SizeU

Final Report

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generate | Student-Led Product Development Studio

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Executive Summary

SizeU is a start-up seeking to change the way consumers shop online by providing an easy way to measure the dimensions of their bodies and using those measurements to recommend clothing through an online store.

Generate's role in SizeU's development mainly encompassed the hardware needs of the company. Specifically, Generate was tasked with designing a hardware solution to collect measurements of length electronically, accurate to at least a quarter of an inch, and in a manner which someone can measure his or her own body without the assistance of an outside party. These measurements include waist, neck, arms, inseam, chest, and wrist. The goal was to simultaneously explore the best way to electronically collect and send this measurement in a "works-like" model while also finding the best customer experience in a "looks-like" model.

The solution proposed is a small, bluetooth connected measurement device which uses a mechanism similar to a traditional tape measure but the experience is not presented in a traditional fashion. We designed the device to accomplish the same tasks of a traditional tape measure while making the experience of using it entirely different. The device is handheld and separates into two pieces which fit together and stay connected with embedded magnets. As the user draws the two pieces apart, a thin tape is extracted from the device. The spool of this tape is attached to a rotary encoder which digitizes the rotational movement. This measurement is read and sent to a user's device (smartphone, laptop, etc) over Bluetooth Low Energy at the press of a button on the device's surface.

This project offered interesting learning opportunities for our Generate team in several disciplines of engineering, especially in the mechatronics domain. Most of the complexity and learning opportunity surrounded the rotary encoder and using it to accurately convert a measurement of rotation to a measurement of length. The solution proposed required effective problem solving in the mechanical, electrical, and software domains to accomplish this goal.

Background Research

To begin the project, we first took time to research similar concepts and potential competitors to understand the market space that SizeU would exist in. There are several online services such as Indochino which supply tailored suits for men. However, the user must supply their own body measurements online. In addition, the company Bagel makes a “smart” tape measure which is accompanied by a mobile application. Although similar to SizeU, Bagel is not meant for clothing measurements nor is it to be used on human bodies. at $89, the product is much more expensive than the target SizeU is aiming for.

Because this project was in the early stages of the design process, we began by brainstorming possible ways of measuring the human body. This helped explore potential solutions and define constraints more clearly. Some of the ideas that we came upon, like building a drone with an attached camera to fly around the person, were simply not feasible for the timeline of this project and thus could not be done to a satisfactory degree if we were to attempt them. Others, like having a tight-fitting shirt with embedded resistors that would measure changes in resistance according to how the fabric was stretched, were deemed not appealing to the customer, as they would involve clothing that would most likely make them feel uncomfortable. This is especially applicable in the case where the customer is already uncomfortable with their bodies. In addition, we thought about using a 3D scan of the user’s body to obtain measurements, but we realized that the project would require the user to be naked for accurate measurement, which we felt was an inefficient process. In addition, that project would be either through a built-in camera on a phone or computer, which would be more difficult to operate individually, or through shipping a physical camera, of which the camera would be more expensive than we thought SizeU would have wanted. With this information in mind, we narrowed down our idea to a product that performs the role of a tape measure and sends the information wirelessly to a phone or computer, but that does not feel like a tape measure when operating it or reading measurements. For example we don’t want any numbers on the tape.

With the decision to create a product that functions like a tape measure but doesn’t have the look or feel of one, we wanted to research not only what the device should look like but what the best components would be to measure length. In order to do that, we bought a device that performed a similar function; the Health-o-meter Digital Tape Measure. Once it arrived, we deconstructed it to understand about how it worked and what components were inside. We learned about how the Health-o-meter used a rotary encoder to measure length of extracted tape. The teardown of this device is further explained in the mechanical design section of this report.

Systems Overview

The proposed system design is a small measurement device which uses a retractable tape to acquire length measurements and sends them via Bluetooth Low Energy (BLE) to a connected device. This connected device can be anything that is BLE enabled including a smartphone, tablet, or laptop. Specifications of these devices would determine if they can be used with our proposed solution.

On a side note, we (the Generate team and client team) decided that the scope of our work does not encompass the user experience for the software side of the product. Moreover, our work only involved collecting and reporting measurements, not receiving them and handling them on an application on a UI. This scope definition helped our team stay focused on the problem at hand and narrowed down system requirements making them easier to tackle. Perhaps the most important effect this specification had was determining that our device had to be aware of what measurement was being taken. This would allow creating the software on the application side in the future more simple while only introducing a minor increase in complexity to our design.

The system we've designed and constructed is not integrated yet. The decision to keep integration out of scope was made jointly by the client and our team. The fact that SizeU was early in its development process and the exact needs of the venture were not explicitly determined yet are the main factors that led to this decision.

Although the system is not integrated yet the design process, both the "works-like" and "looks-like" prototypes took into consideration integration in the future. From developing the works like we were able to approximate the size and space that the product would take up. This information guided us in the development of the "works-like" by giving us a specification for space that the electronics must fit in. We selected our components accordingly and used development boards we know are easily miniaturized to fit within that defined space. In short, the electronic and mechanical components of the "works-like" are intended to fit within the "looks-like" and are each designed to make accomplishing such integration as easy as possible in the future.

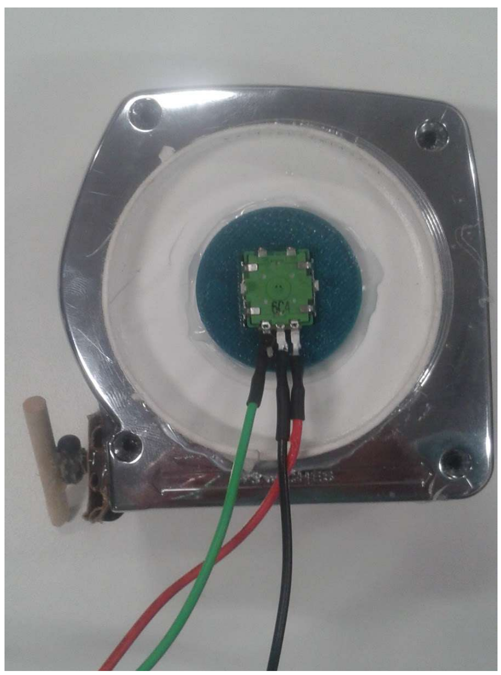
Mechanical Design

Measurement Systems

Three potential approaches were determined to be viable in collecting measurements. Two rely on a rotary encoder and the third uses a line sensor. The rotary encoders is rotational measurement device. It is excellent at measuring the angular change in a system, but is unable to determine the position at which it starts. The encoder used was able to measure 48 positions per rotation, an angular resolution of 7.5 degrees. The hub-mounted encoder was determined the most practical and best fit for the system.

Hub-Mount Encoder

In this configuration, the encoder is mounted to a central spool. The tape is wrapped around the spool. A torsional spring is used to keep the spool in position. When the tape is pulled, the spring will exert a constant retracting force.

