2020 Vision: Wearable Haptic Ultrasonic Object Detector

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Capstone Design ECE 4440 / ECE4991

Signatures

12/16/19 Joshua Raphael Arabit

12/16/2019 Jazlene Rae Guevarra

12/16/19 Renée Lin Mitchell

12/16/19 William Tiger Zhang

Statement of work:

Joshua Arabit

Joshua is responsible for planning and integrating the different subsystems together in order to have a fully working device by the end of the semester, aiding in the design of embedded software with Bill, and supporting the population and debugging of the PCB. Planning the final integration of the subsystem included the cognizant role of understanding how all the systems connected together and to update the planning of integration whenever a design of a subsystem was changed throughout the life of the project. Once the subsystems were designed and finished, Joshua led the integration process by supporting the testing of the subsystems once they are connected to each other and made sure that all input and output connections were seeing the intended data and/or measurements. In addition to the integration of all the subsystems, Joshua also worked with Bill to design a motion sensing algorithm that will take in the distance data from the sensor and determine if it should notify the user with a haptic vibration. Most of his duties consisted of pair programming and debugging of software solutions for the algorithm and testing the device once it was the algorithm was on the microcontroller. The last of his duties consisted of aiding in the population of the PCB through soldering proper connections and debugging any mistakes in the design of the PCB.

Jazlene Rae Guevarra

Jazlene is responsible for designing the wearable device contraption on which the PCB and components will be mounted, designing SolidWorks 3D model, as well as the test plan and decision tree diagrams that will provide the team with official methodology for ensuring the success of the project at the end of the semester. She took charge in organizing the team in assigning tasks and keeping track of what is done and what is not, and continually helps with technical writing and creating diagrams for team document submissions. For designing the wearable contraption, the team had to decide whether they wanted to focus on marketability or functionality, and which provides the most stability to accommodate for the sensor based on the available design options. Jazlene chose three different contraption products online and made different alternatives for the wearable contraption. After the Midterm Design Review, the team ultimately decided to use a Bluetooth headphones collar design, which allowed her to perform preliminary designs. Additionally, she designed a box using SolidWorks to house some components. For the test plan, by referencing the team's system integration diagram and Multisim schematics, she typed out an outline, dividing the plan by each subsystem of the project and organized the data into a decision tree that will provide guidelines for how to ensure that the project will work at the end of the semester.

Renée Mitchell

Renée's primary responsibilities in the group are hardware-oriented and include designing the printed circuit board (PCB), selecting appropriate components to purchase, and assembling them on the PCB. In creating and refining the circuit schematic, Renée used the National Instruments (NI) Multisim Component Wizard toolbox as well as the NI Ultiboard Parts Wizard toolbox to fashion specific device footprints. The ultrasonic sensor, vibration motor, MSP430G2553 Launchpad (during the prototyping stages), MSP430G2553 integrated circuit, and

JTAG unit are examples of components that require custom footprint designs as dictated by their respective datasheets. After wiring the Multisim schematic for each iteration of the board, she prepares the Ultiboard PCB configuration and then submits the resulting gerber files to FreeDFM for a design report. In this role, it is necessary to take into consideration such changes and adjust the design of the hardware accordingly. Finally, when the parts come in, Renée solders them onto the board for testing, and then she works with her teammates to configure the testbench according to the data that they hope to collect.

William (Bill) Zhang

Bill is responsible for designing and writing the embedded software which would the logic of the device. This involves writing code to interface with the sensor and motor and designing an appropriate algorithm which would process the sensor data to trigger the haptic motor when an object is incoming. In designing the software, Bill had to create a flow diagram for the midterm review showing the basic logic of the program. Then, when actually implementing the algorithm, Bill had to figure out how to best approximate velocity given the limited distance data provided by the ultrasonic sensor, how to deal with noisy data coming from the sensor, and also empirically determine constants to use in the code (such as velocity threshold). In addition to writing the software, Bill also helped Joshua with testing the different subsystems, with more focus on the MSP430 subsystem and the software involved. This included testing the initial subsystem demo for the midterm review, testing if the MSP430 could successfully read data from the ultrasonic sensor, and also testing the final product in both controlled laboratory environments and uncontrolled environments (like outdoors).

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Abstract

2020 Vision: Wearable Haptic Ultrasonic Object Detector is a device that increases situational awareness in the user's blind spots, and involves the design, development, and production of a wearable device that communicates with the user using haptic feedback, a method of communication using the sense of touch, of incoming or approaching objects in the user's environment. The Texas Instruments MSP430G2553 microcontroller chip communicates with the MB1010 Ultrasonic Sensor and performs the necessary algorithmic calculations and power the embedded system to full functionality, which entails detecting incoming collisions and notifying the user of potential dangers in the environment using haptic feedback.

Background

Disabilities of any shape or form can be significant hindrances in performing simple routine tasks. They also put those affected in the position of being deficient in capabilities compared to the average healthy person, which can lead to inferior feelings. As such, there is great motivation to address this topic. Specifically, within the realm of disabilities, visual impairment is particularly grievous due to its alienating nature and how it affects physical mobility (if there are any doubts in the mind of the reader about its alienating nature, just consider the negative connotation of the popular idiom, "the blind leading the blind"). With this issue at hand, the team is inspired to start a project that aims to ameliorate the lives of those who are visually impaired.

As precedent for this project, consider the field of autonomous vehicles and its association with object detection studies. Engineering has seen the development of robots with the ability to identify objects for the purpose of navigating office and work settings and performing basic tasks, such as an autonomous system that can aid nurses in hospitals by helping with bed transports [1]. Similarly, but even with nonmobile systems, electromechanical surveillance systems deploy object recognition techniques. In military applications, image processing object detection establishes security measures, such as hyperspectral imaging for continuous tracking [2]. This finds anomalies in order to detect objects that "stand out from the cluttered background" [3].

While there have been projects produced that produce wearable systems to aid the visually impaired [4][5], this particular project is simpler and straightforward to use. Even though engineers have produced smart systems that perform more than object detection, the aim of this project is to solely prevent object collision in the user's environment. There are a few reasons for this, the primary one being that the team has a very limited timeframe to realize this project. The project heavily emphasizes haptic feedback, and the focus of this semester will be on making that feature as reliable and user-friendly as possible. The second reason is that a simpler system can also be easier to understand and use by a greater population than with a complex system. For instance, very young children can make use of this product, which may not be true of more advanced systems that require greater understanding and ability to navigate multiple functions. The same can be said for those with Alzheimer's or other memory impairments who cannot independently deploy the product.

Courses that will provide the background knowledge needed include Fundamentals of Electrical Engineering I, II, and III, as well as Embedded Programming and Analog Integrated Circuits.

Constraints

Design Constraints

The device was visualized to have a small compact form factor to be fashioned into wearable device the user can wear ideally strapped on their head or shoulder area, or anywhere on their body. Therefore, we have a considerable constraint on the weight of the given components and parts, as well as the power source of the device that must also be wearable, or at least portable for the user to carry around, also constraining how the software algorithm designs and how we process calculations. There exists multiple components and parts that we considered useful for device functionality, however they each must be carefully researched to determine their conformity to the constraints.

Economic and Cost Constraints

MSP430 vs MyRio

The MSP430 was an appropriate choice for this project due to the available interface with MC1010 ultrasonic sensors as well as the competency of the team in programming such boards. The unanimous completion of a prerequisite course, Introduction to Embedded Programming, serves as motivation to put collective knowledge to use in building a product that is more advanced than is included in the class curriculum. Another popular option that classmates are using is the myRio, yet the team feels more confident in programming MSP430, as well as in the potential for interfacing with sensors. The specific board model that is featured in the Embedded Programming course is the MSP430, which the project shall use as well.

Object Detection Sensors

The components that were considered for the sensors for object detection are: ultrasonic, radar, sonar, LIDAR, and computer vision, and based on research concerning capabilities, functionalities, and constraints, ultrasonic, radar, and LIDAR were the best options out of the five listed. We ultimately decided to use ultrasonic sensors, specifically a MB1010 ultrasonic sensor, for this project because of its availability and price, which is $29.95 per unit, on Digikey. It has low power consumption, which is good for a wearable device, and its data quantity is not as extensive since it will be collecting data at a frequency of 20 Hz, meaning that it will not need much processing power [9]. The MB1010 ultrasonic sensor will also have the ability to interface with the MSP430. The only setback is that the sensor will not be able to measure the speed and direction of the object it detects, so we will have to rely on estimations of velocity based on changes in distance data over different time steps.

Radar detection would have been the ideal choice for object detection because radar can handle the capabilities ultrasonic detection lacks: speed and direction measurements, and cannot be affected by environmental variables, like foam, vapors, powder, dust, or uneven services [8], however, radar sensors were not in stock in DigiKey and we would have to wait 15 weeks for the radar sensors, which is outside of the team's schedule for completing the project, therefore putting away radar as the component of choice and choosing ultrasonic detection instead.

Another option was LIDAR, which uses laser light pulses and is the ideal sensor for object detection due to its precision and accuracy, which is the sensor of choice for autonomous vehicles because it can detect any kind of material, such as rock, plastic, metal, chemical compounds, and clouds, even rain and aerosols [7]. LIDAR would also be a good option for object detection for the project because, however, the cheapest LIDAR sensor found only had a range of 2 degrees, meaning that the sensor was only good as a trigger rather than analyzing and measure incoming objects, its speed and direction.

Sonar and computer vision were not chosen as ideal components for the project because of how they will require more processing power, which means object detection will be slower compared to ultrasonic, radar, and LIDAR. Light is 1000000x faster than sound so both laser pulses and radio waves reach obstacles much faster than sound waves do, which is why LIDAR and radar detect objects on the road faster than sonar does. Furthermore, a high speed of radio and laser signals allows a radar and LIDAR to track the position of a moving object in a more accurate manner than sonar would. Sonar would be an ideal choice when the sound waves are travelling through a medium, like water for example, which is why sonar is widely used for underwater object detection, and for a means of a rear obstacle detection system because when parking, a driver mostly monitors either already parked vehicles or other slowly approaching cars [7]. Computer vision was ruled out as well due to cost because of its necessity for more processing power. It has the ability to detect moving objects through image processing capabilities with a camera, however, it has difficulty measuring distance.

External Standards

There were a handful of standards that came into play throughout the course of the project. First, regarding the PCB board design and hardware design, we followed the standards from the Institute for Printed Circuits (IPC), which are the electronics-industry adopted standards for design, PCB, manufacturing, and electronic assembly, where there is an IPC standard associated with just about every step of PCB design, production, and assembly. In our PCB design, we followed the standards from solder mask, copper foils, assembly materials, solderability, and much more to ensure that our design complied with the IPC standards [36].

A few standards that were relevant were from the Engineering in Medicine & Biology Society (EMB). The project is a wearable sensor therefore involving components of biomedical engineering. There were many standards that EMB puts forth such as:

- Promote culture of cost-effectiveness
- Support the preservation of a healthy environment
- Engage in research aimed at advancing the contribution of science and technology to improving healthcare provision
- Observe the rights of human research and strive for a balance between benefits and potential harm [34]

We designed our project around EMB's ethical standards by using components that conform to our compact form device, such as components that are lightweight and small, which were also not super expensive to purchase, addressing the "promote culture of cost-effectiveness" standard addressed above. Furthermore, the battery that powers our device is rechargeable, therefore contributing to preserving the environment because we do not have to purchase new batteries when the battery current battery dies. After integrating all the subsystems together into the final product design, while we were testing our device on a test subject and in an environment outside the lab environment, we were constantly adjusting our software algorithm, the intensity of the vibrations, and the connections of the device, as well as making sure our test subject was okay all throughout testing to ensure the product was working as expected, therefore complying to "observe the rights of human research and strive for a balance between benefits and potential harm."

Another organization involved is the Institute of Electrical and Electronics Engineers (IEEE), which has defined the P360 Standard for Wearable Consumer Electronic Devices [35]. This standard gives overview, terminology, and categorization for Wearable Consumer Electronic Devices, and further outlines an architecture for a series of standard specifications that define technical requirements and testing methods for different aspects of wearable devices, from basic security and suitableness of wear, to various functional areas, like health and fitness. This standard was used to determine how to begin preliminary designs for the wearable contraption for the device and what kinds of components were needed in terms of size and weight. Understanding and know the IEEE P360 standard was crucial for the foundation of our project before continuing onwards with further project designs, testing, and integration.

Tools Employed

Some of the major tools used in this project throughout the semester, that includes software for analysis and for programming, as well as tools for simulation and design, can be seen below:

- C in Code Composer
- Multisim
- Ultiboard
- SolidWorks
- Multimeter, Oscilloscopes, DC Power Supply on the virtual bench
- Soldering Stations, Miscellaneous Hardware tools
- Bread-Board for testing
- 3D Printers

For programming, the software the team used was Code Composer where we developed in C to program software algorithms to take the data received from the ultrasonic sensor and develop logic to create accurate vibration motor triggers into the MSP430G2553 Microcontroller chip.

Multisim and Ultiboard were used as tools for design and simulation for the project's PCB that connected all our components togethers properly. Multisim allowed us to confirm that the components we are using are correct and give us the results we expect to see through simulation, and Ultiboard allows us to take what we have simulated in Multisim and design the layout of the PCB we wanted to manufacture for our project.

