4/5	> 4/5	Optimized
				Difficulty (0=Easy to Accomplish, 10=Extremely Difficult)	10	3	6	5	6	4	2	10	3	1	3	7	4	6	1
				Max Relationship Value in Column	9	9	9	9	9	3	9	9	9	9	9	9	9	9	9
				Weight / Importance	128.1	139.1	145.3	187.5	67.2	120.3	170.3	126.6	139.1	112.5	84.4	89.1	64.1	182.8	139.1
				Relative Weight	6.8	7.3	7.7	9.9	3.5	6.3	9.0	6.7	7.3	5.9	4.5	4.7	3.4	9.6	7.3

Demanded Quality (a.k.a. "Customer Requirements" or "Whats") \ Quality Characteristics (a.k.a. "Functional Requirements" or "Hows")	PomBit	Jiobit	Angel Sense	Gizmo	Apple Watch	Competitor 5
Direction of Improvement: Minimize (▼), Maximize (▲), or Target (x)	**Competitive Analysis** (0=Worst, 5=Best)					
Hard for Child for Remove	5	2	4	3	1	
Easy for Parent to Remove	1	4	3	2	5	
Comfortable	2	5	3	1	4	
Non-Choking	3	1	2	5	4	
Safe to Wear	4	5	3	1	2	
Durable	4	5	2	1	3	
Location Tracking	2	1	3	4	5	
Easy access to data	2	4	3	1	5	
Aesthetically Pleasing	4	3	1	2	5	
Adjustability	3	5	4	1	2	



Information Disclosure Statement:

U. S. PATENT DOCUMENTS					
Examiner Initials*	Cite No.[1]	Document Number Number-Kind Code[2] *(if known)*	Publication Date MM-DD-YYYY	Name of Patentee or Applicant of Cited Document	Pages, Columns, Lines, Where Relevant Passages or Relevant Figures Appear
		US- 9508241B2	24-02-2014	Christopher DePascale	
		US- 9471102B2	14-08-2015	Townsend, et al.	
		US- 20150333302A1	15-05-2015	Johns, et al.	
		US- 10537245B2	28-12-2015	Miller, et al.	
		US- 9980087B2	01-12-2017	Renaldi, et al.	
		US- 10064002B1	30-04-2018	Renaldi, et al.	

15. Appendix 2

Adjustable	Watch Strap	Elastic/Silicon Strap	Helmet Clip	Velcro	
Child-proof	Magnetic Lock	Lock and key system	Complex clipping pathway	Two-handed unclipping	
Aesthetic/Seamless implementation	Bracelet	Anklet	Necklace	Belt	Scrunchie
Charging	Solar Power	Kinetic Energy harvesting	Long-lasting Battery	Pogo-Pin charger	
Removal Detection	Continuous embedded Wire	Magnetic separation detection in Clip			

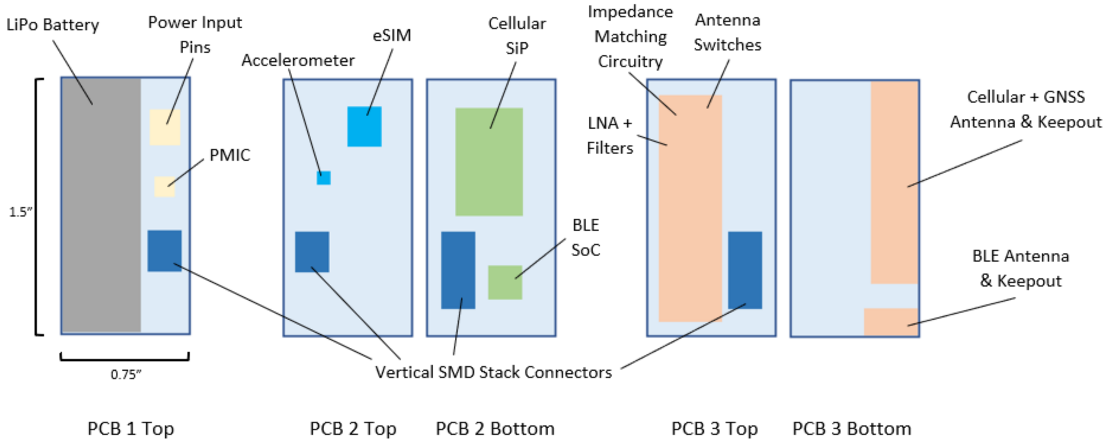
Local Wireless Communication Method	Bluetooth Classic	Bluetooth Low Energy	MQTT	LoRa	zigbee	Radar	WiFi	Nothing
Global Wireless Communication Method	Cellular	Low Frequency Radio	Satellite	Nothing				
Positioning Protocol/Specification	GPS	Ultra Wide-Band	Bluetooth Low Energy	Nothing				