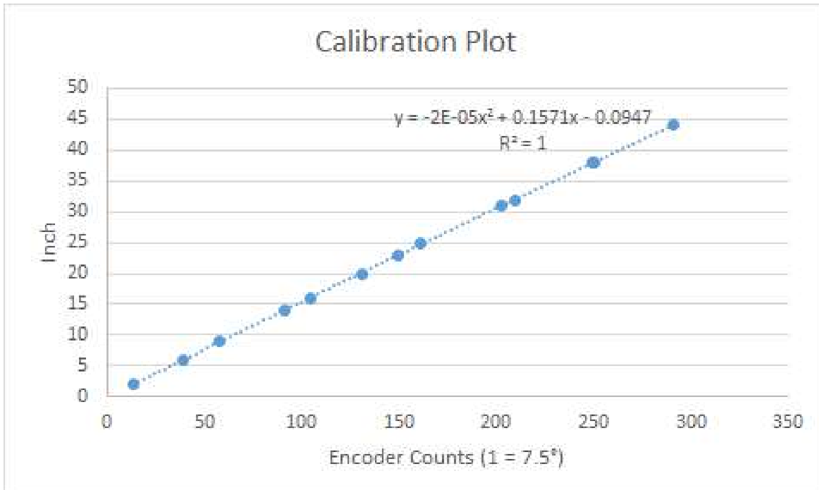


Outside casing of the hub-mount encoder model. The encoder is centered on the spool.

The encoder measures the number of revolutions the spool travels. Since the tape wraps around itself, the radius at which it is pulled constantly varies. The distance the tape is pulled is therefore related by a second-order polynomial to the number of revolutions of the spool. The theoretical relationship is given by:

$$d = -(c^2 t / 2\pi) n^2 + (cR + ctL) n$$

In this equation, d represents the distance the tape is pulled, c is the angle of each encoder step, in radians, t is the thickness of the tape, n is the number of encoder steps measured, R is the radius of the spool, and L is the initial number of layers of tape wound around the spool. However, in practice, this equation tends to be very inaccurate. Calibration is best done by measuring the number of encoder steps against the distance of pull, then plotting the data with a second-order polynomial fit.



This graph shows the calibration data for the functional model.

It is important when construction the spool that the tape is constrained to wrap only around itself, in line with the draw. <u>If the tape is allowed to wind around the spool out of line, the accuracy will suffer.</u>

Roller Encoder

This model uses an external roller wheel to measure the pull of the tape. The tape is wrapped around a hub, and uses a torsional spring to exert a constant retracting force. The tape is pulled out around a wheel mounted to an encoder.

Two roller wheels with tape positioned between.

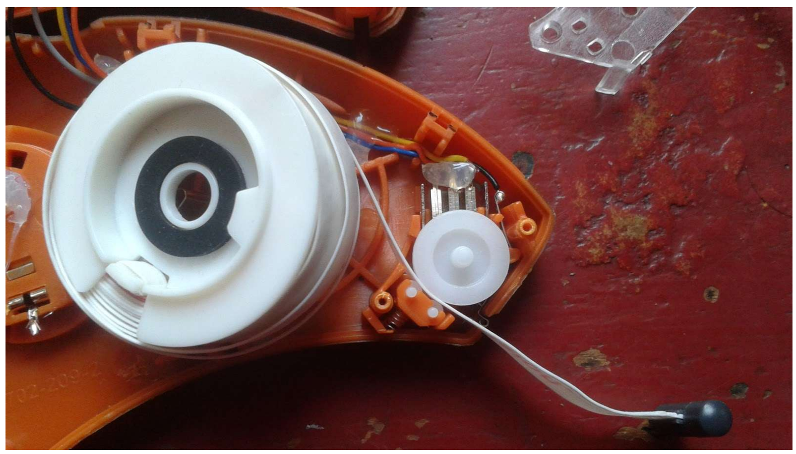
This model requires a high degree of force between the roller and the tape to maintain the no-slip condition, which is necessary for the encoder to accurately measure the amount of pull. Steps that can be taken to increase that force include increasing the radius of the wheel, increasing the frictional coefficient of the wheel by texturing or material selection, increasing the width of the wheel, or increasing the wrap angle. A second wheel can also be used to pinch the tape.

This configuration was determined to be impractical because the high force needed to maintain no-slip prevented the tape from retracting. It was also determined that a flat-band tape must be used, and that a string cannot be used.

Competitive Product Deconstruction

A similar product, the Health-o-meter Digital tape measure, was acquired and taken apart. It used a roller wheel encoder to measure the distance the tape was pulled. It was able to function because the encoder used had much less internal friction than the one used for development of the prototype.

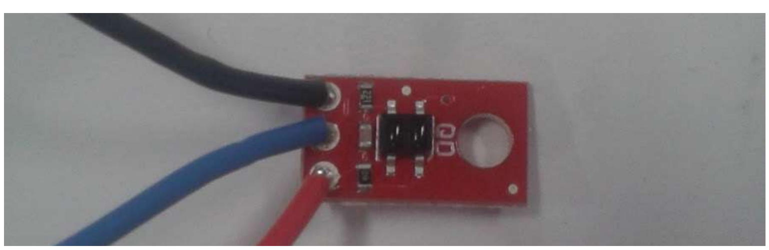
Health-o-meter tape measure



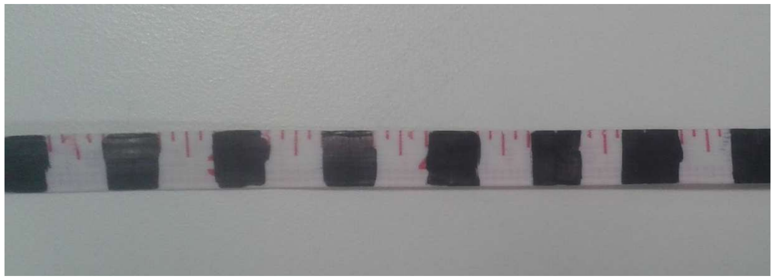
Interior of the Health-o-meter

Line Sensor

A line sensor can also be used to measure the pull distance of the tape. A line sensor sends out a beam. The amount of light reflected allows it to determine if it is looking at a light or dark color. This is interfaced with a tape colored in alternating light and dark strips of equal length. The tape is pulled past the line reader, which counts the number of light and dark sections that pass.



Line reader. The black chip reflects a beam that is used to detect color.



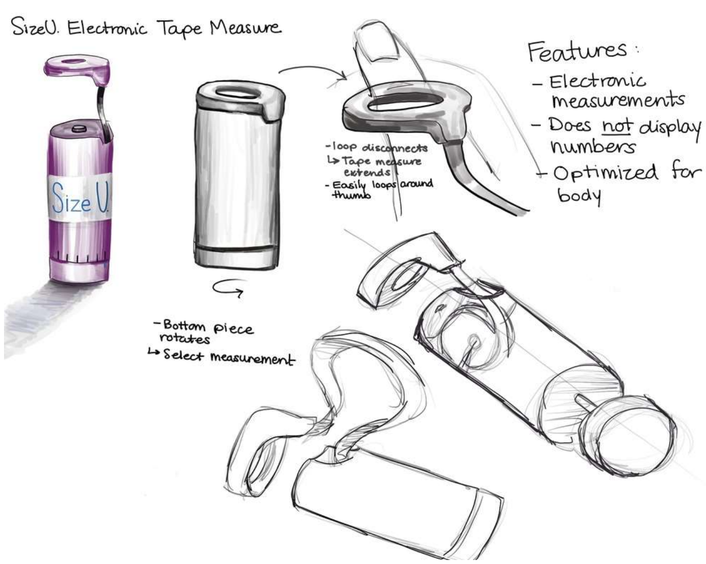
Tape with ¼ inch markings.

Strips of ¼ inch length, centered at each ¼ inch mark, provide a maximum inaccuracy of ⅛ inch. The line sensor was determined to be reliably able to detect the ¼ inch segments when pulled past at a slow rate. It was not tested a fast pull rate.

This system was deemed impractical because it would require the tape to be striped, as like the pattern in the image above, which may be unappealing to consumers. The functional viability of this system configuration was not fully explored.