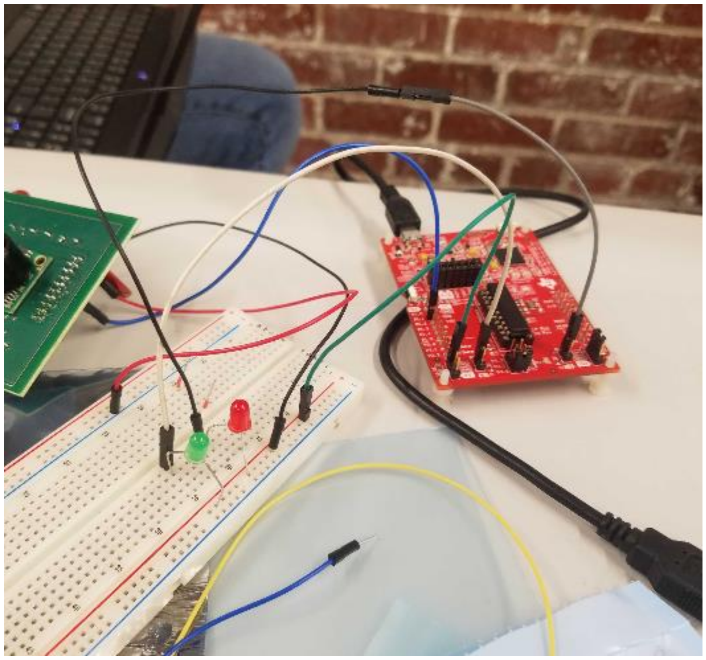


Figure #1: Midterm design testbench setup

SolidWorks was used as a design tool as well, where we designed a 3D model of a box that will house the PCB and the battery and used 3D printers to print the 3D model.

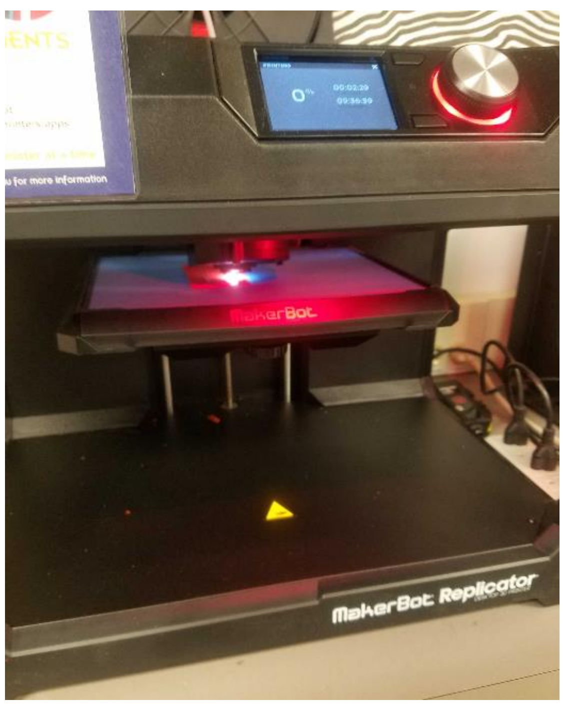


Figure #2: 3D printing the system container

For hardware testing, we used the breadboard, oscilloscopes, multimeter, and the DC power supply on the virtual bench for measurement analysis for debugging purposes to make sure the proper voltages are being inputted and outputted from each subsystem on the board. Once the testing is done, we used miscellaneous hardware tools, such as the soldering stations to solder the components onto the PCB once the subsystems passed several tests, copper wiring for de-soldering components that were soldered on incorrectly, and wire strippers and the X-ACTO knife for fixing incorrect routings on our PCB and stripping wires to make soldering easier.

Ethical, Social, and Economic Concerns

Environmental Impact and Sustainability

The project will have minimal energy impact on the environment and natural resources because one of our main constraints for the device is to have a small, low power source due to the design having a compact form factor fashioned into a wearable device. Because of this constraint in energy, we have components that has low power consumption.

Furthermore, instead of continually buying new batteries, the team bought two rechargeable batteries to prevent waste that would contribute to negative environmental impact due to the difficulty of recycling batteries. Rechargeable batteries are more environmentally friendly than single-use batteries, and not only can they be used repeatedly, but they generate less waste over the long-term. This is most particularly true in the case of power-intensive devices that would drain batteries at an increased rate [37].

Health and Safety

The purpose of the wearable device is to prevent the user from potential injury from any collisions with incoming and approaching objects in their direction. During the testing phase of the project, the user could get hurt from thrown objects at different speeds and directions due to algorithm and detection testing for an incoming object at all cases and situations.

For general use, a concern would be that the user can also obtain injury or discomfort from the vibrations from the haptic feedback motors. There is the possibility of misjudgment of the vibration motor’s intensity, and also an increase in temperature of the working motor, or even from the battery itself.

The most major potential for harm comes from the transmission and reception of ultrasound signals. Even though the MB1010 sensor is compliant with ROHS3 standards, California Prop 65 still warns that use of this device could lead to “cancer and reproductive harm” [21]. A well-known effect of ultrasound is that as ultrasound waves pass through a tissue, they tend to heat it up. The tissue can easily be warmed up to 40 degrees Celsius, however, the heat is usually easily carried away by blood circulation or simply dissipated into surrounding tissue. Another well-known effect of Ultrasound are cavitations, which are small bubbles of gas that are released upon exposure to extreme negative pressure. These bubbles can cause cells or even tissues to rupture in a worst-case scenario. Also, ultrasound is sound at very high frequencies, above those most people can hear, which is usually above 20kHz, and some technologies emit constant ultrasound at higher volumes.

At high decibels, ultrasound’s high-frequencies can still cause direct damage to human ears. Ultrasound in excess of 120 decibels may cause hearing damage, and exposure to 155 decibels causes heat levels that are harmful to the human body. 180 decibels may even cause death. With this information, we must be careful with how we set the ultrasonic object detection sensor and where we plan to place the sensor on a human body, since we designed the device to be wearable, meaning that the sensor will constantly be near the human body [21].

In the article, *“Effects of Ultrasonic Noise on the Human Body* - *A Bibliographic Review*”, written by Bożena Smagowska, states these health concerns regarding the harmful effects of ultrasonic noise to the human body, also mentioning its effects on hearing, thermal effects, and more, however, health standards for ultrasonic noise had been discussed and set in place in Poland with the assumptions that (a) high audible frequencies (10-20 kHz) cause annoyance, tinnitus, headache, fatigue, and nausea and (b) ultrasound components (over 20 kHz) with high sound pressure level may cause hearing damage [22].

Manufacturability

The device will be mounted on a Bluetooth headphone collar that the user can wear on the base of their neck. The Bluetooth headphone collar mounts the ultrasonic sensor and the vibration motor, and their connections extend through long wires to the power source and PCB packed in a small backpack, such as a fanny pack. The original design was to 3D print a box that will be clipped to the belt loop of pants or shorts; however, the backpack was easier to adopt since user’s automatically knows how to wear one without assistance.

Manufacturing this device will be simple and cheap because all that is really necessary is a stable mount that will keep the sensor and vibration motor in place on the Bluetooth headphone collar, thick wires that can withstand environmental factors, and a small backpack to carry the PCB and battery. Additionally, all components are small, light, and cheap. Furthermore, the device design is fashionable and marketable, and does not stand out a lot in public when in use. The Bluetooth headphone collar is very subtle against the body, and the wires can be adjusted by packing the extra wire in the backpack, which is also a design that is not too eye catching.

Ethical Issues

As exciting as the development of haptic feedback can be, there is a very real and growing concern over the intrusiveness of such a feature in electronic devices. Zoltan Istvan, an author who represents the Transhumanist Party, reveals of haptics and virtual reality that "we're approaching an age when we're going to be rewriting a huge amount of the rules of what it means to either harm somebody, or hurt somebody, or even scare them or bother them" [10]. In considering this particular project, the intentions behind the product are motivated by good, so that it may aid those who would appreciate being notified of nearby danger. Surely it can be put to good use from ensuring children’s safety in playing games to protecting military personnel when they are on the field. However, it is important for engineers to consider the ethical implications of their projects, and here it is crucial to discuss when haptic feedback is welcomed as opposed to when it is intrusive. In addition to the ethical concern on intrusiveness of the device, there comes the discussion of the ethical duty as engineers to create and fabricate a safe device for the user. This is due to the fact that the device will be worn close to the user's body which could cause real physical harm if the device is implemented through malpractice and negligence. One portion of our project that could be an ethical safety concern would be the battery powering the device, because any forceful impact to the battery could cause it to rupture. As a result, the team made sure to follow industry standards, especially focusing on the standards of wearable devices to ensure that we are able to create a safe device for everyday use.

Intellectual Property Issues

As far as patents go, there are three that are helpful to illuminate in light of this project. The first is US20050131646A1, filed by Theodore Camus for his "method and apparatus for object tracking prior to imminent collision detection" [6]. In the abstract, Camus describes his product as "a method and apparatus for performing collision detection" where "a safety measure is activated based on the classification using the collision detector" [6]. This certainly shares many aspects with 2020 Vision, since it outlines the basic framework of the project. Even though it seems based on the patent description that this invention is primarily employed within vehicles, it would not be surprising if the patent holder files a claim against a 2020 Vision patent application due to the striking similarities [6]. However, a potential difference is the use of the MSP430 microcontroller system, as well as the specific use of vibration motors as the actuator of the device.

A similar patent is US9401090B2, filed and held by Yutaka Mochizuki of Honda Motor Co Ltd., entitled "Collision avoidance system for vehicles" [7]. Similarly to [1], the patent states that, "when the collision avoidance system determines that the vehicle is approaching a situation of increased collision risk, such as an intersection, the communications is increased" [7]. Once more, the team faces a patent that describes the basic framework of the object, with the collision avoidance system and communications signifying the ultrasonic sensing and vibration motors, respectively. As such, the previous assertions still hold true that 2020 Vision is still patentable as long as the team emphasizes the use of MSP430 and vibration motors. Additionally, 2020 Vision is meant to be a wearable system for a user, not an accessory for a vehicle, though the device architecture certainly does not exclude that possibility.

Finally, another noteworthy patent is US20170154505A1, whose holder is Ernest Kim of Nike, Inc. In this case, the patented system is a wearable one, with the title being "Apparel with ultrasonic position sensing and haptic feedback for activities" [8]. One key difference between this invention and 2020 Vision is that this product functions first and foremost as "an article of apparel" which includes a fabric, with the fabric constituting a large portion of the device [8]. 2020 Vision may utilize fabric as a potential use case; however, that would not be part of the patentable system.

The invention of Camus is a dependent claim, for he claims benefit from a previous patent in order to make his case. Mochizuki's and Kim's inventions, however, are independent claims, not needing to cite any precedents for their work. In the case of Camus, he refers back to his previous patent entitled "Method and apparatus for object tracking prior to imminent collision detection" [9]. As such, object tracking as a means for detecting potential collisions is clearly a concept that Camus borrows from his earlier work. More specifically, the very first claim Camus makes in both patents is "a method for performing collision detection, comprising: detecting an object within a first operational range of an object tracker; determining a classification of said object using said object tracker; tracking said object using said object tracker; detecting said object within a second operational range of a collision detector; and activating a safety measure based on said classification using said collision detector" [6] [9]. In fact, it seems that [6] is simply a simplification of [9]!

If the team were to submit a patent for 2020 Vision, the title would be "Wearable ultrasonic object detector employing haptic vibration feedback through MSP430 programming." Even though [6], [7], and [8] are all systems that incorporate significant aspects of the essence of 2020 Vision, there is yet to be a patent that unites these elements into the wearable device that the team intends for it to be. The team could also incorporate these three patents as dependent claims, since their authors have previously outlined a design similar to the team's. Therefore, 2020 Vision is patentable.

Detailed Technical Description of Project

What it is and How it Works

The purpose of our device is to use ultrasonic sensing to detect incoming collisions, especially in the case of the sensor being placed in its user's blind spot. The final product consists of the following components: Printed circuit board (PCB) with an MSP430G2553 microcontroller as the driving integrated circuit (IC), the code from the project repository compiled and uploaded onto that IC (see Appendix II), an MB1010 ultrasonic sensor connected to the appropriate through hole ports in the PCB, and a vibration motor, or even an actuator of the user's choice, connected to the appropriate through hole ports in the PCB. The entire system is powered using a 3.7 V 3000mAh Lipo rechargeable battery.

The design is flexible, and it is really up to the user where to place the sensor and how to signal incoming collisions. For the purposes of the demonstration, we used vibration motors and placed the sensor on the back of the user's head, attached to headphones.

The design that is documented below extensively uses the following software packages: Code Composer Studio (CCS) version 8, National Instruments (NI) Multisim, and NI Ultiboard. CCS guides the software development portion of this project, whereas the NI products guide the parallel hardware development of 2020 Vision.

The MB1010 sensor outputs an analog signal which changes amplitude depending on how far the nearest object it senses is. The further the nearest object is, the higher the amplitude. This analog signal is converted to a digital signal using the MSP430's ADC conversion capabilities, so in the end, we have an input of a continuous stream of numbers which represent the distance of the nearest object over time.

The ultrasonic sensor that we chose has two key limitations: it can only detect distance and only detect the distance of a single object. For our design, we wanted a device that would be triggered on *moving* objects, so we needed some method of obtaining or estimating the velocity of an object. Additionally, because the sensor is unable to distinguish between different objects, we had to write the software with the assumption that all data was indeed from a single object.

First, because velocity is distance over time, we needed to keep track of past distance points. To do so, we stored all incoming points, collected at a rate of 1 point per 50 ms, in a *history* array of set size S, evicting the oldest value when the array is full. To mitigate some noise in the data, we applied an averaging filter before adding it to the *history* array, taking the average of the last A points (note that A < S). Then, to estimate the velocity, we take the difference between the oldest point in *history* and newest point in *history*. Note that we do not divide by time because it would be a constant scaling factor due to the consistent data collection rate. After this, we would turn on the haptic motor once the device detected a velocity above a threshold V.