16. Appendix 3

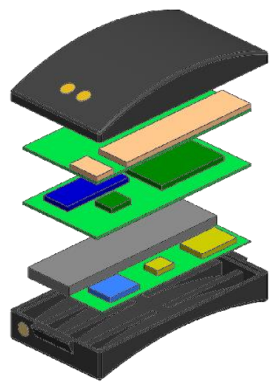
A3.1: Allergy Indication on Top of Electronics Package

A3.2: Fully Assembled Band Showing Adjustability Points

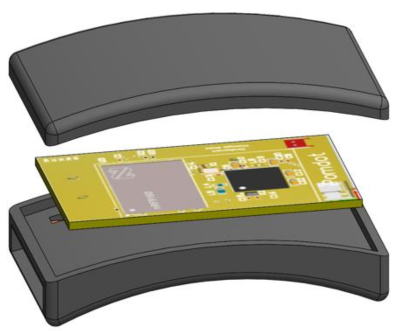
A3.3: PCB Stack Proposed Layout



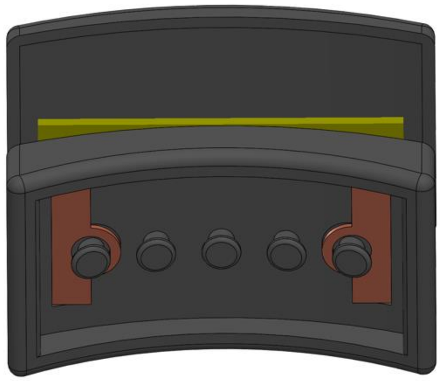
A3.4: Electronics Package Prototype 1



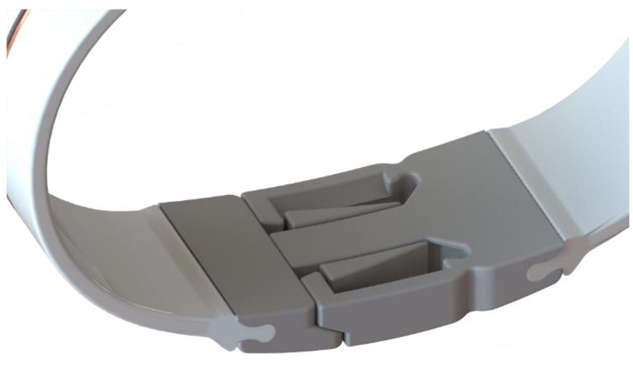
A3.5: Electronics Package Prototype 2



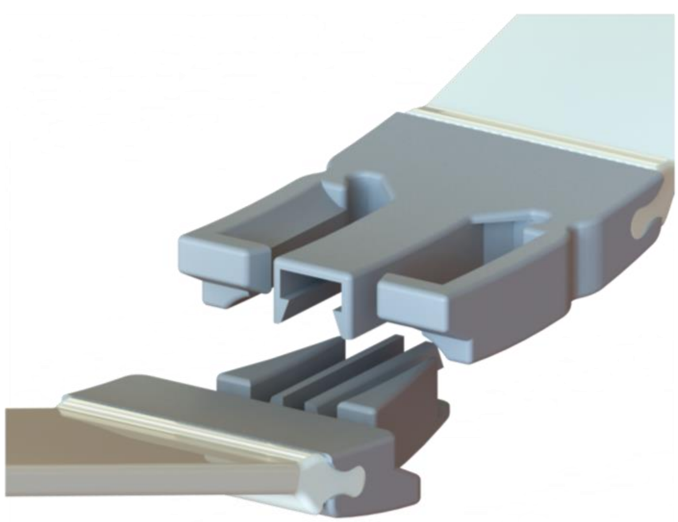
A3.6: Conductive Surfaces on the Underside of Electronics Package