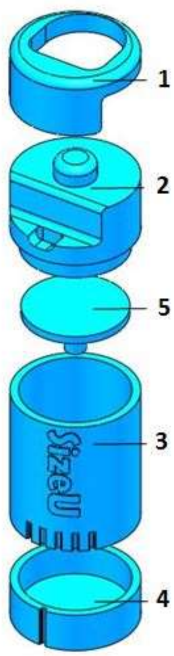
Assembly Overview

The assembly shown below was designed by the Generate team to be eventually used as housing for the works-like model. This section will go over the direct components and features contributing to the assembly as well as manufacturing methods, alternative designs and a step by step intended use.

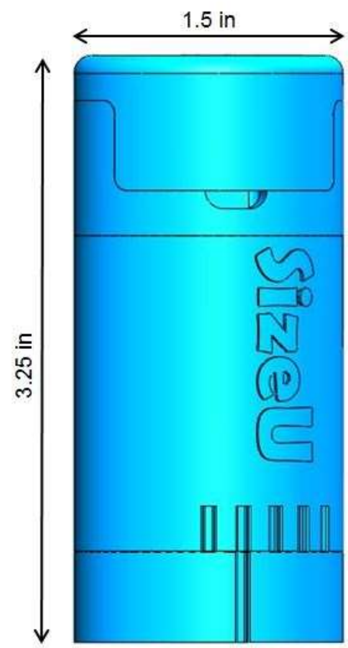


The approach taken when creating an assembly model was to start solely with what it would look like and make small modifications to be able to accommodate the works-like model, including all electrical components. With this being said, there may be extra components added to the final product.

Shown is the assembly of the team's final looks-like model design choices and CAD. The assembly as it is sits at 3.25 inches high and 1.5 inches in diameter when all assembled. The model is broken into six components, including the retractable device. Each component has a purpose in the model, and, as previously mentioned, components may require modification in order to incorporate the works-like aspect.

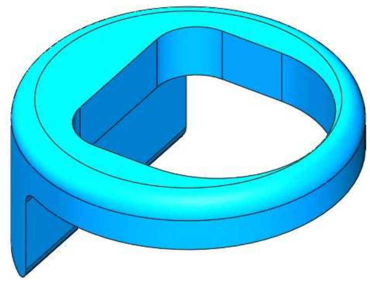


Exploded View of CAD



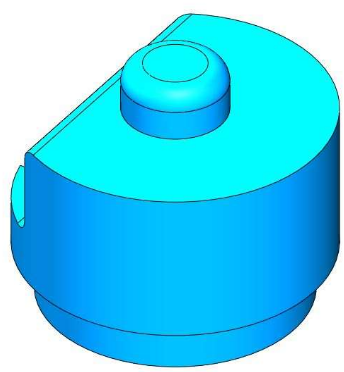
Assembly Overall Dimensions

1. Thumb Hole/ Hoop Component



Thumb Hole CAD

2. Button and Retraction Feed



Button and Retraction CAD

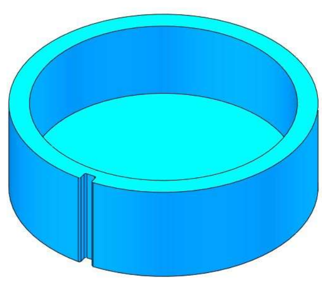
3. Body

This is where the entire works-like model will be held. The inside is hollow with a minimum wall thickness to allow maximum room for the rotary encoder, BLE board and the rest of the electrical component attachments. An inserted plate could be added to this section to allow easy access to the electrical components for assembly. The exterior of the body is very freely controlled and can be altered to different colors, textures, and even shape to better reflect user feedback and other changes down the road. As it stands, there is an extruded “SizeU” to represent the possibilities and paths that the exterior could follow. This section can also have slots for the LED lights, placed above the cut outs for the measurement adjustments.

Body CAD

4. Rotating Base

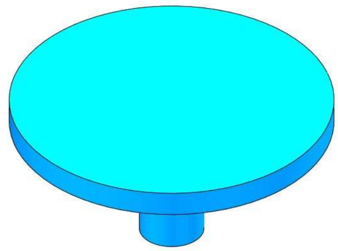
The rotating base allows the user to select which measurement they will be recording. For the purposes of the looks-like model the base rotates freely, 360 degrees, but in the functional version it will click between slots (seen on the body) to indicate each measurement. Again for the looks-like only, the base is attached to the twisting inserter (below) as the mechanism that allows it to rotate.



Rotating Base CAD

5. Twisting Inserter

This component is exclusively designed for the looks-like model to be able to rotate, and will be one of the main components that needs to be modified for the model to function. As of now, it consists of a flat cylinder with a pin attachment for the rotating base, previously described.



Twisting Inserter CAD

6. Retraction Mock

The team decided that for the best usability feedback we would use a retraction device such as a badge or keychain, to allow for simple retraction that is easily replaceable if broken. It is important that the diameter is less than 1.3in to fit properly in the body. A potential shortcoming of this model is that it does not account for the flat tape that we would hope to have in the final design, allowing a better feel when taking measurements and traction for the overall device.

Example of Retractable Badge

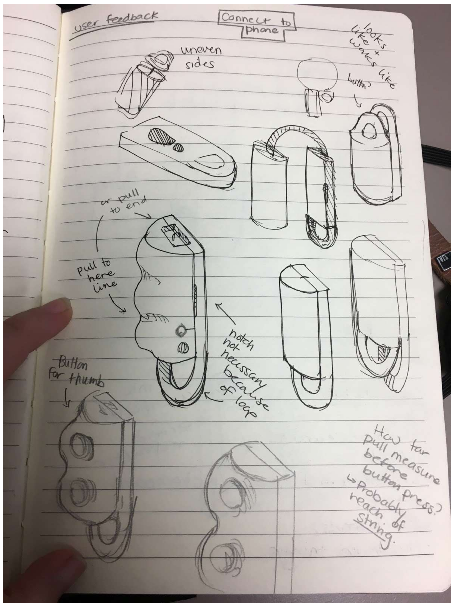
Assembly Manufacturing Recommendations

3D Printed Model

The assembly, as it stands today, was 3D printed using SLA to accommodate for the small features as well as tolerances that the model has. The team suggests that the prototyping continues with similar methods to reach an end design. Below are a few vendors that have quoted the current design to get an estimate of how much the prototyping will cost. Although SLA 3D printing will suffice as this is a very early stage design, it can be modified down the road to allow for injection molding, making sure to keep the wall thicknesses constant to prevent sinks and voids.