After implementing this, however, we noticed that the averaging filter was not effective enough to mitigate all the noise. As a result, the device would have many false positives (where the motor would vibrate even though no object was incoming). To deal with this, we decided to add an outlier exclusion component to our algorithm. Essentially, to trigger the motor, the velocity would have to be above V *and* the most recent point added to history cannot be an outlier. For our definition of an outlier, we went with the most common definition where a point is considered an outlier if it is more than Z standard deviations above the mean. The mean would be the average of the *history* array, and the standard deviation was calculated using the definition of a sample standard deviation, =ni=1(xi - x)2n-1where x is the mean, n is the number of samples (size of *history*), and xiis the ith element in *history*. Because the definition of standard deviation involves a square root function which is computationally expensive, we used a quicker function which approximates the square root instead (the function can be found in the GitHub repo). Adding this additional constraint significantly reduced the false positive detection rate, but had a tradeoff of letting the user have slightly less time to react to incoming objects (because it would take longer for the algorithm to determine if a point is not, in fact, an outlier).

All the given constants' (history size S, average filter size A, velocity threshold V, outlier threshold Z) values were determined empirically. That is, we tested a range of values for each until we found one which seemed to be optimal.

Components Used

Firstly, the actuator of the system is a vibration motor from Seeed Technology Co., Ltd. More specifically, it is their model 316040001 [13]. As for the ultrasonic sensor, the team uses the MaxBotix Inc. MB1010-000 component [14]. The integrated controller used is the Texas Instruments (TI) MSP430G2553IN20 (MSP430) part [15]. The voltage regulator is the LD1117V33C [16], which drives down the power supply from the battery from 3.7 volts down to 3.3 volts so that the MSP430 may function within its recommended operating range [15].

The battery supply used is the 3.7V 3000mAh 407090 Lipo Battery Rechargeable Lithium Polymer Ion Battery Pack with a JST Connector [17], and then Adafruit Industries LLC 261 JST connector wires to solder the leads onto the board [18]. For the header components, the team utilized the TE Connectivity AMP Connectors 1-2199298-6 connection header for the MSP430 [19], and the On Shore Technology Inc. 302-S141 component for the JTAG header [20]. Passive components used are as follows: 10uF capacitor - TDK Corporation FG14X7R1A106KRT06 [26], 0.1uF capacitor - KEMET C315C104M5U5TA7303 [27], 47k ohm resistor- Stackpole Electronics Inc CF14JT47K0 [28], and the 330 ohm resistor - Stackpole Electronics Inc CF14JT330R [29]. Test points for the system are of Keystone Electronics 5010 [30]. The charger for the rechargeable battery is the Adafruit Industries LLC 1904 ("MCP73831 Battery Charger Power Management Evaluation Board") [31].

Design Decisions and Tradeoffs/Problems and design modifications

Initially, the team planned to include a MOSFET (more specifically, the ZVN3306A) to help drive the motor, and this design decision draws from faculty advice. However, after the midterm demonstration, the team realizes that the MOSFET really is not necessary and would be more counterproductive due to the delay that it introduces into the system. As such, the final design excludes the MOSFET, and it works just as well as we expect. For a device such as this, one cannot afford to factor in more delay, because that would drastically decrease the amount of time the user has to react. Given the potential scenarios outlined in this report, this could be a dangerous situation, especially in military applications.

Due to our decision of using the MSP430 microcontroller, we have to add a spy-bi-wire circuit with a corresponding JTAG header in order to flash our embedded code into the microcontroller. Once we were able to check out the design of the spy-bi-wire circuit and connect it to our MSP we found that we were having a hard time trying to flash the code even after checking our connections and making sure we power the MSP to prep it to receive the code. However, after all our attempts and our project timeline, we decided to flash the code with a MSP development board that has a header were we can attach our microcontroller. Once we knew that the MSP is working on the development board, we then transferred the chip onto or PCB and tested it with the other subsystems. Luckily, most of the time we transferred the chip onto the header on our PCB the chip was fully functioning with the other subsystems. As a result, we were able to flash working code onto our device with the cost of additionally time spent on debugging due to switching chips back and forth.

In order for us to cut the cost of the system and to make the final PCB more concise with the components that are needed in order to accomplish the task, we decided to use just the MSP430 chipset instead of trying to implement the use of a development board such as the MSP430 launchpad given to us during intro to embedded programming course. The use of a development board will lead to unneeded components and features such as the internal light emitting diodes (LEDs), USB FET system, and other space taking features. Additionally, the development board will take in more current than just the chip itself in order to power those additional features. Having just the MSP on the PCB means that we are able to trace exactly which pins we need for our system and leave out the unnecessary clutter. Having only the MSP chip would mean that we have to add a spy-bi-wire circuit for us to flash code onto the MSP through the use of a JTAG connector. Other than the spy-bi-wire and the extra component header, the resulting board is lightweight and simplified with the design choice.

When implementing the algorithm, we had to choose between using a velocity threshold or a distance threshold. This was especially important because the ultrasonic sensor can only output distance data, making the distance threshold method more accurate compared to the velocity threshold method which would involve approximating the velocity. In the end, we decided to go with a velocity threshold despite the lower accuracy. First, we determined that the approximation of velocity we were able to get was close enough to the actual velocity of incoming objects when we tested the code on actual sensor data. Additionally, we also wanted to use a velocity threshold so that the motor would not constantly go off if an object is nearby but not moving -- this would have a large negative effect on the user's experience, which we wanted to avoid.

As mentioned in the earlier design description, we had the option of choosing a more noise tolerant algorithm with outlier exclusion or a quicker algorithm without outlier exclusion. In the end, we made the decision based on how the user experience would be affected. A more noise tolerant algorithm means a lower false positive rate so the user would not experience vibrations for false alarms as frequently. A device which has a high false positive rate would constantly vibrate while the user is wearing it, negatively affecting the user's experience -- this would likely make them not want to use our device. On the other hand, the user does experience a small reduction in reaction time if an object is actually incoming. However, when we tested the time reduction, we saw that the objects were usually still detected with ample time for the user to react (e.g. 1.2 second to react vs. 1.5 seconds to react). Thus, we decided the tradeoff was worth it and went with the outlier exclusion algorithm.

Furthermore, in terms of the contraption we planned to mount the device on, our preliminary designs consisted of various options: headband, backstrap, and Bluetooth headphone collar. We wanted a contraption that would keep the ultrasonic sensor steady so that the distance data will remain accurate for efficient vibration triggers. For the final design, the Bluetooth headphone collar was chosen because when a user wears the collar, the collar will remain in position despite the user turning their head or twisting their bodies. Since the ultrasonic sensor will be positioned on the back of the user, even if the user moves a lot, the sensor will be consistently pointing to the back direction. In addition to the sensor, the vibration motor was mounted on the inside of the collar, where the user can easily feel the vibration against their neck. The sensor and the vibration motor are connected to the PCB and battery with long wires protruding from the collar. The PCB and battery are housed in a small backpack. Originally, the PCB and battery were to be housed in a small 3D printed boxed that was supposed to be hung from the user's belt loop or clipped to their pants. However, we ultimately decided to use a small backpack instead since it was easier and more intuitive for the user to wear without much struggle. Furthermore, the extra wire can be adjusted and tucked into the backpack depending on the user.

Block Diagrams

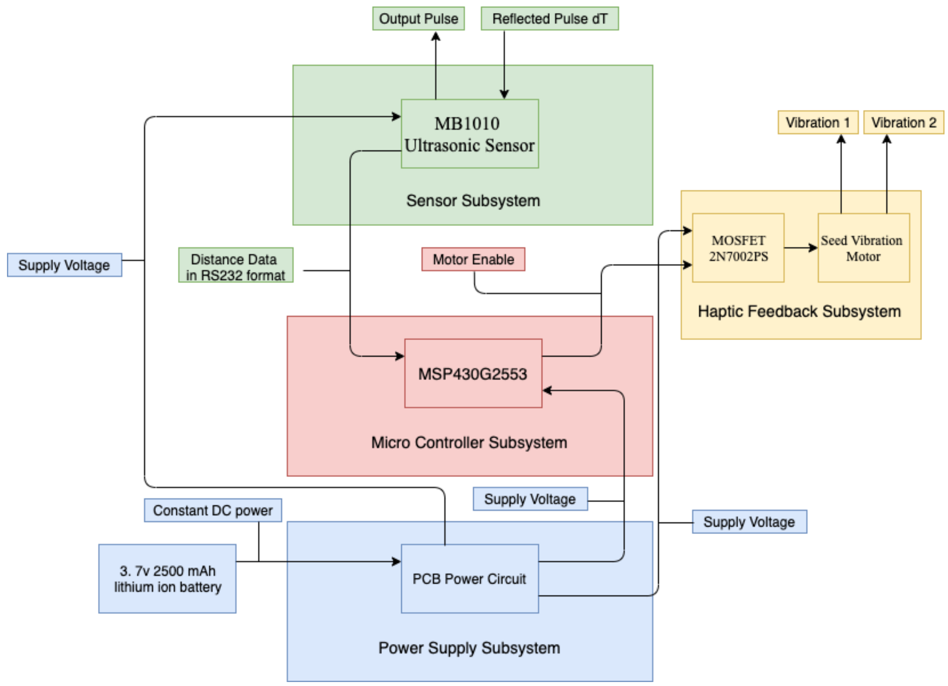


Figure #3: Block diagram during midterm design review

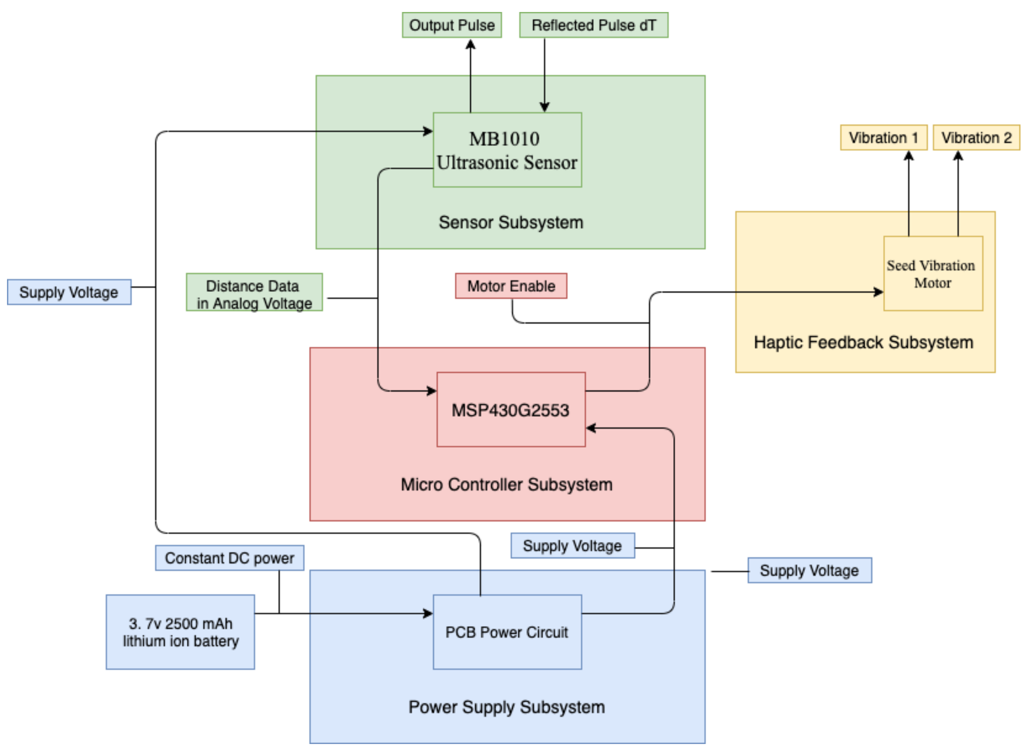


Figure #4: Final block diagram during demo day of the prototype

The figures above show our high-level design architecture of our intended system. Our device incorporates four major systems that all work together synchronously to achieve our intended task. The power system converts our 3.7v DC battery voltage to usable VCC for our sensor and MSP430G2553, this system will be the foundation of the project due to the fact that our system will have to be hosted on a wearable platform and sufficient power will be needed in order for the other systems to work properly. The next subsystem is the sensor system which is the MB1010 sensor that interfaces with the power supply and the MSP. In our initial design we were going to use the RS232 serial data output of the sensor, however opted for the analog output due to the ease of use of the ADC in the MSP. After the sensor sends voltages to an input pin on the MSP, the microcontroller uses a motion detecting algorithm that will trigger an output port from the MSP subsystem. Once the output port is high, the haptic motor subsystem will sense this pin and activate the vibration motor which notifies the user of an incoming collision. In our final block diagram we decided to remove the MOSFET acting as a switch for the haptic motor due to the fact that the output pin will be able to provide enough power to the motor and that the addition of the MOSFET draws more unnecessary current from our power supply.