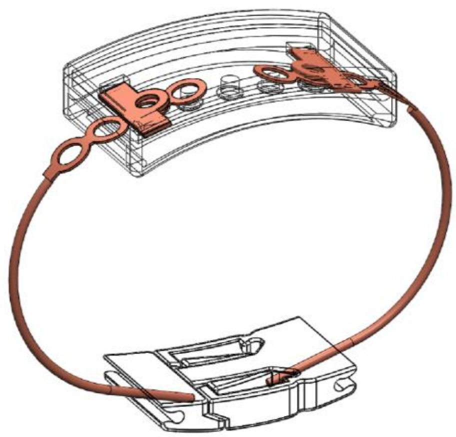
A3.7: Clip Mechanism (Locked)



A3.8: Clip Mechanism (Unlocked)

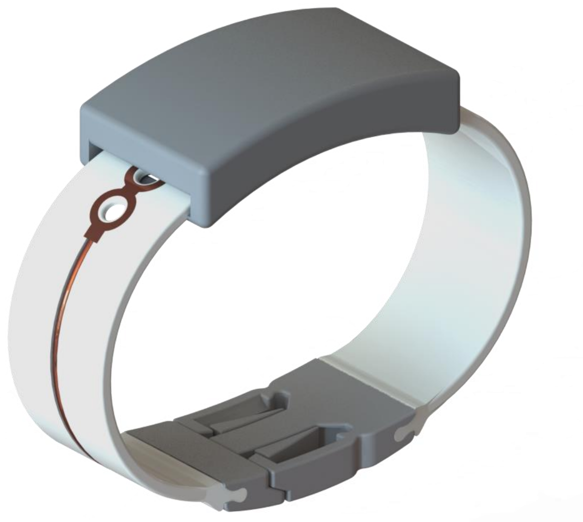


A3.9: Circuit Running Through Band and Clip