Vendor	**Material**	**Cost Per Assembly**	**Turnaround Time**
The Empire Group	SLA Accura 25	≈$175.00	Under 1 week
InterPRO Models	SLA-SR-Xtreme	≈$300.00	Under 1 week
Northeastern University Library	SLA	≈$40-60	Heavily depends on queue

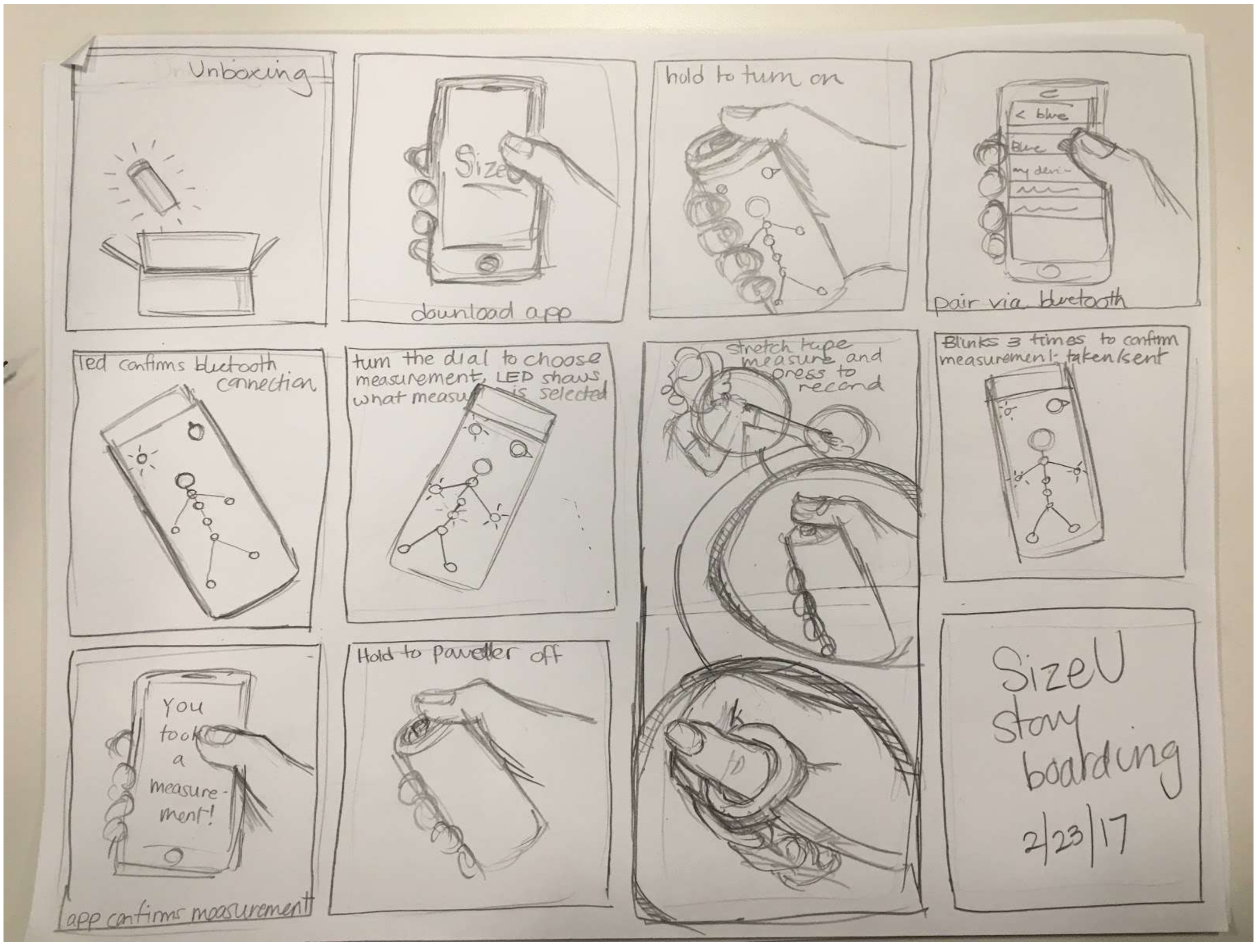
Alternative Designs



There were a number of ideas discussed before landing on the final shape that we chose for the looks-like prototype. The general size and cylindrical layout is a necessity of the inside components, but the external housing shape could be changed, for example making it curved for a clear place for the user to put their fingers. However, we chose not to do this because there are a variety of hand positions utilized to take the different measurements that would not all fit with the same curves. Some sketches of other designs (not tested or prototyped) are pictured above.

Intended Use

The looks-like model was created to allow the user to have an effortless, straightforward experience when using the device. Along with an app guiding the user through the experience, the design was created with minimal moving components while still maximizing the utility and usability. The following picture depicts the user interaction that a customer would expect to have.



1. The device is turned on by holding down the Button (component 2).

2. The Thumb Hole (component 1) is placed around the thumb or stepped on by the foot, depending on the measurement required.

3. The Thumb Hole is completely detached and stretched away from the assembly, utilizing the Retraction Mock (component 6).

4. Once the appropriate length is reached the button on the Button and Retraction Feed (component 2) is pressed to record the measurement. For the neck measurement, ensure that The Thumb Hole is placed flush to the Button and Retraction Feed after wrapping the circumference of the neck, before the button is pressed.

5. The user will then rotate the base (component 4) again to select a different measurement. This process can be repeated until the desired number of measurements is reached.

6. The device is then turned off the same way it was turned on, by holding down the button.

Electrical Design

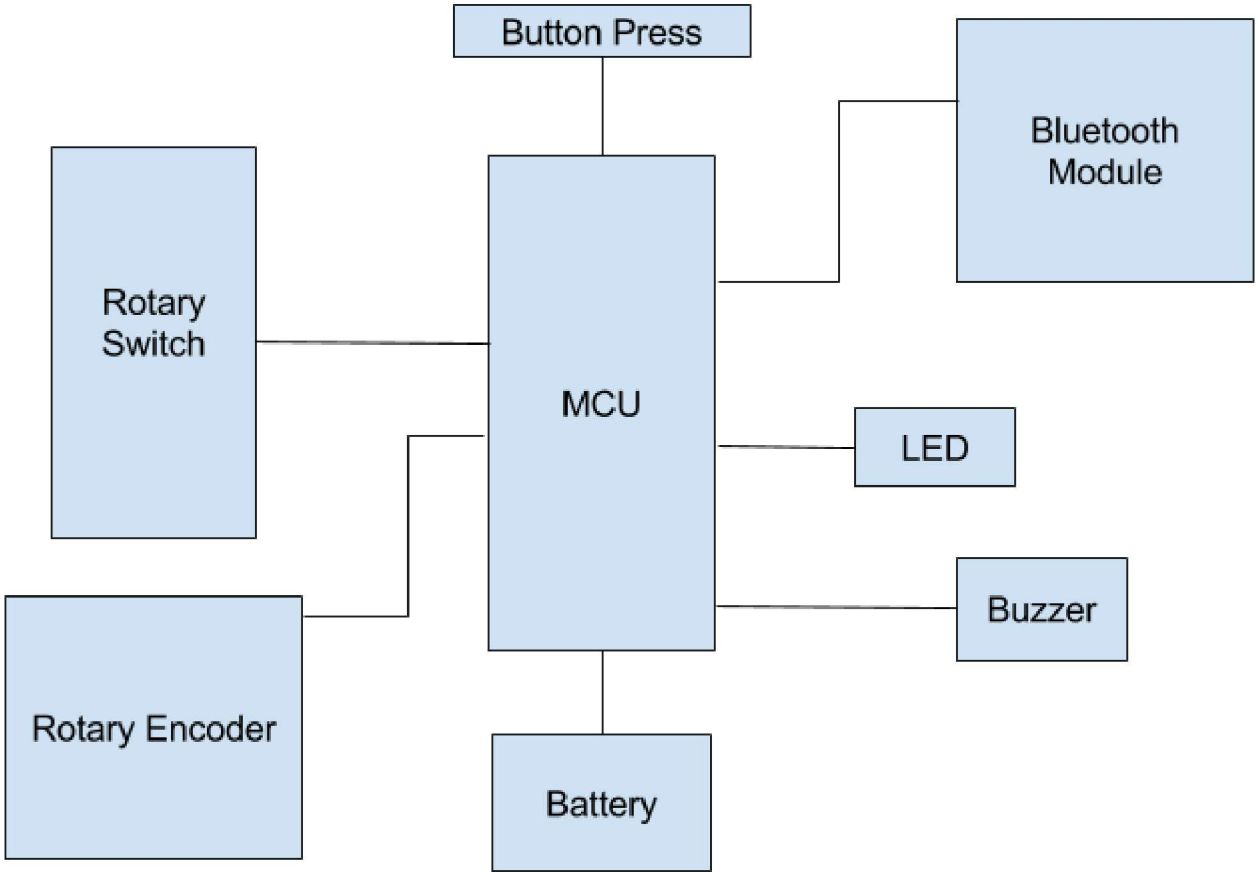
Design Overview

As we were familiar with the hardware and software implementation of the open-source electronics platform Arduino at the start of the semester, we decided to prototype our works-like model using an Arduino Uno and connect the various components to the Arduino using a breadboard. Arduino is great for prototyping but any embedded microcontroller system would work.