Board Layout and Schematic Design Decisions

The following is the final schematic for the project:

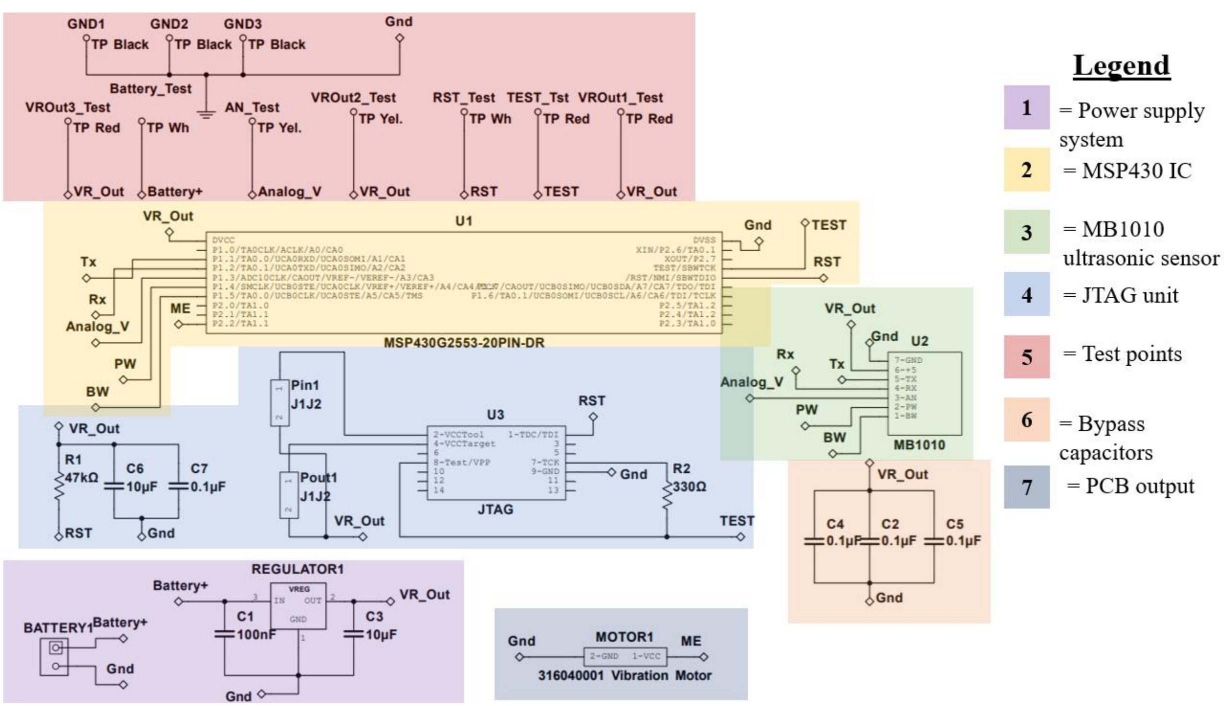


Figure #5: Final schematic from NI Multisim with annotations and legend

As displayed in Section 1, the power supply subsystem consists of the battery and the voltage regulator. For this project, the team employs a 3.7V 3000mAh 407090 Lipo Battery Rechargeable Lithium Polymer Ion Battery Pack with JST Connector [17]. As such, there is an expected 3.7 volts on the net Battery+, and should the voltage begin running low, the battery is rechargeable with its corresponding charger, the MCP73831 Battery Charger Power Management

Evaluation Board by Adafruit Industries [31]. Because the MSP430 is expecting an input of 3.3V on average [33], a voltage regulator must drive down the input voltage by 0.4 volts. The team uses the LD1117V33C low-dropout regulator [16] to achieve this purpose. The configuration that includes the 100nF and 10uF capacitors is from the recommended schematic shown in the datasheet [16].

Section 2 includes the Texas Instruments MSP430G2553IN20 integrated circuit [15], with the TE Connectivity AMP Connector to store it [19]. The ports on the left-hand side correspond with the ports of the sensor, while the ports on the right-hand side correspond to ground as well as the JTAG ports. Here, it is important to note that this schematic corresponds with Figure #7 below of what the schematic should have been, and there is only one change between what the team published for manufacturing and what the ideal board is: the motor needs to be triggered by a pin other than Analog Voltage. This is a mistake that Renée, the primary hardware manager, made when she failed to understand how the MSP430 was receiving its input signal. She mistakenly thought that it is through a port other than Analog Voltage, when that is not the case. As such, the team made a manual correction to the board by cutting the offending trace shown below in Figure #6 and wiring P2.2 to the output of the motor:

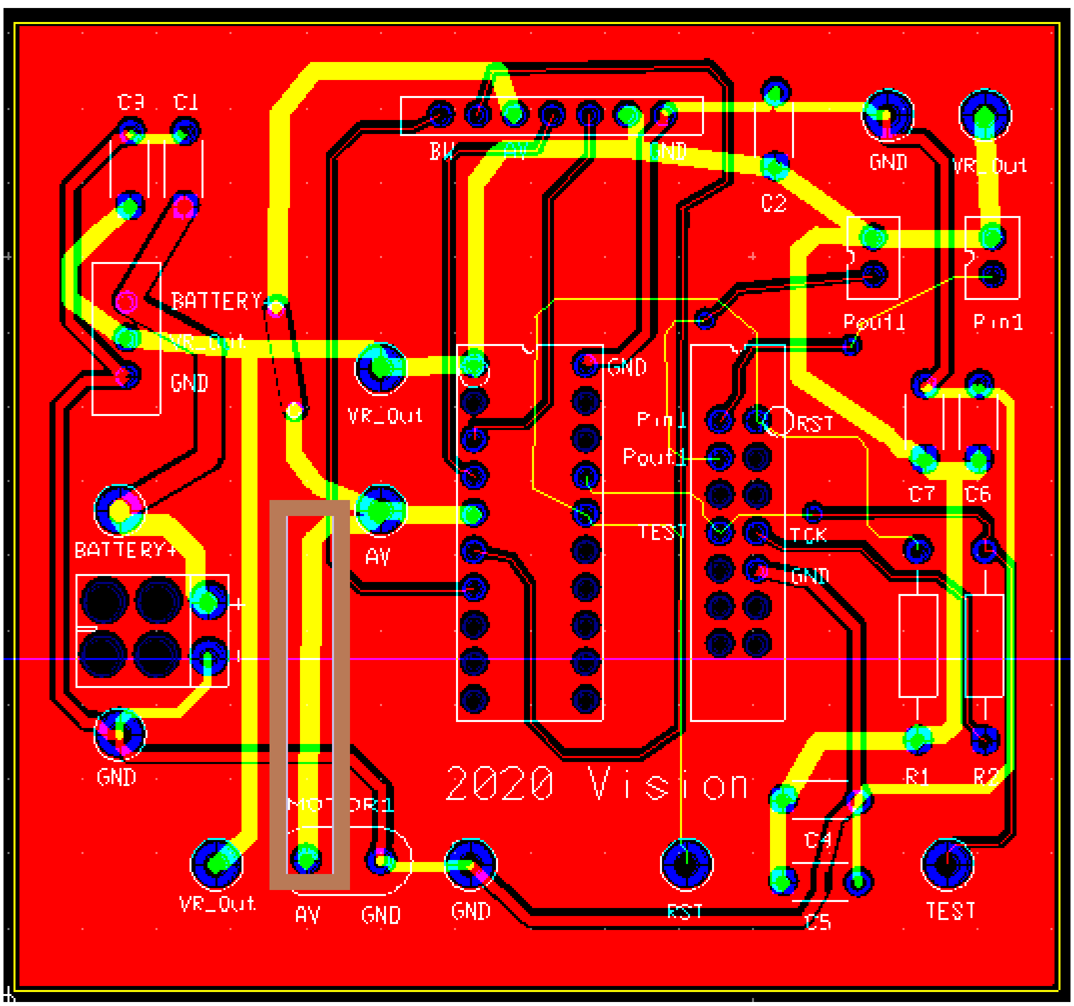


Figure #6: Final manufactured PCB, with offending trace in brown box

This PCB export from NI Ultiboard shows what the effect of the manual correction is, and anyone who wishes to recreate this project in the future should follow these connections:

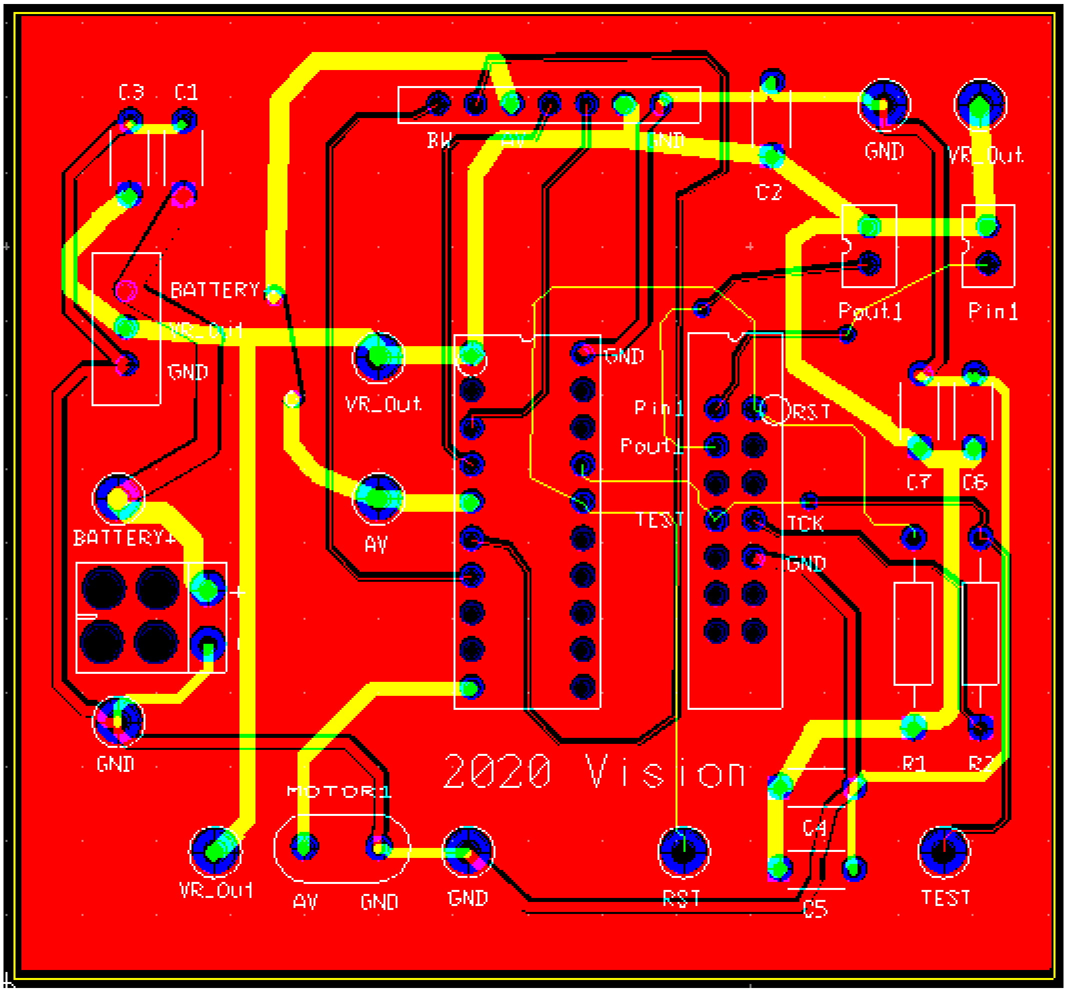


Figure #7: What the final PCB should have been (accounting for manual connection)

Overall, in the figure of the schematic, it is important to note that the P2.2 port labeled "ME" to signify "Motor Enable" is connected to the motor.

Additional necessary considerations include involving the JTAG header, as defined by its dimensions [20], to make it easier to program the microcontroller once it is placed on the board. Finally, the team used 0.1uF bypass capacitors at the C4, C2, and C5 positions to correspond with the active components of the MSP430, sensor, and battery, respectively. This does not include the capacitors for the linear voltage regulator and JTAG units, where the data sheets provide recommended layouts. For instance, here is what the data sheet for the voltage regulator recommends [32]:

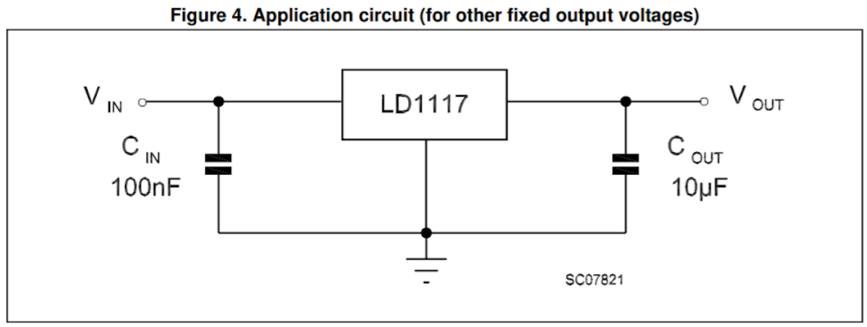


Figure #8: Linear voltage regulator recommended configuration

Similarly, here is the schematic layout from Texas Instruments, as posted on its wiki for its products [38]:

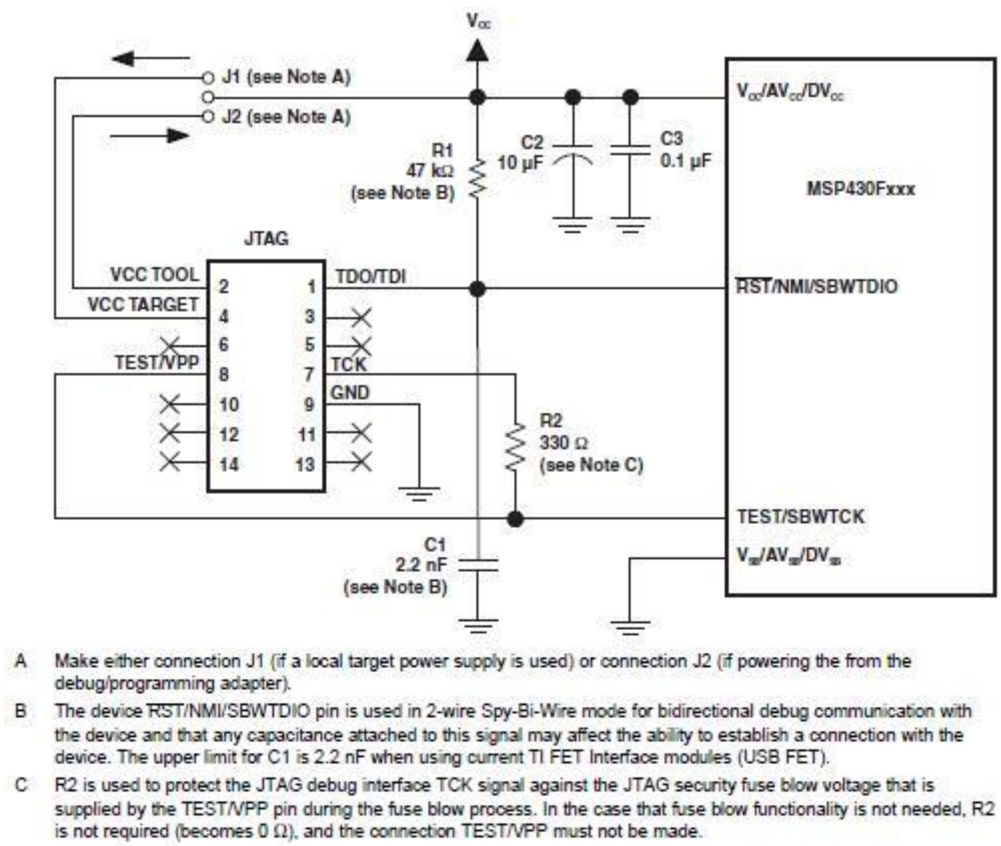


Figure #9: JTAG configuration based on recommendation from Texas Instruments

As such, those configurations should be recreated on the PCB. For JTAG, the label "Pin1" in the Ultiboard printout corresponds to "VCC Tools" and Pout1 corresponds to "VCC Target" in the above Figure #9.