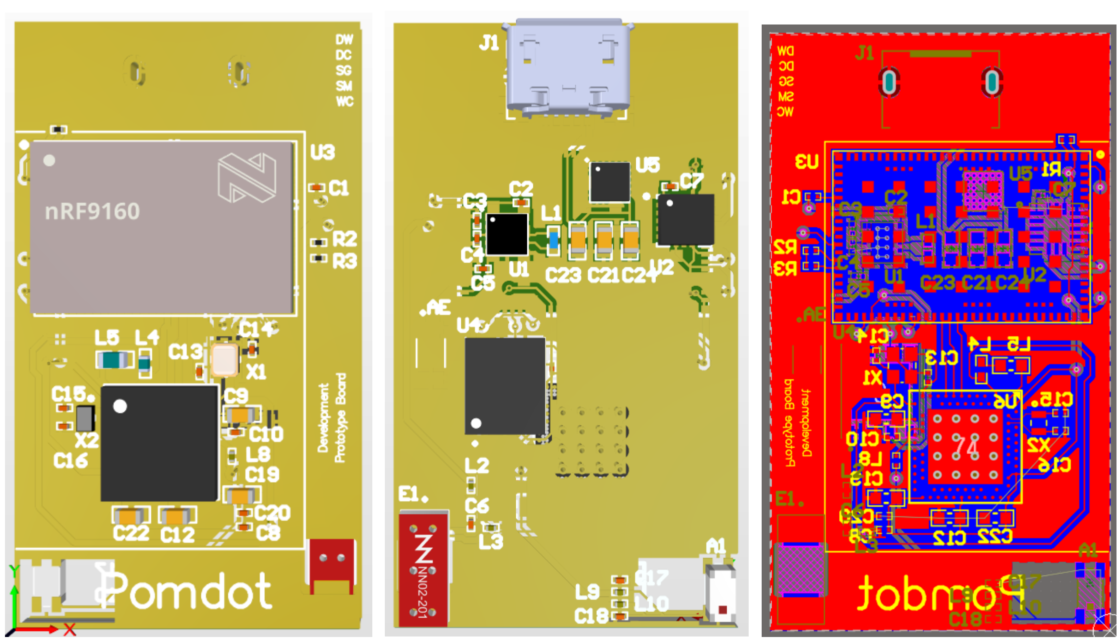


A3.10: Current Prototype Showing PCB in Electronics Package

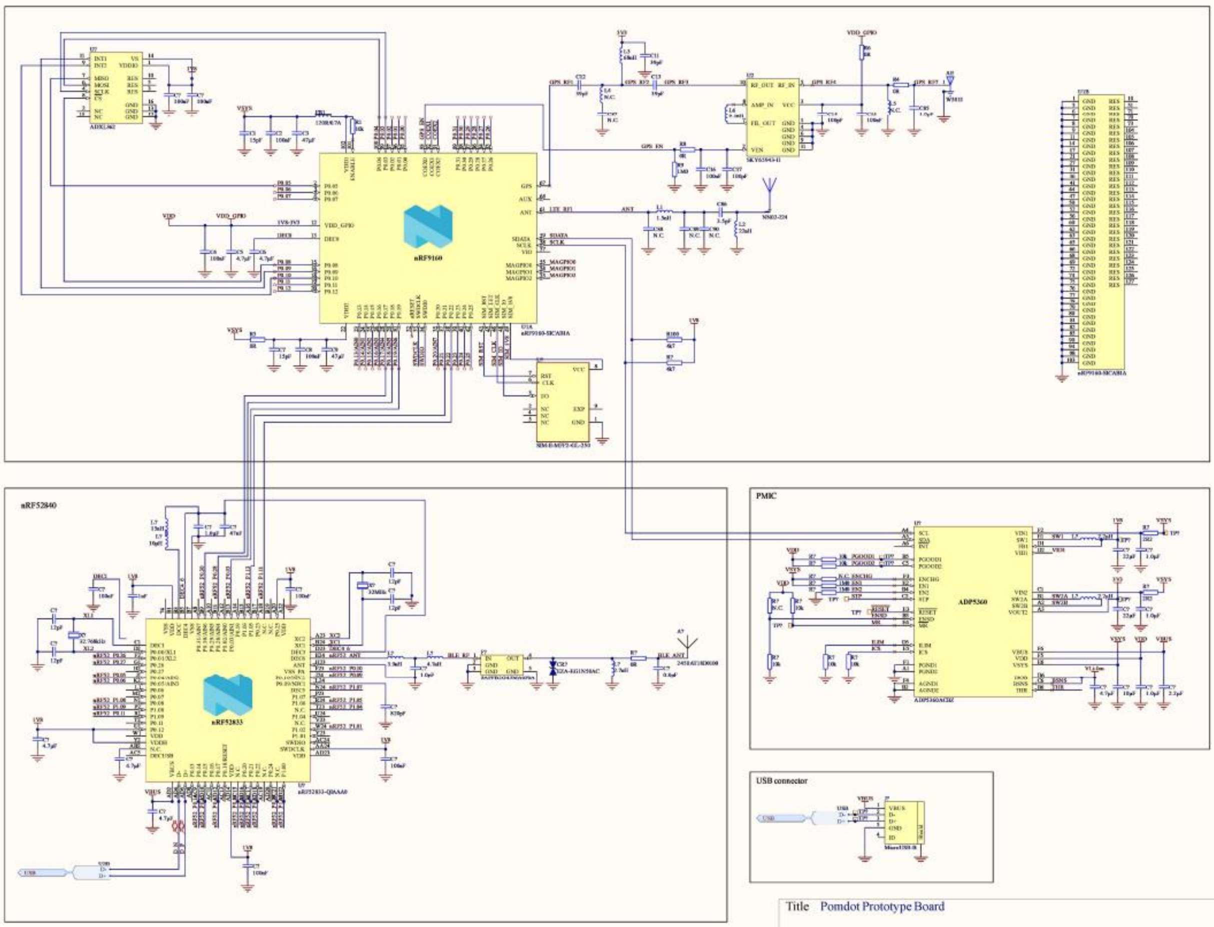
A3.11: Current Prototype Showing PCB in Electronics Package