For the inputs to the works-like prototype, we used a single button that sends the measurement of the length of tape extracted and the selected measurement type from the device over BLE to an application on the user's cell phone. A rotary switch was used to select the measurement being taken and a rotary encoder, which is attached to the spool and rotates with it, is used to find the length of tape that has been extracted from the prototype.

For the outputs of the prototype, we used an RGB LED and a piezo buzzer for signaling to the user if the works-like prototype has connected or disconnected from the receiving device and whether the prototype is sending, has successfully sent, or has failed to send a measurement.

Because the looks-like prototype's focus was only on the physical interactions that the user has with the device, it has no electronic elements within it. Below is a representation of the hardware subsystems interconnected in the system:



Components

- The components in our electrical design are a Bluetooth Low Energy (BLE) breakout board, a button, an RGB LED, a rotary switch, and a rotary encoder. They are hooked up to an Arduino breadboard and wired to an Arduino Uno, which will power and control them.
- The BLE board is used to connect the Arduino to an app on the user's phone through the Bluetooth Low Energy protocol. By using it with our software, the measurements can be sent wirelessly and displayed on the user's device for verification.
- The button is used to communicate to the prototype to send a measurement to the receiving device. Once pressed, the current measurement will be displayed for the user to see.
- The RGB LED is used to signal to the user if the device has connected to a receiving device and, once the button is pressed, alert the user to the status of the prototype. If the measurement is still sending, the LED blinks blue. If it sends successfully, the LED blinks green. Otherwise, if the measurement fails to send, it blinks red.
- The piezo buzzer performs the same function as the RBG LED by buzzing a “fail” or “success” tone to the user if the measurement has failed to send or has sent successfully. We incorporated it into our design to allow for audio feedback to the user,

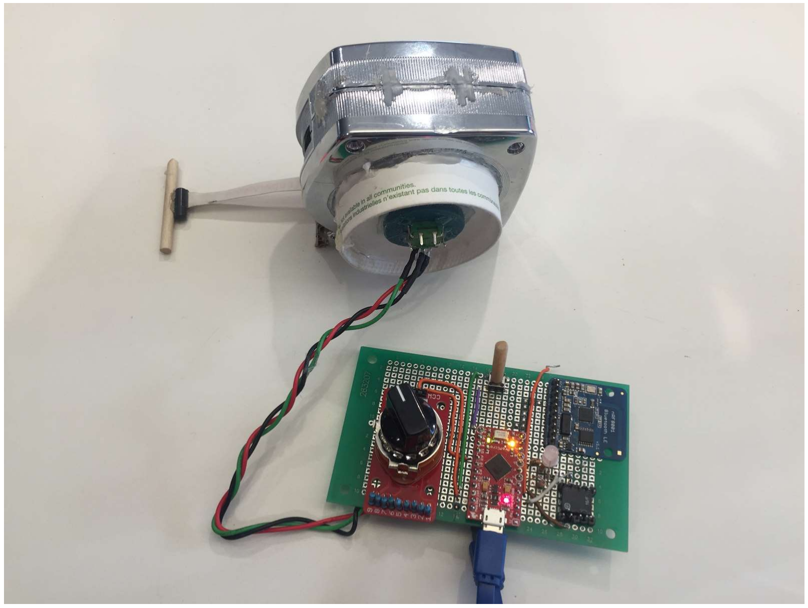
which would supplement the visual feedback to that the user would already have with the LED.

- The rotary switch is used to signal to the device what measurement is being taken. The measurements that we chose to measure were waist, wrist, arm, chest, neck, and inseam for a total of six measurements. These measurements are the standard six measurements that tailors use to adjust clothing for both men and women, but if the client desires to adjust the device to focus on women exclusively, the six measurements are easy to change.
- The rotary encoder records the number of rotations which have occurred within the tape measure. This is used to get an accurate body measurement up to within a quarter of an inch. The details to its operation are described in-detail within the mechanical section of this report.
- The placement of each sensor was not highly considered on the protoboard since our project focused on both a looks like and works like model. However, from the pictures shown below most components can be packed tightly together besides for the rotary switch.

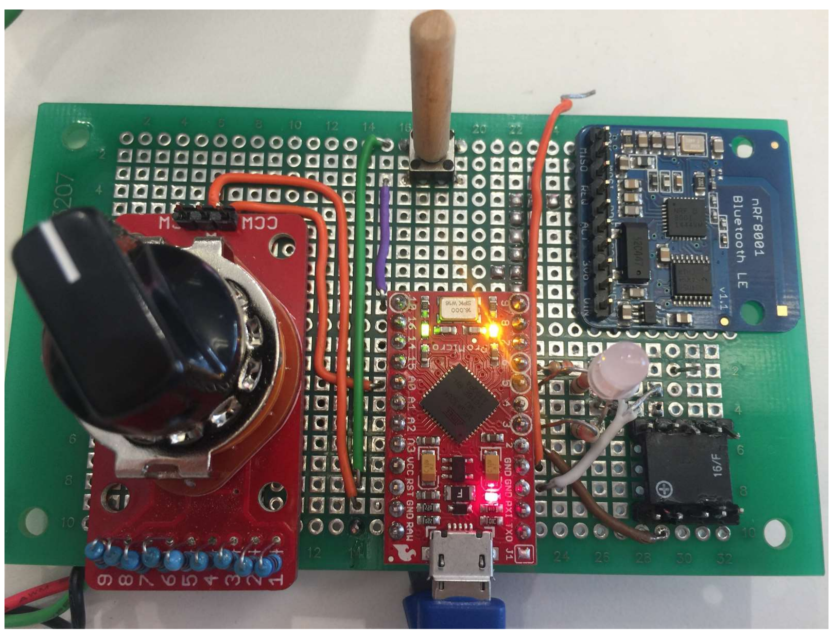
Links to the Spec Sheets:

- Adafruit BLE board
- Button
- RGB LED
- Buzzer
- Rotary Switch
- Breakout Board for the Switch
- Black Knob for the Switch
- Rotary Encoder (Designed in-house)