The battery footprint is from the Fundamentals of Electrical Engineering II final project footprint that all team members partook in during the Spring of 2017. They recalled how the battery through hole footprint allowed their PCBs to keep the project's battery in place without straining its leads, and decided to use the same footprint for the PCB.

Finally, the sensor and motor leads are placed at opposite ends of the board for relative proximity purposes. Even though the long length of the wire leads allows for placement anywhere on the PCB, the placements help the user develop an intuitive understanding of the board. On one end, the sensor is attached to the board and senses the user's surroundings, and on the other end the vibration motor serves as the actuator. One can think about it as "input" and "output" outlined clearly on the board!

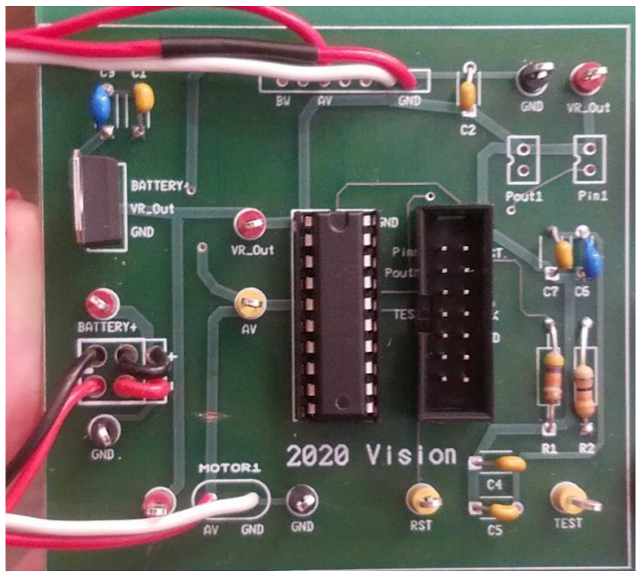


Figure #10: Final PCB with components soldered in

Because Pout1 and Pin1 are connected to the power supply net `VR_Out`, the team did not find it necessary to solder in the appropriate two-pin headers into those parts. Those ports existed so that the team could use jumper cables to power the JTAG unit if necessary, but fortunately the team never had to do that.

Because the team made a change to the design, it is also appropriate to show the back of the PCB:

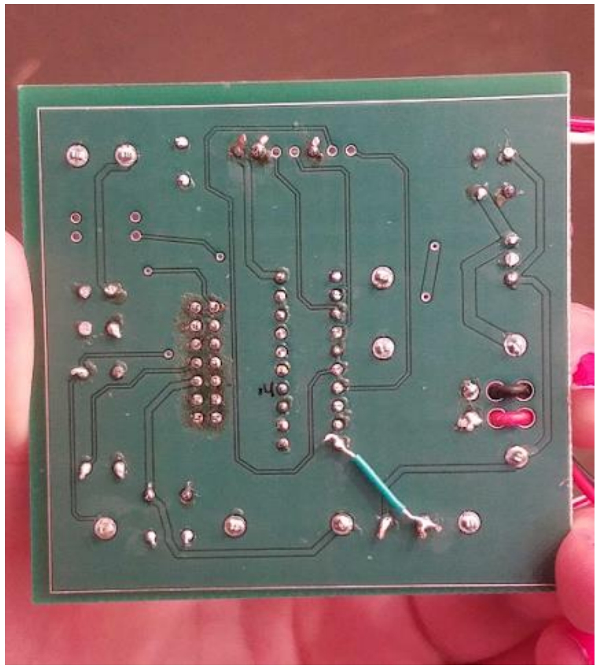


Figure #11: Back of the PCB

The green wire soldered between the motor's positive input and P2.2 effectively creates the same effect as one would have with the PCB illustrated in Figure #7.

Finally, the following images demonstrate how the sensor and motors are mounted on the system for demonstration:

Figures #12 and #13: Sensor and vibration motor attached to headphones

The team decided to use headphones for the demonstration because they are very common, especially among fellow students at the University. The Green LED functions as a visual display of when the vibration motor goes off, but should this device go into mass production, that LED would not contribute any meaningful functionality (unless, of course, users decide that they prefer it). The leads from the sensor are attached to the top of the PCB, while the leads to the motor are attached to the bottom of the PCB, with "top" and "bottom" defined in the Ultiboard layouts above.

Project Time Line

Figure #14: Initial Proposed Project Gantt chart

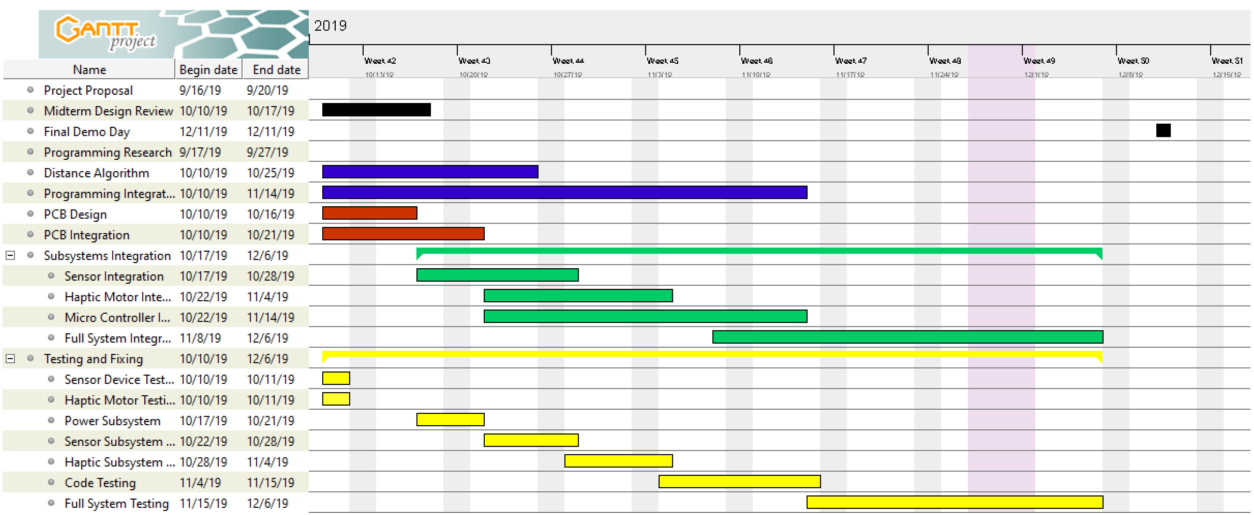


Figure #15: Final Project Gantt Chart

The figures above show the project Gantt charts which helped the team organize their deliverables for the project, keep track of design times, and visualize the parallel and serial nature of the tasks laid out during the initial proposal of the work. Our project's serial tasks were focused on being able to test the subsystems whenever we had the system populated and ready for testing. We wanted to work in a linear fashion due to the fact that being able to debug the system in one subsystem is better than trying to debug when multiple systems are integrated together. The portion of our project that gave us the ability to parallelize the tasks and save on time was developing the object detection algorithm in conjunction with designing and testing the analog components on our PCB. During the latter half of our project we were able to parallelize the testing and design portions of our project to make sure that we are testing finished subsystems while we also worked on the next subsystem and prep it for testing. The team split the responsibilities as given:

Team Members	Responsibilities
Joshua Arabit	• **Primary** - System Integration • **Secondary** - Software Design and Implementation
Renée Mitchell	• **Primary** - Hardware Design • **Secondary** - System Integration
Jazlene Guevarra	• **Primary** - Hardware and Software Testing • **Secondary** - CAD and Wearable Platform Design
William Zhang	• **Primary** - Software Design and Implementation • **Secondary** - Software Testing

Table #1: Team Member Responsibilities

Test Plan

Below is the original test plan from the proposal, which is subdivided by subsystem. It starts with checking the Power Supply Subsystem, then the MB1010 Ultrasonic Sensor Subsystem, to the MSP430G2553 Subsystem, and finally the Haptic Feedback Subsystem.

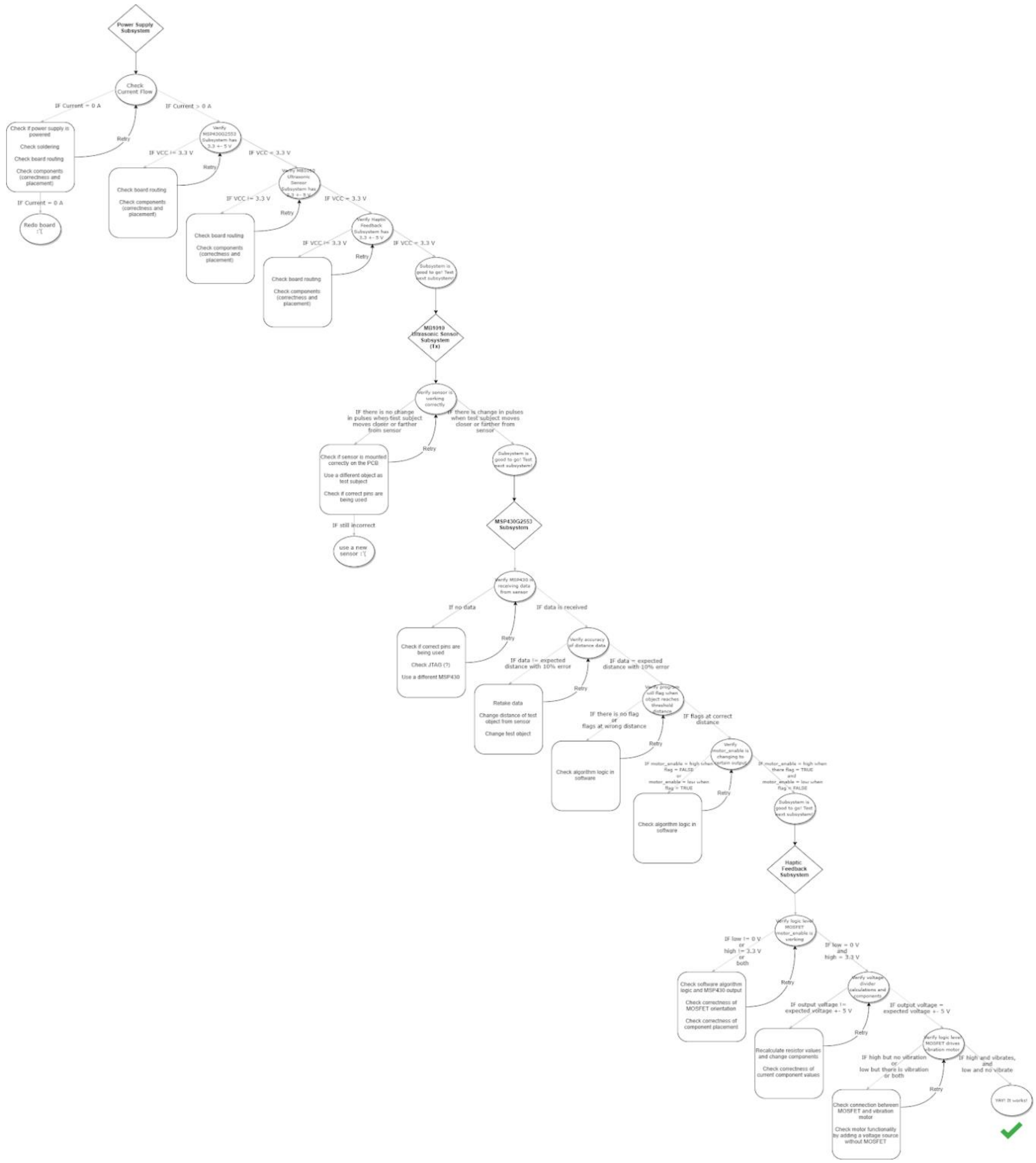


Figure #16: Original Test Plan from Project Proposal

However, the design of the test plan was based off of our goals for the Midterm Design Review, therefore modifications to the test plan had to be made. The device was programmed to detect an object once it is within a certain minimum threshold distance, and when an object is within that threshold distance, then the vibration motor will vibrate to warn the user. This initial design was using the NI Virtual Lab Bench as the power source that will feed 3.3 V into a breadboard, which is connected to the PCB with the ultrasonic sensor, the MSP430, and the vibration motor. Changes to the design after the Midterm Design Review were adding velocity calculations and a minimum speed threshold in the software algorithm, in addition to the minimum distance threshold, and removing the MOSFET that was originally used to trigger the vibration motor.