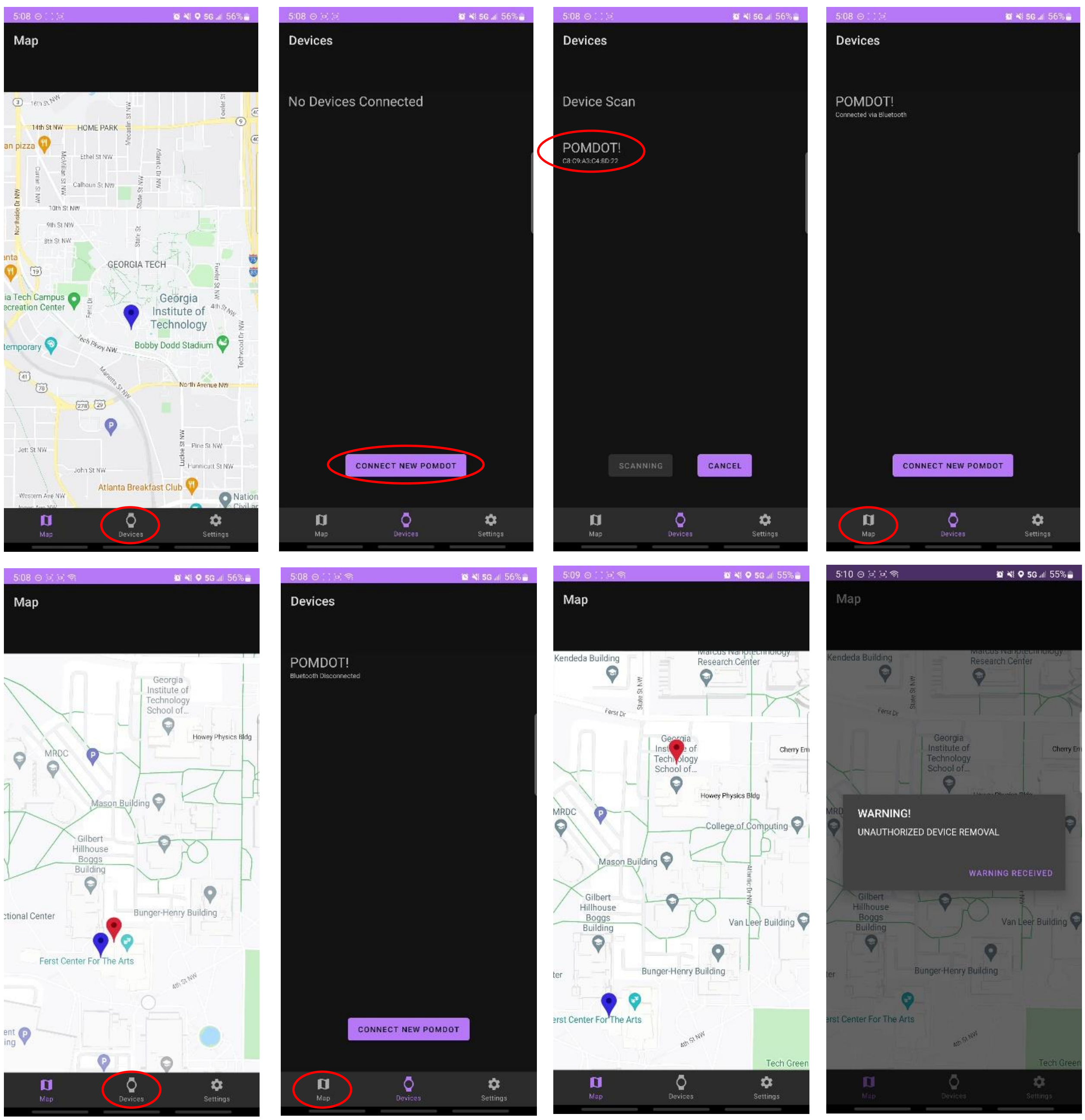
A3.12: Pomdot Development Board PCB Layout