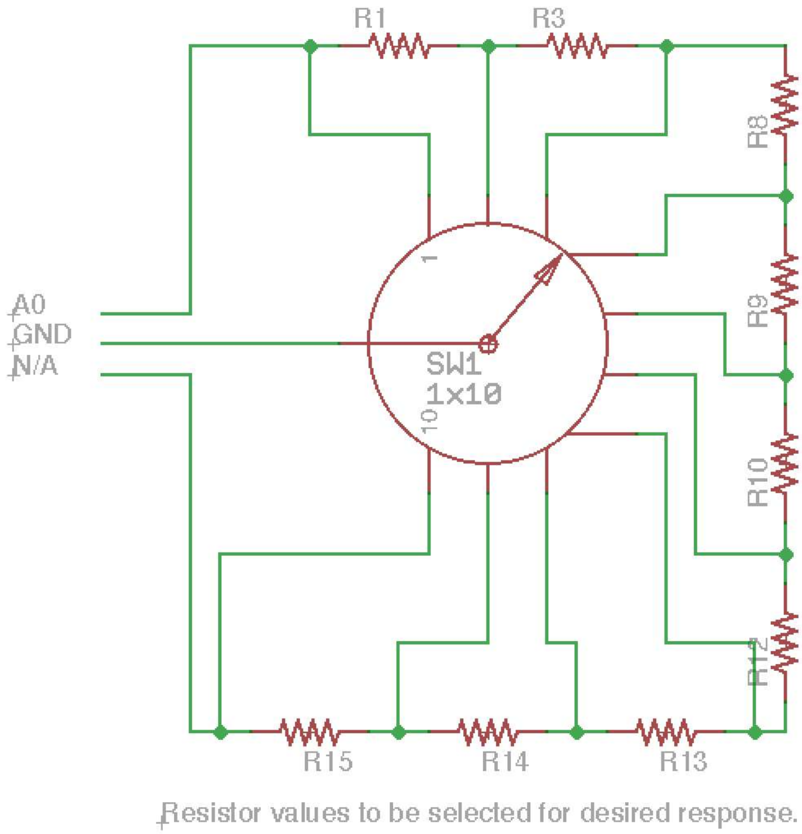
Circuit Board



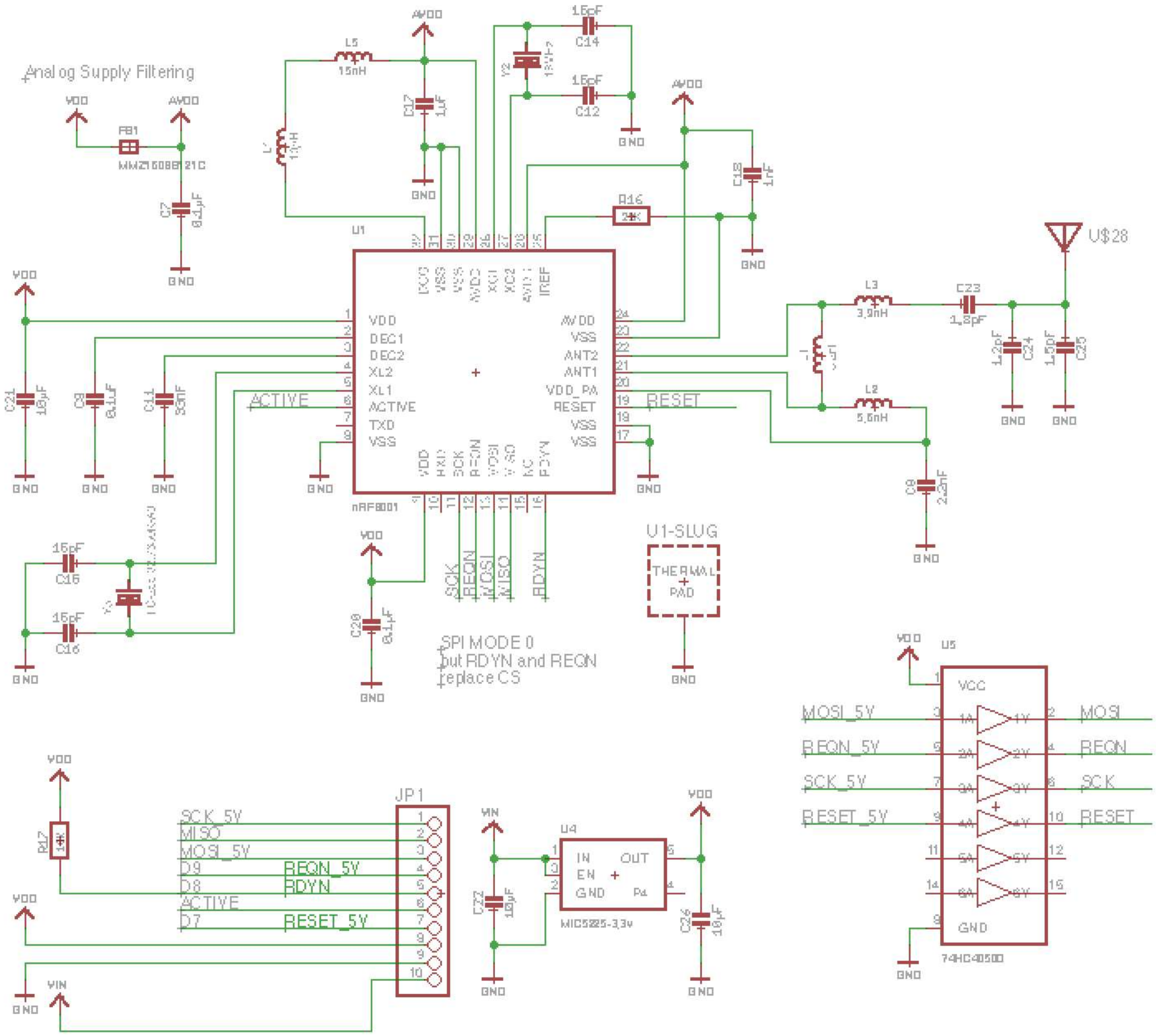
Prototype board attached to rotary encoder enclosure



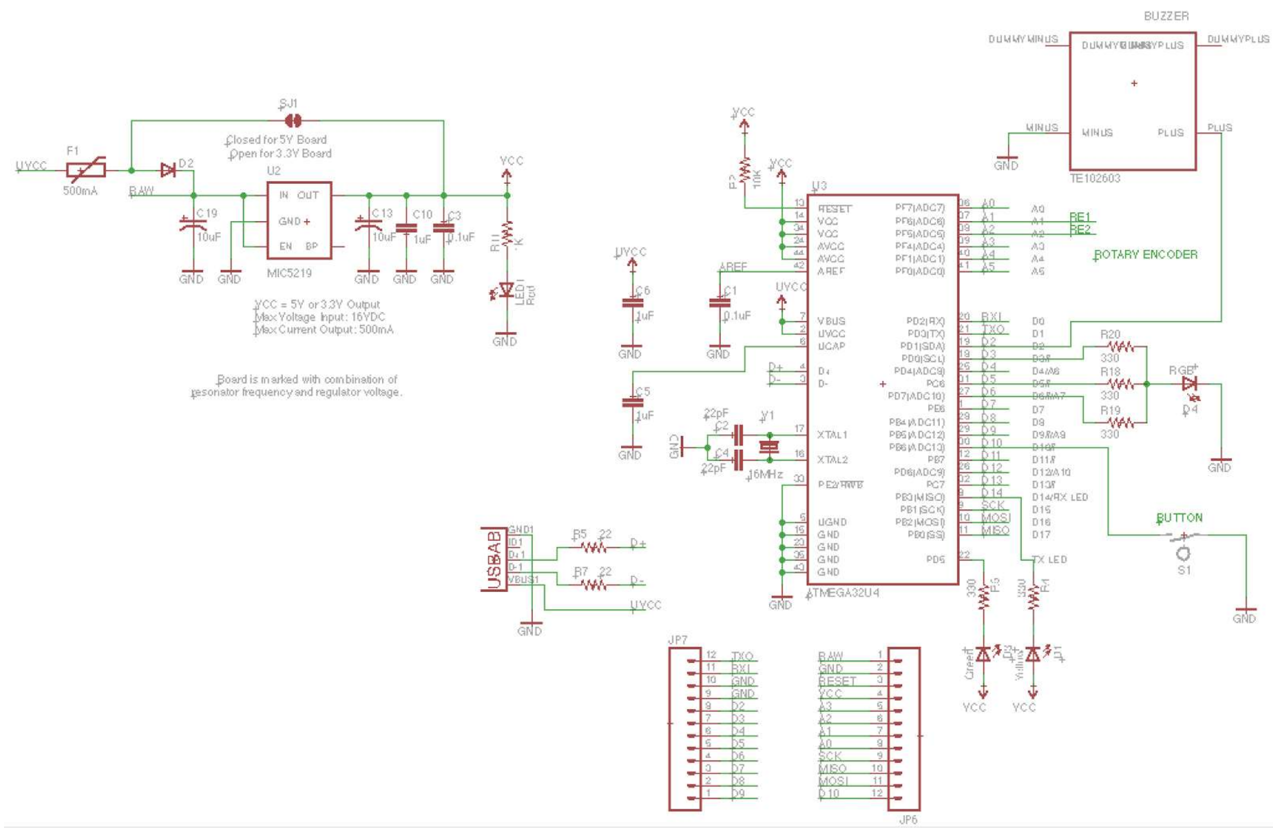
Prototype board including BLE board, rotary switch, speaker, and microcontroller