Power Supply Subsystem

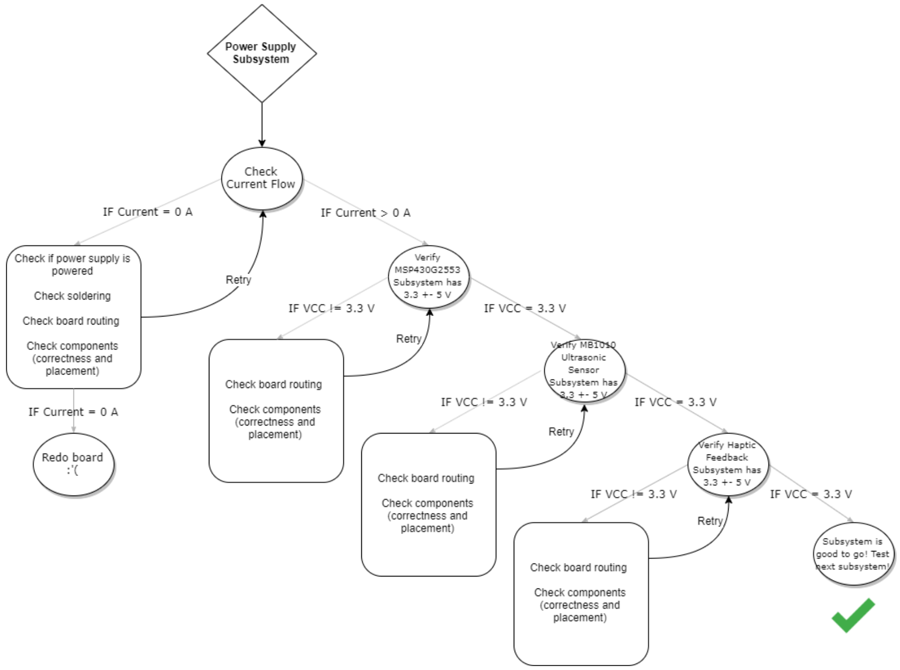


Figure #17: Original Test Plan Power Supply Sub-Tree from Project Proposal

Modifications that needed to be changed to the Power Supply Subsystem is to include a test for the voltage regulator right after the “Check Current Flow” test. In order to test the functionality of the voltage regulator, we want to see if the voltage regulator has voltage and drops the source voltage down to the expected voltage necessary to power the rest of the subsystems. Otherwise, we followed and passed all the necessary checks to ensure that all the subsystems are powered correctly by the power source.

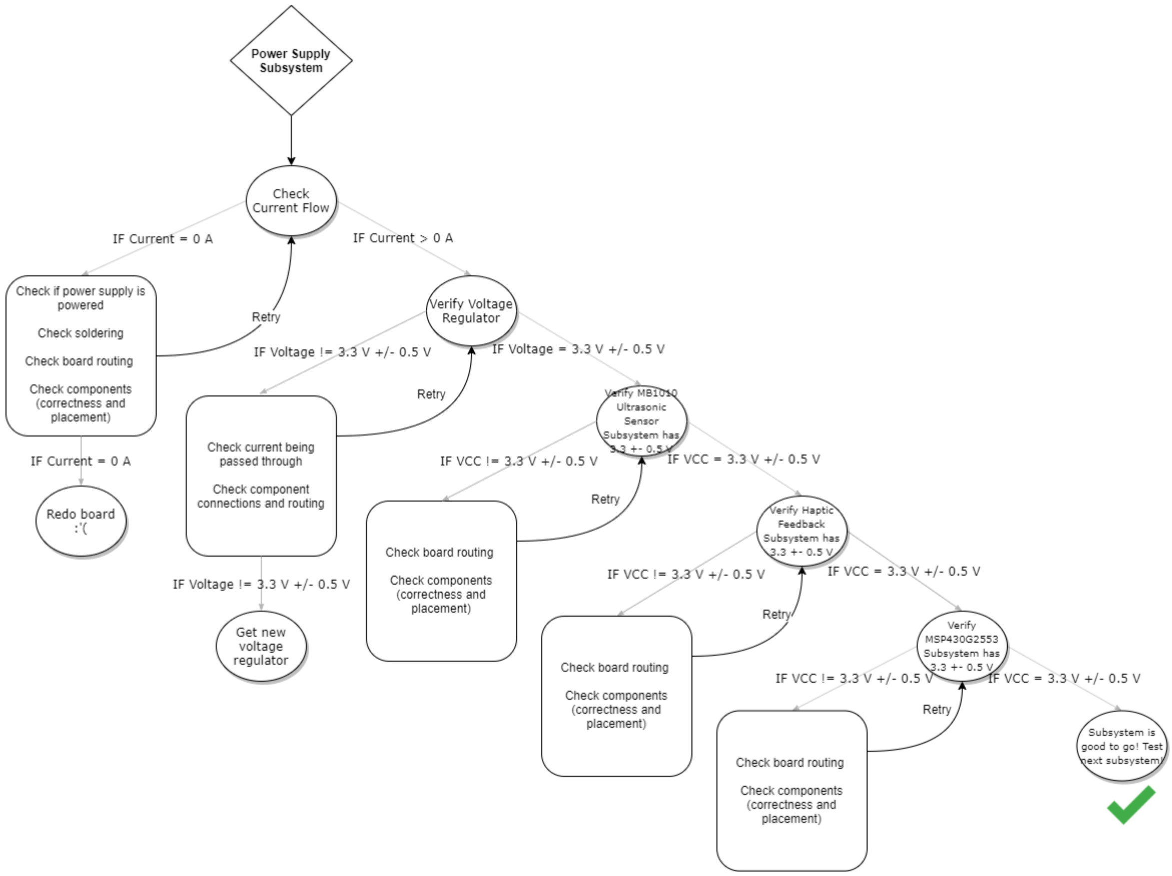


Figure #18: Modified Test Plan Power Supply Sub-Tree

First, we are checking if the current is flowing into the general PCB once the battery is connected to the board. This check will verify that the battery is properly connected and soldered onto the PCB. If the check fails, further checks we must make is to make sure the power supply is powered, check the board routing, and/or check the components on the PCB (the correctness and placement). If all these extra checks fail, then we must redesign the PCB and then perform the test again.

Once the "Check Current Flow" test passed, we will then check for voltage regulator functionality, verifying that the voltage regulator works and drops the voltage down the expected voltage 3.3V +/- 0.1V, as mentioned earlier. If the voltage regulator does not drive the supply voltage to 3.3V +/- 0.1V, check if the correct components are used or are placed at the correct locations and/or check if there is current being passed through the voltage regulator. If all these additional checks fail, then will need to change the voltage regulator to a new voltage regulator component and repeat the checks to verify that the voltage regulator functions the way it is expected to function. If the voltage regulator passes the check, then the team can continue to test the power supply on the other subsystems.

Next, we check if the correct voltage is supplying the MB1010 Ultrasonic Sensor Subsystem, which is expected to be 3.3V +/- 0.1V. If the voltage supplying the MB1010 Ultrasonic Sensor is not the expected voltage, then the additional checks must be to check the board routing and check if all the related components are correct or are placed correctly on the PCB, then retry the test. Once the test passes for the subsystem, repeat the same steps for the MSP430G2553 Subsystem and the Haptic Feedback Subsystem. Once the checks for all the subsystems passes, the Power Supply Subsystem Test Plan Decision Tree is complete and successful, and related components are ready to be soldered onto the PCB.

MB1010 Ultrasonic Sensor Subsystem (Analog Output)

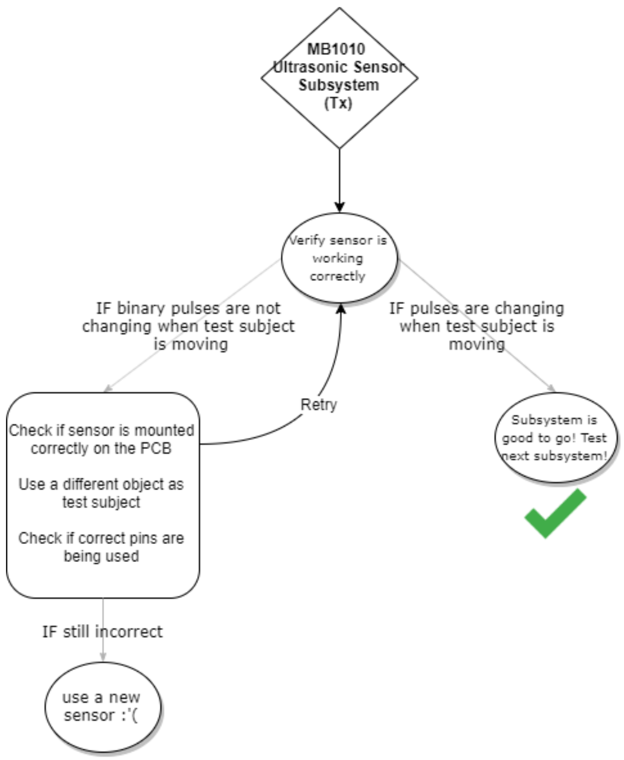


Figure #19: Original Test Plan MB1010 Ultrasonic Sensor Sub-Tree from Project Proposal

The most important modification to the MB1010 Ultrasonic Sensor test plan was the design decision to change from the Tx output to the analog output. Therefore, instead of only checking to verify if the sensor is working, we are able to include more tests that verifies if an object is nearby or far away based on voltage output from the sensor.

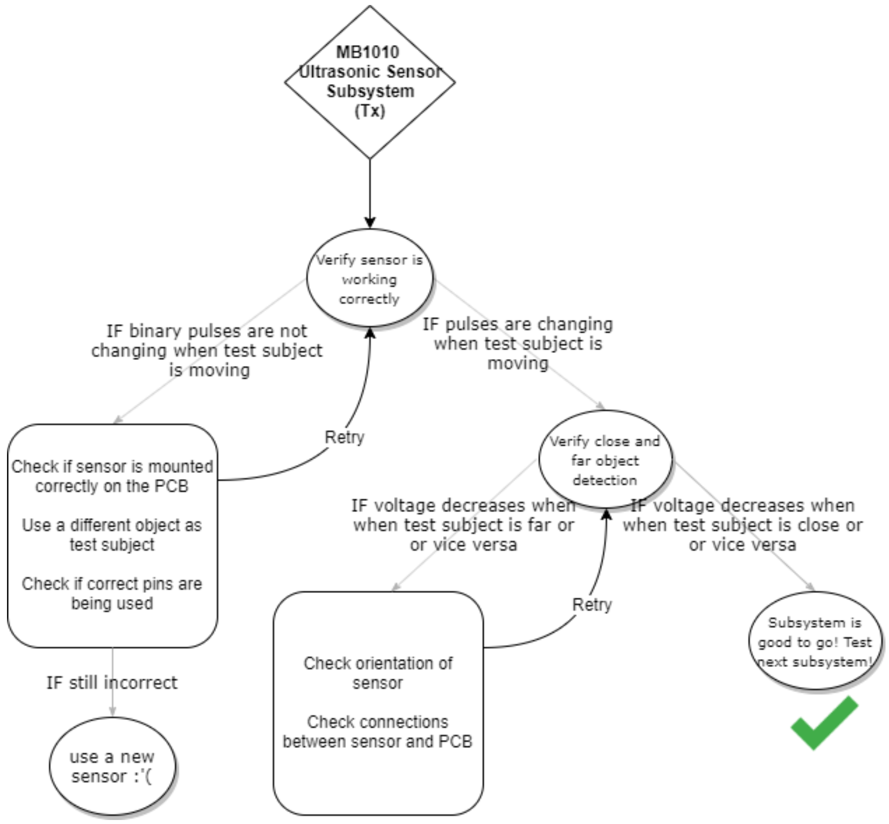
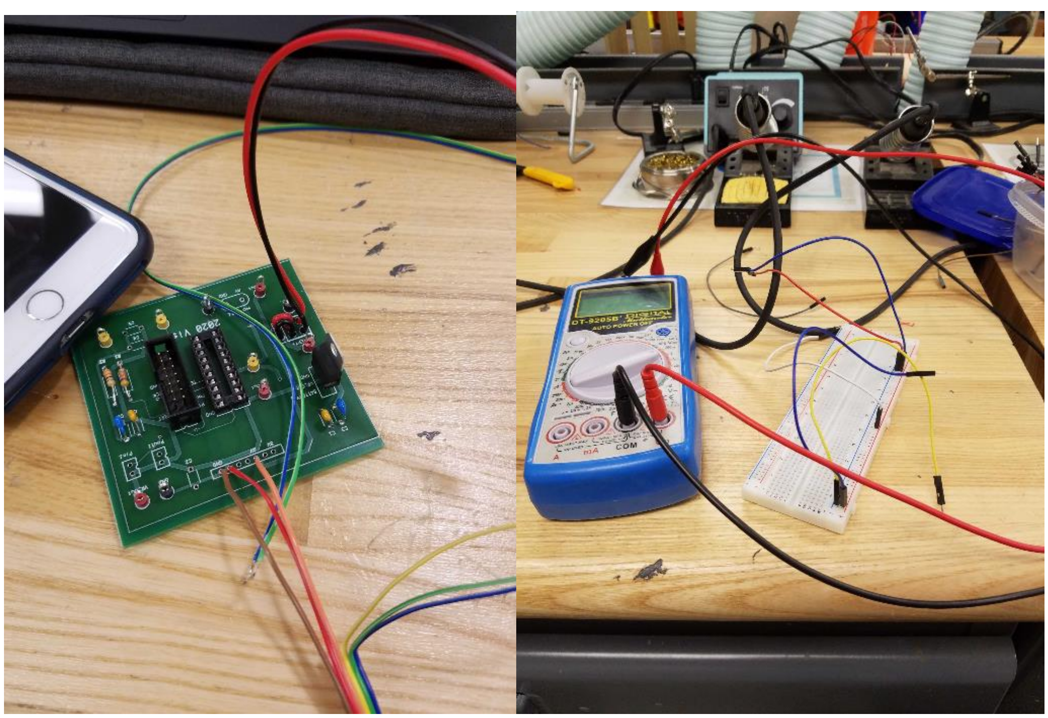


Figure #20: Modified Test Plan MB1010 Ultrasonic Sensor Sub-Tree



Figures #21 and #22: Testing the sensor mounting

Once all the Power Supply Subsystem tests have passed, the next test plan follow is for the MB1010 Ultrasonic Sensor Subsystem. First, we want to verify that the sensor that is planned to be soldered onto the PCB is working, otherwise a new sensor needs to be used. If the +5V and GND connections are connected to a breadboard in the proper locations dictated by the DC power supply cable, then using the digital multimeter connected to GND and the Analog pin of the sensor, the output voltage can be observed. If the output voltage is changed sporadically, even with a test object intentionally in the range of the sensor, then the sensor does not function the way it is expected. Otherwise, if the voltage changes in respect to the test object moving in range of the sensor, then the sensor works as expected.