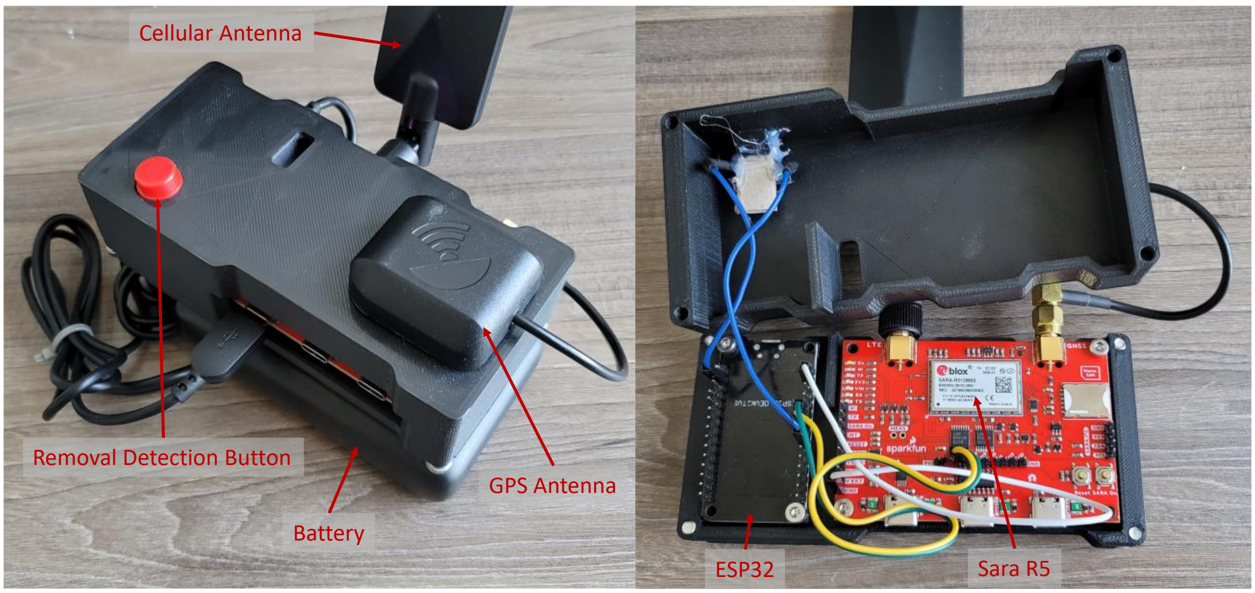
A3.13: Pomdot Development Board Schematic



A3.14: Companion Application Use Flow:



A3.15: Medium Fidelity Electronics Prototype



A3.16: Medium Fidelity Mechanical Prototype

A3.17: Medium Fidelity Electronics Prototype Bill of Materials

Purpose	Part ID	Vendor	Cost

Cellular/GPS	SARA-R510M8S	Sparkfun	$133.95
BLE, microcontroller	ESP32	Amazon	$20.88
GPS Antenna	uxcell GPS Active Antenna 90-Degree SMA Male Plug 28dB	Amazon	$12.51
Cellular Antenna	9dBi RP-SMA Male 3G 4G LTE Cellular	Amazon	$7.99
Pushbutton	SP-22SH	Digikey	$5.46
Enclosure	3D Printed	Invention Studio	$0.00
		Total:	$180.79

A3.18: GPS Accuracy Testing Results

Conditions	Average Range (meters)
Optimal (outdoors, clear sky)	± 1
Suboptimal (indoors, access to windows, lightweight building materials	$\pm(3-10)$
Adversarial (indoors, no windows, heavy building materials)	No GPS Lock

A3.19: Bluetooth Connectivity Testing Results

Conditions	Average Range (ft)
Optimal (outdoors, line of sight)	260
Wall Penetration (industrial walls)	6 Walls*
Floor Penetration (industrial buildings)	4 Floors*

* Varies with structural thickness and composition.

17. Appendix 4

Power Budget:

Power Consumption Components						
	Part ID	Operating Voltage (V)	Avg Current (mA)	Avg Power (mW)	Duty Cycle	Dimensions (mm)
MCU + LTE + GNSS + Flash	nRF9160	3 - 5.5				16 x 10 x 1
Cellular Non-BLE		3.7	1.45	5.365	50%	
GPS Non-BLE		3.7	4.5	16.65	50%	
GPS BLE		3.7	2.5	9.25	50%	
BLE + MCU + Flash	nRF52833	3.7	0.15	0.555	50%	5 x 5 x 1
Power Management + Voltage Monitor	ADP5360	3.9	0.01	0.039	100%	3 x 3 x 1
Cellular + GNSS Antenna	NN02-224	3.7	1	3.7	100%	L x 7 x 3
BLE Antenna	2450AT18D0100	3.7	0.2	0.74	50%	8 x 4 x 1
Accelerometer	BMA400	3.6	0.01	0.036	100%	2 x 2 x 1
GNSS LNA w/ Filters	SKY65943-11	1.8	2.9	5.22	100%	3 x 3 x 1
				36.335	**25.275**	
Misc. Components						
eSIM	SIM-E-MFF2-GL-250					6 x 5 x 1
Antenna Switch Module x 2	BGS18GA14					2 x 2 x 1
BLE SAW Filter	SAFFB2G45MA0F0A					1 x 1 x 1
Power Supply						
Battery	Custom					L x (W - 8) x H