The Schematics for the Rotary Switch



The Schematics for Bluetooth Module



The Schematics for the MCU and rest of system

Software Design

Design Overview

The software was written in the Arduino Integrated Development Environment (IDE), which has a very similar style and syntax to C++. The microcontrollers that we used, the Arduino Uno and the Arduino Pro Micro, are programmed in this language, which has the defining characteristic of running all code in an endless loop. This enables repetitive tasks, like polling for the Bluetooth or updating the length of string extracted from the device, to become easy to implement and code without the addition of several overarching, hard-coded loops. Because of its unique structure and its open-source nature, Arduino is a popular method to prototype ideas and devices, and because of our familiarity with the platform from our previous classes, we decided to use it to prototype for SizeU.

We wrote most of the code by adding different components added over time. We started with the most important feature of the prototype, the integration of a Bluetooth Low Energy chip, which at first presented a challenge to our team. The board that we started with, the BLE Nano Kit from RedBearLabs, had little documentation and was difficult to code, leading to an exorbitant amount of time spent just learning how to work its own unique workspace. We therefore decided to use the Adafruit nRF8001 Breakout Board, which had a convenient guide to wiring the board and sample code to get started and gain familiarity with the specific syntax of the board.

With the easy-to-follow instructions, we were able to quickly get up to speed on using the device and began to experiment with incorporating a button to send data. Because the board had a phone app already made by the manufacturer specifically to send information over BLE from the Arduino to the phone app itself, we decided to use it to prototype our design because even though the finished product of our prototype may involve interaction with a computer, it almost certainly involved a mobile interface and creating an API for the computer was out of scope for our semester-long involvement.

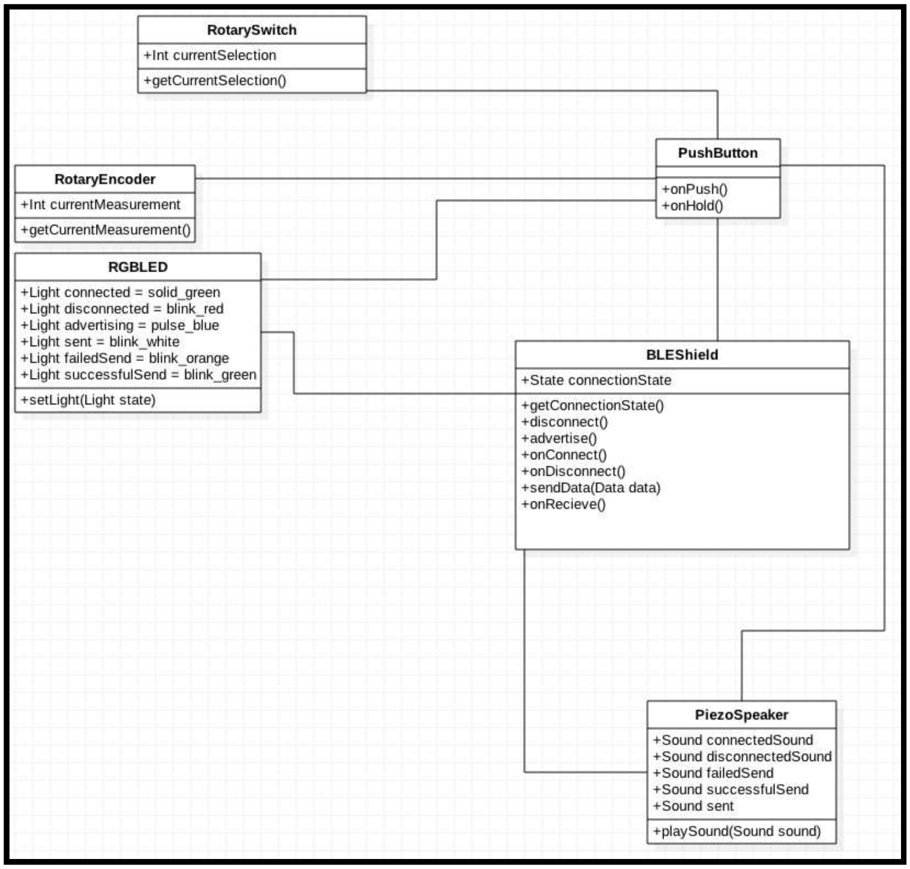
Having decided where to send the data from our prototype, our next task was to provide feedback to the user by lighting an LED to let that user know that the board had successfully connected to the phone over BLE. After doing that, we then needed to send data to the phone app, which we did by wiring a button to the Arduino and sending “dummy” data over a Serial connection to the phone. Because we needed a way to differentiate between the different measurements that the user could take, we looked into using a dial, multiple buttons, or a switch to complete the task. Multiple buttons would take up too much room, so that was ruled out, as was the dial because the dial does not have discrete values as its range. Rather, it uses a continuous spectrum to determine its position, which would have been more complicated to account for. In addition, the haptic feedback of a switch felt better to the user and provided a better user experience.

With the rotary encoder and the corresponding software system finalized to provide accurate numbers, we focused on integrating the encoder with the current prototype to form a singular works-like prototype. The hardware connections were fairly easy to fix, as that mostly consisted of connecting the rotary encoder to the correct pins on the Arduino. The software side was more difficult, as the code had to be reworked to change the “dummy” code to actual live measurements that changed with each setting on the switch.