Next, we want to specifically test if the sensor outputs the correct voltage for an object that is close to or far. If an object is close to the sensor, then the output voltage should be small, and the closer the object is moving towards the sensor, the smaller the output voltage will become, and if an object is far away, then the output voltage should be large, and the further away the object is from the sensor, the larger the output voltage will become. If this test fails, then the additional checks necessary to look into is checking the orientation of the sensor and if the correct pins are being used between the sensor and the breadboard. Once these checks are fixed and/or verified, then we can retry the test to see if the output voltage changes accordingly.

Once the checks for all the subsystems passes, the MB1010 Ultrasonic Sensor Subsystem Test Plan Decision Tree is complete and successful, and related components are ready to be soldered onto the PCB.

MSP430G2553 Subsystem

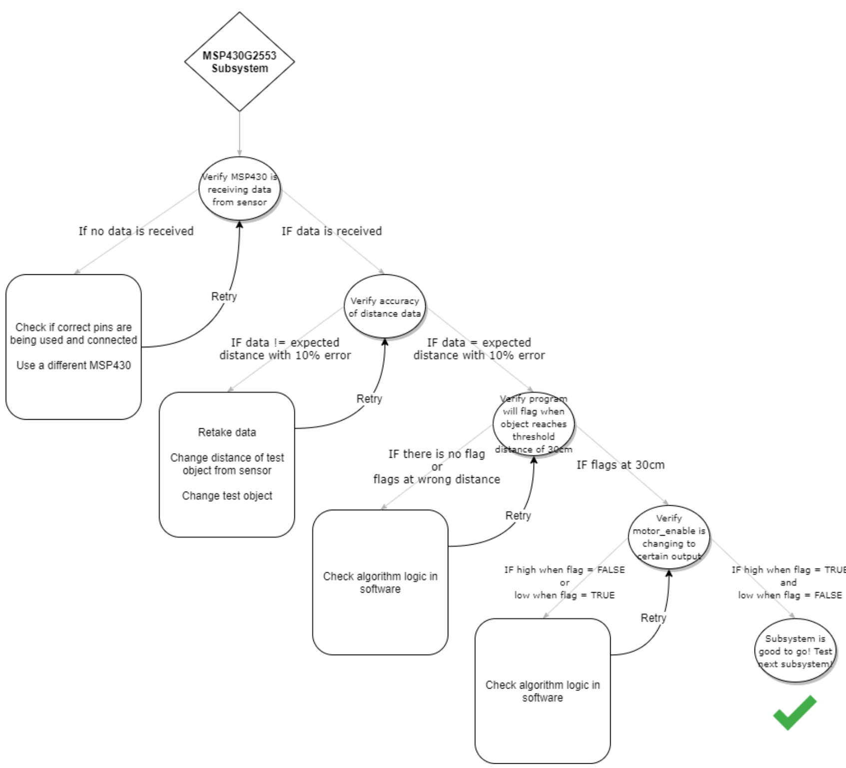


Figure #23: Original Test Plan MSP430G2553 Sub-Tree from Project Proposal

Modifications that needed to be changed to the MSP430G2553 Subsystem is to include testing for the algorithm for detecting object speed and for detecting outliers, which determines if the sensor is detecting one object or multiple objects. Furthermore, we want to include tests that accounts for projectile objects (objects thrown at the user) and outdoor testing (usage outside of a lab environment).

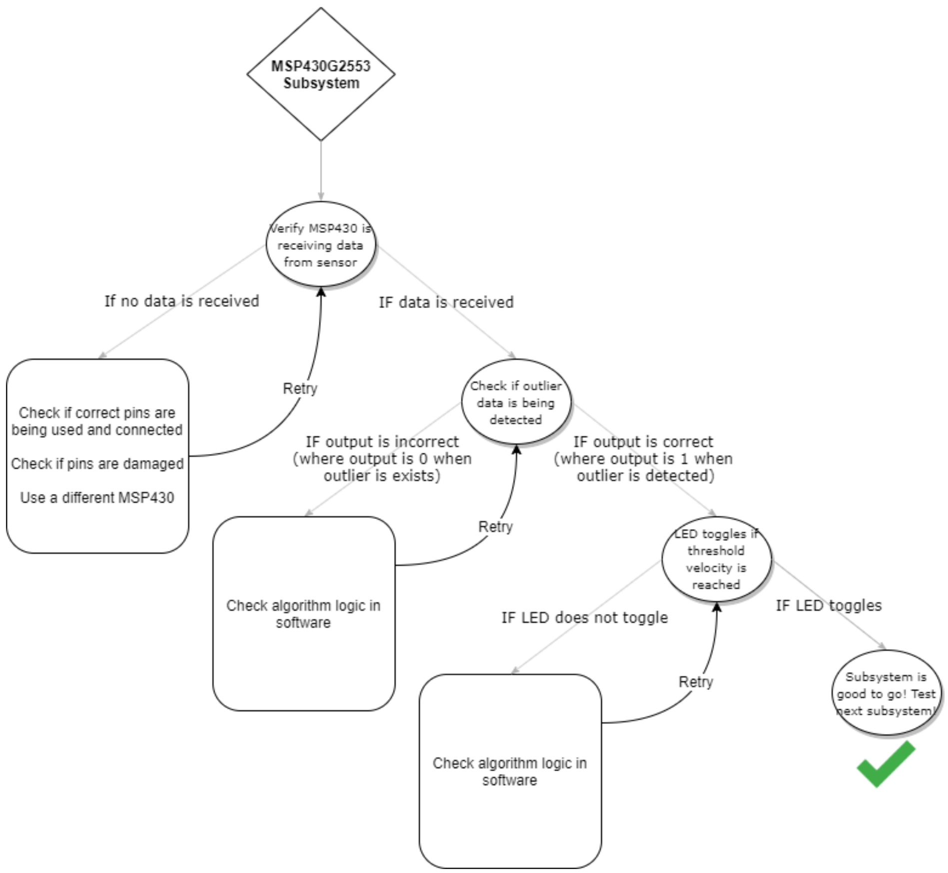


Figure #24: Modified Test Plan MSP430G2553 Sub-Tree

First, we verify if the MSP430G2553 is receiving the data from the MB1010 Ultrasonic Sensor successfully. If no data is being received from the sensor, we need to check if the correct pins are being used and are connected properly, and/or use a different MSP430 and retry the test. If the MSP430 successfully receives data, we can move on to the next tests that will verify the functionality and efficiency of our software algorithm: testing outlier data and testing the velocity threshold.

To test the outlier, if the sensor detects an object, but there is also another object at a different distance, the software algorithm should output a 1, indicating that there is an outlier in the data. Otherwise, the algorithm output will be a 0. We can verify the correctness of the algorithm by using Code Composer's debugger tool and see the variable values changing from the live sensor data. If the test fails, then the necessary steps to be taken is to edit the software algorithm logic and retry the test. Next, speed threshold value will be tested. If a moving object is exceeding the minimum speed threshold, then MSP430 red LED should trigger, otherwise, the green LED will trigger. If this check fails, similar to the previous test, the necessary steps to be taken is to edit the software algorithm logic and retry the test.

Once the checks for all the subsystems passes, the MSP430G2553 Subsystem Test Plan Decision Tree is complete and successful, and related components are ready to be soldered onto the PCB.

Haptic Feedback Subsystem

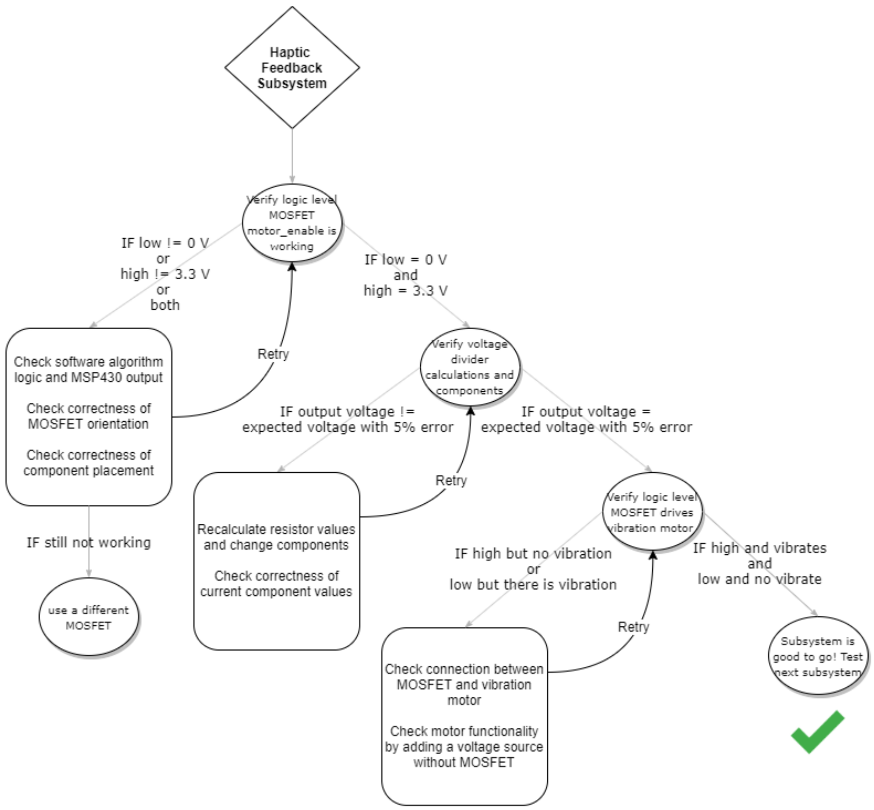


Figure #25: Original Test Plan MB1010 Ultrasonic Sensor Sub-Tree from Project Proposal

For the Haptic Feedback Subsystem, lots of the modifications will be removing remnants of the MOSFET and `motor_enable` that was originally supposed to trigger the vibration motor, however, our final design does not have the MOSFET anymore, therefore a lot of the tests in the original test plan for the Haptic Feedback Subsystem must be removed. The only test we would need to perform in this subsystem to ensure correct and expect functionality would be to check if the vibration motor is working when voltage is supplied to it. This can simply be tested from the breadboard using a Virtual Lab Bench. If this test fails, then additional checks include checking the connections and component orientation, otherwise we must use a new vibration motor and retry the test. Once the check passes, the Haptic Feedback Subsystem Test Plan Decision Tree is complete and successful, and related components are ready to be soldered onto the PCB.