18. Appendix 5

Electrical Bill of Materials:

Electrical BOM					
	Part ID	Vendor	Unit Cost	1000x Unit Cost	Alternatives
MCU + LTE + GNSS + Flash	nRF9160	Digikey	$ 27.11	$ 18.96	AVT9152/RAK8211
BLE + MCU + Flash	nRF52833	Digikey	$ 7.20	$ 3.62	BGM220SC22HNA2
Power Management + Voltage Monitor	ADP5360	Digikey	$ 5.48	$ 2.93	MAX20360, DA9070
Cellular + GNSS Antenna	NN02-224	Digikey	$ 4.55	$ 2.58	0830AT54A2200
BLE Antenna	2450AT18D0100	Digikey	$ 0.67	$ 0.29	
Accelerometer	BMA400	Digikey	$ 1.70	$ 0.96	
GNSS LNA w/ Filters	SKY65943-11	Digikey	$ 3.45	$ 1.73	
eSIM	SIM-E-MFF2-GL-250	Digikey	$ 5.43	$ 2.56	
Antenna Switch Module x 2	BGS18GA14	Digikey	$ 2.20	$ 1.18	
BLE SAW Filter	SAFFB2G45MA0F0A	Digikey	$ 0.23	$ 0.12	
LiPo Battery	Custom	Grepow	$ 5.00	$ 2.60	
			$ 63.02	$ 37.53	

19. Appendix A6

Wellness or nonmedical wearable	IEC/UL 62368-1 Audio/Visual, Information and Communication Technology Equipment – Part 1: Safety Requirements
Medical device safety	IEC 60601-1, IEC 60601-1-11 – and all related standards
EMC	IEC 60601-1-2 (or equivalent for nonmedical applications)
Usability	IEC 60601-1-6 (or equivalent for nonmedical applications)
Biocompatibility	ISO 10993
Software cybersecurity	ANSI/CAN/UL 2900 Standard for Software Cybersecurity for Network-Connectable Products, Part 1: General Requirements
Software Lifecycle Process	IEC 62304
SAR for wireless communication devices in EU	EN 50566: 2013, EN 50566: 2013/AC:2014, EN 50360: 2001, EN 62209-1: 2006, EN 62209-2: 2010, EN 62311: 2008
AR/VR/MR equipment	ANSI/CAN/UL 8400 Standard for Safety for Virtual Reality, Augmented Reality and Mixed Reality Technology Equipment – Part 1: Safety (in development, world's first dedicated equipment safety standard for AR/VR/MR)

20. Appendix 7: Budget

Date	Vendor	$ Amount	Purpose/Description
23-Feb	JioBit by Life360	$141.56	GPS/BLE Locator, research solutions/competition
23-Feb	Amazon	$159.90	ESP32, LTE/GPS Breakout board for prototype
24-Feb	Amazon	$22.30	LTE, GPS antennae for lo-fi Prototype
11-Mar	Amazon	$12.51	Alternative GPS antennae for lo-fo prototype
14-Mar	McMaster Carr	$24.97	Magnets (charging attachment)
4-Apr	Grainger	$10.40	Alternative magnets for connection design
7-Apr	Digi-Key	$190.92	Electronics components for PCB med-fi Prototype
11-Apr	Amazon	$17.35	Copper foil for conductive loop in wristband
11-Apr	Amazon	$45.56	Microphone for project video recording
13-Apr	Hologram	$10.00	Cellular data plan for mid-fi prototype
18-Apr	JLCPCB	$50.00	PCB order for mid-fi prototype
19-Apr	Thingspeak	$79.00	Server for hosting cellular communication
	Total	$764.47	

21. References

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