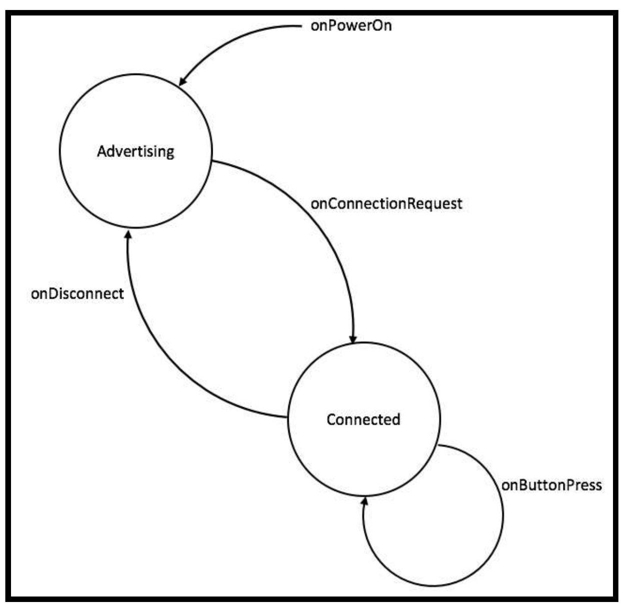
In order to use the Adafruit Bluetooth Low Energy chip on our circuit, we first had to download the specific Adafruit BLE library from the website of Adafruit Industries and copy the library files into where we had saved the libraries that had come with Arduino IDE. Once we did that, we no longer needed to use any other libraries for our code to function properly.

The process we found most effective for developing the software in parallel with the hardware solution was a more discrete, staged development. As mentioned above, we took each electronic component that was to be used in the software (BLE board, Rotary Switch, LEDs, Buttons, Rotary Encoder, and Piezo Speaker) and got them working separately first. This piece-wise unit addition made management of each component and the code in general much easier to transition. Moreover, translating the implementation to software was quite easy, as we used a Unified Modeling Language (UML) approach to planning the integration of components together. Pictured below, the UML design allowed visualisation of the relationships between components and which parts of the hardware, and their respective software, had to interact with each other during operation. The graphic also illustrates data points and the methods a component is responsible for, which made the software easy to divide and complete. To construct this graphic and the information within each block, we used a program called StarUML, which also allowed us to store pseudocode for each component inside of the information block. It’s external link can be found here for reference. From this point, we had a big-picture, high-level software design and were able to start integrating the smaller pieces of software we had together, which made the process easier to tackle.

Our recommendation for next steps in the software development process would be to start moving away from prototyping development environments and moving to a more robust, industry-standard microcontroller set. Arduino is fantastic for prototyping and proof of concept, which has been completed here; however, in the future, most embedded systems are typically developed in C, which gives more control over the operations and memory footprint of the device.



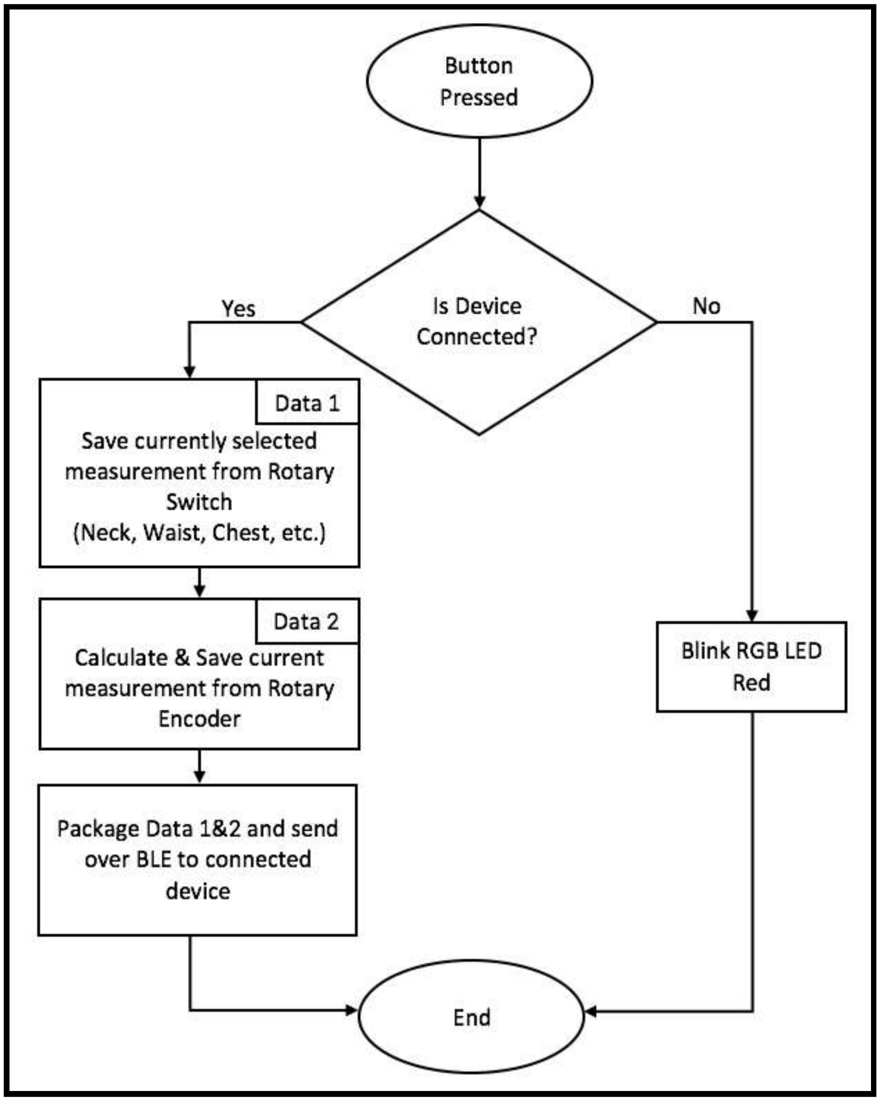
UML Representation of Software Design



BLE State Machine

Software Operation Overview

The basic operation of the software is quite simple with the primary function being passing data read from components to the BLE chip and sending that to the connected device. The data pieces being read from the device are the current length of tape extracted from the device (read from the rotary encoder) and the current measurement selection (read from the rotary switch). In basic terms, at any moment when the device is powered on, if the push button is pressed the device goes through the following operational steps pictured below. This describes the general operation of the device once it is connected. As depicted above in the BLE state machine, when the device is powered, it is either advertising or connected. When it's advertising, it is not connected to anything and is simply indicating it is available for connection. In order to connect with a device, an outside device must initiate the process remotely, which we did by downloading the Bluefruit LE application on our phones and using that interface to find, connect to, and receive the data from the prototype. In the future, an official SizeU application, either for the computer or the phone, can be written to perform the same function. As long as the specific device has Bluetooth Low Energy capability, the app will work and would be a great way to interface with the users outside of the product.



Function of device

Next Steps

Currently, we have two separate prototypes, one that works like the finished product and one that simply looks like the finished product. For the works-like prototype, the device can send accurate measurements over Bluetooth Low Energy to the user, who can adjust the measurement being taken on the device by physically adjusting the switch to one of six different positions. Right now, the device is always on and will not turn off unless the power cable is disconnected from the computer or battery pack, but in the future, a simple on/off button or switch could be implemented to fix that.

Moving forward, gathering user feedback on the looks-like prototype to finalize what the end design would look like is one option for SizeU. Another step would be to combine both the works-like and look-like prototypes into one cohesive prototype that performs every function and visually and texturally feels accurate to the final goals. In order to manufacture the product, the process could be completed in-house, which would be costly and would probably not be the best approach. Therefore, once the entire prototyping and experimenting process is completely finished, finding an outside manufacturer to create a sample batch of 50-100 unitsto send to users would be something to consider. The actual amount of units needed is debatable and depends on the size of SizeU, the amount of funding it has, and the number of early customers that the company has. In addition, when deciding on the manufacturer, things to look for are price, amount of units needed and how fast they are needed, and where the manufacture is located, which would impact shipping cost and on-site visits to check out the facilities.