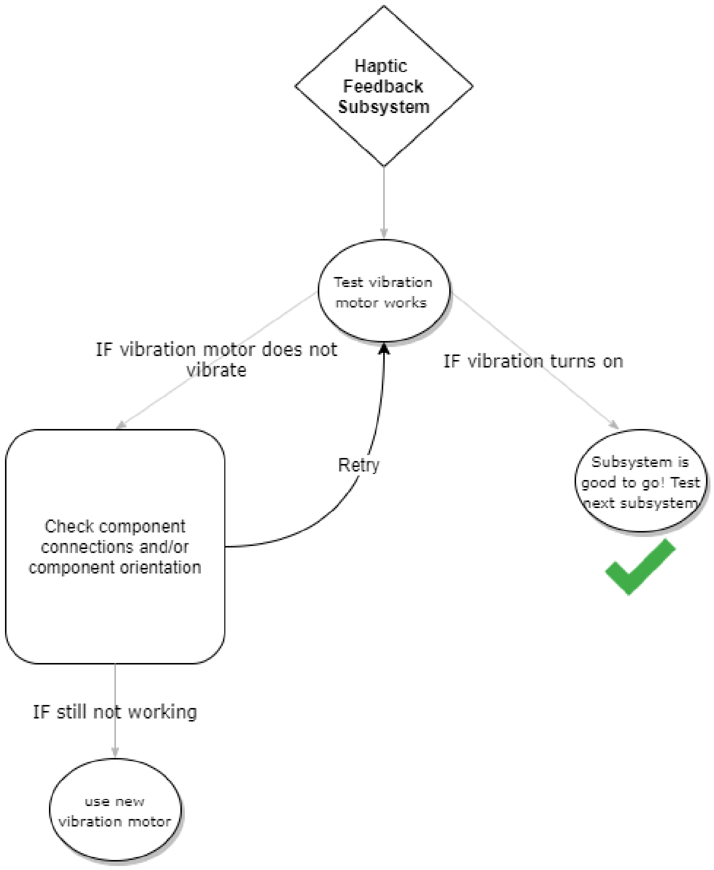


Figure #26: Modified Test Plan MB1010 Ultrasonic Sensor Sub-Tree from Project Proposal

Final Test Plan

Below is the updated final test plan for the overall process to ensure final demo functionality. All the modified decision trees for the subsystems have been compiled together in the figure below:

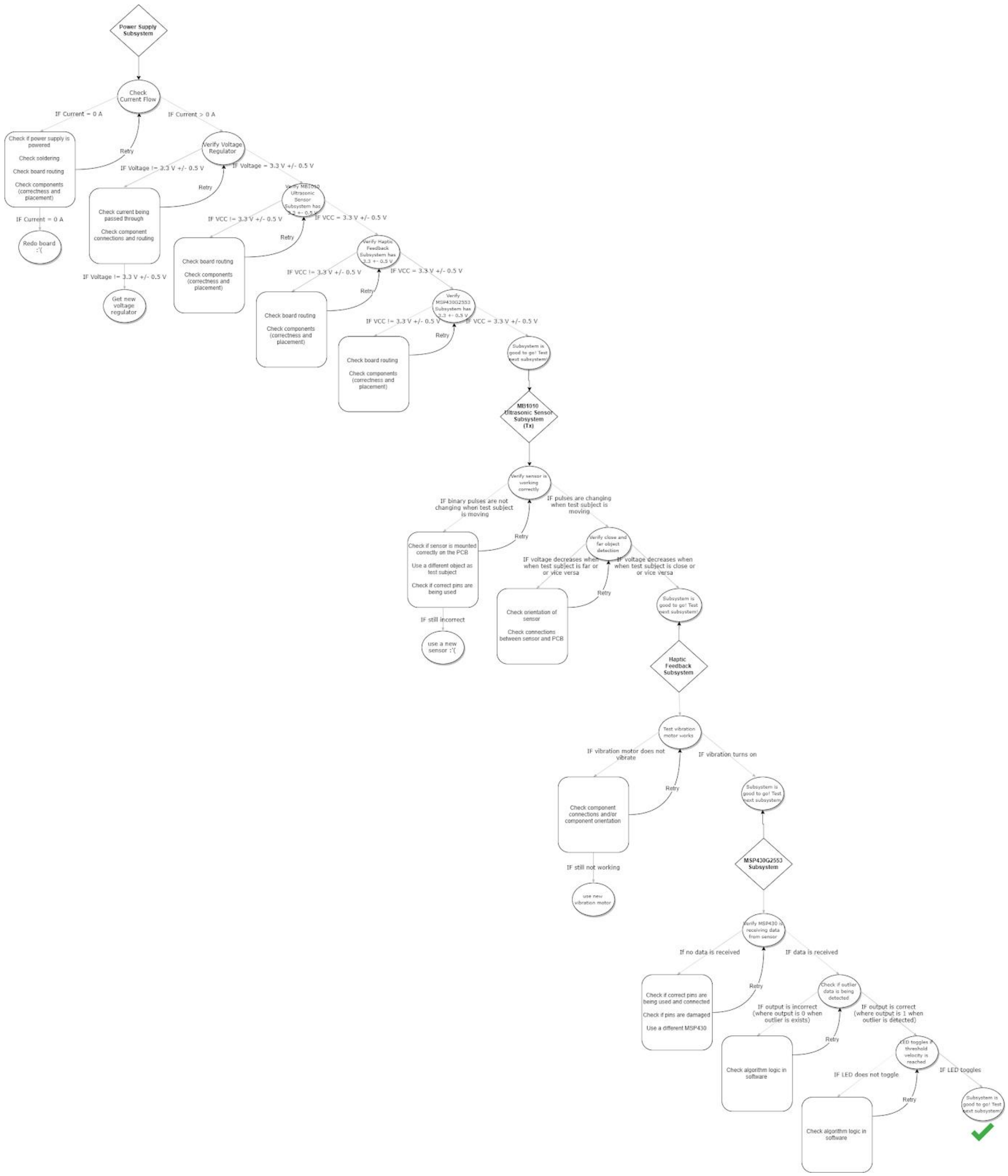


Figure #27: Modified Test Plan

Figure #28: Testing working system without the housing for the circuitry

Final Results

Below are the success criteria and technical expectations of the project discussed in our original project proposal that the demonstration should encapsulate:

- The haptic feedback module works with sufficient intensity to notify the device's user of incoming collisions and/or approaching objects within a user's environment
- The device detects incoming collisions and/or approaching objects at a fast enough speed to trigger the ultrasonic sensor for object detection, followed by notification amounting to no more than one second with the haptic feedback module
- The overall product, which includes the device that fulfills the technical requirements, is sufficiently comfortable as a wearable device. "Comfortable" can be a subjective term, so here it is characterized specifically by:
    - A lack of hindrance as the user performs day-to-day tasks, such as walking and sitting down, etc.
    - The vibrations from the haptic feedback module are not to the extent that the average user is easily frightened by them.

According to these success criteria, our final device did hit all of them.

For the haptic feedback subsystem, we tested the vibration motor on a breadboard first, along with the Virtual Lab Bench and a DC power supply. We inputted different voltage values to check the intensity of the vibrations from the motor in order to determine what voltage is the best voltage that allows for sufficient intensity of the haptic feedback system to notify the user of incoming collisions and/or approaching objects within the user’s environment.

Furthermore, the device detects incoming collisions and/or approaching objects at a decent speed to trigger the vibration motor upon detection. Because we are running algorithms and calculations within our software to calculate object speed and outlier data, as well as flagging when the object is approaching at a threshold velocity, the processing time might be a little slower than originally expected, but still effective nonetheless.

Regarding the final wearable contraption design, the PCB and battery reside in a small backpack that the user can wear intuitively. The PCB connects to the ultrasonic sensor and the vibration motor on a Bluetooth headphones collar with long protruding wires, which can be easily adjustable by stuffing the excess wire into the backpack. The Bluetooth headphones collar is very lightweight and the user can barely feel it around their neck. The collar can be worn on top of clothing too, because the vibration intensity of the vibration motor is enough to feel through clothing. Wearing our device will not prove a hindrance to the user performing day-to-day tasks, such as walking and eating, because the device is very lightweight, and all the wiring are at the user’s backside, therefore performing tasks with one’s arms and such, walking or running around, will still be smooth. As for the vibrations, they are subtle, but they are strong enough to be felt through a layer of clothing. They will not frighten a user, but the vibrations will feel a little weird or uncomfortable at first, but we want the user to be notified of anything approaching and that may be dangerous, and for the user to always be aware of the vibrations when they go off is a good thing. One of our team members is wearing the Bluetooth headphones collar and the backpack, as seen in the figure below:

Figure #29: Final Product Design Worn by Team Member

Also written from our proposal, one feature that we wanted to implement if we had time was our device differentiating between objects coming toward the user as opposed to objects that the user is approaching. However, upon further inspection into this goal, we realized that it was not possible given the limited capabilities of the ultrasonic sensor we selected. This is because the sensor can only track the distance of a single object at a time, which means there is no way to see where any surrounding objects are. Thus, given only a linear stream of distance data, it cannot be determined whether the user is approaching an object or if an object is approaching the user since both scenarios would produce identical data. This goal could possibly be accomplished if we used a sensor which provided more information (for example, a radar sensor), as discussed in the future work section.

Costs

Appendix I of this report includes an outline of the financial cost for manufacturing one device and 10,000 2020 devices, which amount to $101.27 and $847,404.60, respectively. It is hard, however, to factor in the effect of automation into the cost because this device is so user-oriented. Should automation of manufacturing come into play, the individual components to be assembled are undoubtedly mass produced in this manner. For the placement of parts, automation may dictate all connections and attachments except for the sensor and vibration motor, because those leads ought to be soldered in according to convenience and the individual desires of the users. As such, the team expects that automation would decrease the production cost significantly, yet the time for assembling the sensor and vibration motor must remain allocated to the end users.

Future Work

After going through the design process and creation of our device, there are many suggestions for future students if they want to attempt to recreate or add onto future implementations. The first suggestion would be to change the sensor type such as a mini radar sensor that is able to gather distance and angle data so that object differentiation would be easier to implement and velocity calculations would also be eased with the better sensor. The learning curve for the new sensor will be the drawback from using radar compared to the simple distance data given by the ultrasonic sensor.

In addition to changing the sensor, a second suggestion would be to abstract the sensor subsystem and the haptic motor subsystem to one device and send data wirelessly through a communication protocol in order to remove the amount of physical wires on the device. This will cut down the form factor of the device and increase the usability for the user, with the only downside of increasing the complexity of the design such as creating an additional PCB for the sensor and haptic subsystem and having its own power supply. Additionally, the wireless communication between the two PCBs would implement additional components and software practices in order to incorporate a low-latency, reliable protocol for the device.

The last suggestion for future students when implementing this project would be to design a reliable housing and attachment for the sensor and the PCB so that choosing how to wear the platform can be easily recreated for future use and help with testing later on in the final portions of the project. The use of 3D printing proved to be helpful with creating custom housing for our project, however implementing a professional 3D printing service could lead to better results that can be custom fitted to the PCB and device to create a better wearable platform.

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Appendix I: Cost Estimations

Component	Quantity per device	Individual cost rounded to the nearest cent (US dollars)	Cost for 1 unit quantity (US dollars)	Cost for 10,000 unit quantities (US dollars)	Vendor	Manufacturer	URL
JTAG Header	1	0.32	0.32	1204	DigiKey	On Shore Technology Inc.	https://www.digikey.com/products/en?keywords=ed10522-nd&fbclid=IwAR3s_fRq2bfnRP_xB3_GBGTSPOxREwD8DLLUj1r2UNQINOT1GpmP0a2FXLc
MSP430 Header	1	0.45	0.45	4500	DigiKey	TE Connectivity AMP Connectors	https://www.digikey.com/product-detail/en/te-connectivity-amp-connectors/1-2199298-6/A120351-ND/5022043?fbclid=IwAR0OeJJ6V64TTbMJeTWveMsO7wtbMBQynj31Eav4tT4L3_0dJwD23IJ8zkU
MSP430G2553IN20 IC	1	2.69	2.69	11843	DigiKey	Texas Instruments	https://www.digikey.com/product-detail/en/texas-instruments/MSP430G2553IN20/296-28429-5-ND/2638885
Vibration motor	1	1.22	1.22	12200	DigiKey	Seeed Technology Co., Ltd	https://www.digikey.com/products/en?mpart=316040001&v=1597
10uF capacitor	2	0.14	0.28	2436	DigiKey	TDK Corporation	https://www.digikey.com/product-detail/en/tdk-corporation/FG14X7R1A106KRT06/445-173132-3-ND/5802746
0.1uF capacitor	5	0.05	0.25	1900	DigiKey	KEMET	https://www.digikey.com/product-detail/en/kemet/C315C104M5U5TA7303/399-9859-2-ND/3726116
330 ohm resistor	1	0.01	0.01	41.25	DigiKey	Stackpole Electronics Inc	https://www.digikey.com/product-detail/en/stackpole-electronics-inc/CF14JT330R/CF14JT330RTR-ND/1741399
47k ohm resistor	1	0.01	0.01	41.25	DigiKey	Stackpole Electronics Inc	https://www.digikey.com/product-detail/en/stackpole-electronics-inc/CF14JT47K0/CF14JT47K0TR-ND/1741444
Voltage regulator	1	0.55	0.55	1939.1	DigiKey	ST Microelectronics	https://www.digikey.com/product-detail/en/stmicroelectronics/LD1117V33C/497-1492-5-ND/586013
Rechargeable battery	1	11.69	11.69	116900	Amazon	SparkFun Electronics	https://www.digikey.com/product-detail/en/sparkfun-electronics/PRT-13851/1568-1493-ND/6605199
Charger for rechargeable battery	1	6.95	6.95	69500	DigiKey	Adafruit Industries LLC	https://www.adafruit.com/product/1904
Ultrasonic sensor	1	29.95	29.95	175560	DigiKey	MaxBotix Inc.	https://www.digikey.com/product-detail/en/maxbotix-inc/MB1010-000/1863-1002-ND/7896774
JST connector wires	1	0.75	0.75	7500	DigiKey	Adafruit Industries LLC	https://www.digikey.com/product-detail/en/adafruit-industries-llc/261/1528-1126-ND/5353586
Test points	10	0.35	3.5	14340	DigiKey	Keystone Electronics	https://www.digikey.com/product-detail/en/keystone-electronics/5010/36-5010-ND/255332
PCB production	1	37.8	37.8	378000	OSH Park	OSH Park	https://oshpark.com/
Lead wires to connect motor and sensor (15.4 m per spool)	1	4.95	4.95	49500	DigiKey	Adafruit Industries LLC	https://www.digikey.com/product-detail/en/adafruit-industries-llc/3169/1528-1737-ND/6193589
TOTAL COSTS			**101.37**	**847404.6**			

Figure #30: Costs in a table format

As depicted above, the total costs are $101.37 and $847,404.60 for manufacturing one unit and ten thousand units, respectively.

Appendix II: Useful Links and Team Picture

Link to the private Github repository of MSP430 code: https://github.com/bzh0807/2020vision

Link to video of working demonstration (only available to anyone at UVA): 2020Vision.mp4

Figure #31: Team 2020 Vision