University of Wisconsin-Madison

Radiation Distance Safety Meter

BME 200/300

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Contents

1. Abstract

Many thyroid complications are treated with radioactive Iodine (I-131). The radioactive patient is then hospitalized afterwards to avoid exposing others to harmful levels of radiation. To instead be discharged immediately, a mechanism that alerts individuals (i.e. family members) of dangerous radiation exposure is required. A previous semester designed a belt that uses a thermal and proximity sensor that beeps when an individual is within a one meter range of the patient. Our client, Dr. Sarah Hagi, a radiologist at King Abdulaziz University Hospital, proposes the creation of a device that more accurately alerts individuals of total radiation exposure. The proposed design incorporates Bluetooth technology to calculate family member's total radiation exposure as a function of proximity to the patient and time.

2. Introduction

2.1. Thyroid Physiology

The thyroid gland is a hormone secreting organ located in the neck just below the larynx. The two main hormones it produces, triiodothyronine (T3) and thyroxine (T4), are synthesized from iodine and tyrosine and play a large role in metabolic regulation. Specifically the functions that the thyroid controls include weight, blood pressure, body temperature and metabolism.

When iodine is introduced to the bloodstream, whether it be from diet or another source, the thyroid is naturally the destination for the iodine since it makes up a portion of the hormones T3 and T3. Taking advantage of this physiological property, doses of radioactive iodine (I-131) have been used to treat conditions like hyperthyroidism and thyroid cancer for a number of years. When the thyroid uptakes this radioactive iodine, the beta radiation of this isotope targets the DNA of the mutated cells in order to destroy them.

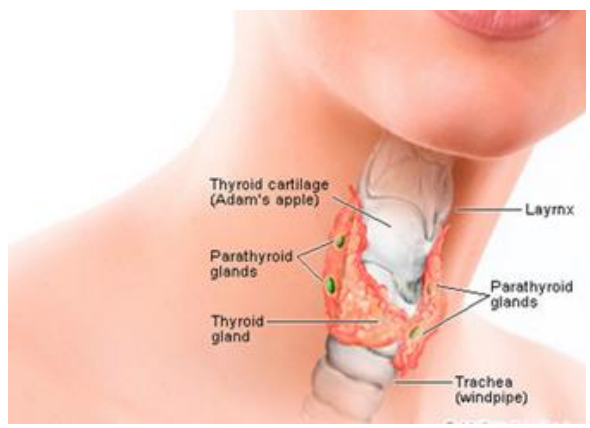


Figure 1. Structures of the Thyroid gland.[1]

Hyperthyroidism is the most common type of thyroid disorder that is treated by radioactive iodine therapy. This general diagnosis is characterized by an overproduction of T3 and T4. There are various specific causes of hyperthyroidism including toxic adenomas, Graves' disease, and sub-acute thyroiditis. Hyperthyroidism initially causes the body's metabolism to be in an overactive state and causes restlessness.[2] After a period of time, fatigue will begin to take over as the body is overstimulated for too long. Common symptoms associated with hyperthyroidism include weight loss, high blood pressure, nervousness, rapid heart rate and irregular menstrual patterns in women.

Thyroid cancer is another thyroid complication that radioactive iodine is used to treat. This cancer is diagnosed at a much lower age than other adult cancers with 2 out of 3 cases are in people younger than 55 years old.[3] For reasons unknown, thyroid cancers are about 3 times more likely to occur in women than men with an estimated 47,790 and 15,910 new cases in 2014, respectively. Some of the factors that may increase the chance of getting thyroid cancer include low iodine within diet and radiation exposure which puts countries with less strict radiation laws more at risk. Due to advances in treatments, the 5 year survival rate for thyroid cancers is very high at 97.8%.[4]

While radioactive iodine treatments are desirable for their effectiveness and low cost, there are also some drawbacks to this treatment method. Even though 90% of the radiation given from the iodine is beta radiation and is used to destroy mutated cells in the thyroid, 10% of the radiation is given off in the form of gamma radiation. The gamma radiation can act at a much greater distance than the local beta decay, and thus can be dangerous to people within close proximity of the recipient of the radioactive iodine dose. In patients treated with I-131, the ambient gamma radiation given off is significant within 3 meters of the patient and is at a relatively high rate within 1 meter of the patient. A typical dose of I-131, which corresponds with a 600MBq of radioactivity, leads to an approximate 30μSv/hr gamma radiation for persons within 1 meter of the patent. The ambient gamma radiation falls at an approximate inverse 1.5 power with relationship to distance which would lead to a 10μSv/hr ambient dose at 2 meters and a 5μSv/hr ambient dose at 1 meter.[5] For these reasons it is recommended that the patient doesn't remain within these distances of other people for an extended amount of time. Children and pregnant women are particularly warned about the risks of this gamma radiation due to their increased risk of developing cancer from radiation exposure.

2.2. Project Motivation

Since the patient is being released from the hospital to their home very shortly after they are treated with the radioactive dose of iodine, the family of the patient will be responsible for caring for the patient during the six week period that the patient remains radioactive. Our clients, Dr. Sarah Hagi and Professor John Webster, proposed a device that would be able to keep track of the family members' total radiation exposure over the treatment period. An algorithm that relates distance between the patient and the specific family member and the time that they remain within that distance from the patient, to the total amount of ambient radiation that distance and time equates to would be used to add up total radiation exposure over the treatment period. Using this an algorithm structure like this, along with a feedback system that displays the total amount of radiation exposure to the family member would allow the family member to keep themselves at a safe amount of total radiation exposure while still being able to take care of the patient.

2.3. Problem Statement

Radioactive iodine (I-131), used to treat multiple thyroid conditions, poses a health risk to individuals who remain in close contact with the patient after treatment. To protect other's health, individuals at risk, such as family members, are advised to avoid exceeding 5mSv of cumulative radiation exposure.[5] A device was created last year that alerts patients of other's close proximity. Our client, Dr. Sarah Hagi from King Abdulaziz University, has requested improvement from last year's device via either a modification, or a new device proposal.

2.4. Previous Design

There is only one current design for detecting the proximity of individuals to radioactive patients in a house setting. Designed in the fall of 2013, a previous group engineered a wearable belt with a proximity Ping))) sensor and a D6T thermal sensor. Together, both sensors help to recognize a person within a one-meter radius of the patient. If a person is detected in dangerous proximity of the patient for too long, the patient is alerted via a buzzer and LED light.

The belt was made of nylon and polyester, with the polyester cut to 8.5' wide to completely cover the microcontroller. Styrofoam is used to hold the LED and sensors in place, and two grommets expose the thermal sensor and LED. All of the wiring is threaded through the components of the belt and then stitched into place. The design allows the patient access to the microcontroller, the belt, and the on/off switch. To allow the belt to be worn by patients of different waist sizes, two 12" nylon straps are secured with D rings. The electronics are hooked up with an Arduino: The battery and switch powers the Arduino which in turn powers all of the other components.

Some benefits of this design include comfort, and effectiveness at detecting a human being directly in front of the patient, as well as accurately alerting the patient when an individual comes within a one-meter range. One drawback is the limited range of sight of the two sensors. Since there is only one proximity sensor and one thermal sensor in the front of the belt, the belt only has a sight of 15.71 degrees. Anyone to either side or behind the patient remains undetected. Additionally the belt only alerts proximity and has no method of tabulating total exposure of each individual coming in close-proximity of the patient or tracking which specific individual (out of the number of individuals at risk) comes within range. In other words, the previous design can only detect that a human is close, not which human, or how much radiation they have been exposed to within the 4-6 weeks that the patient remains dangerously radioactive.

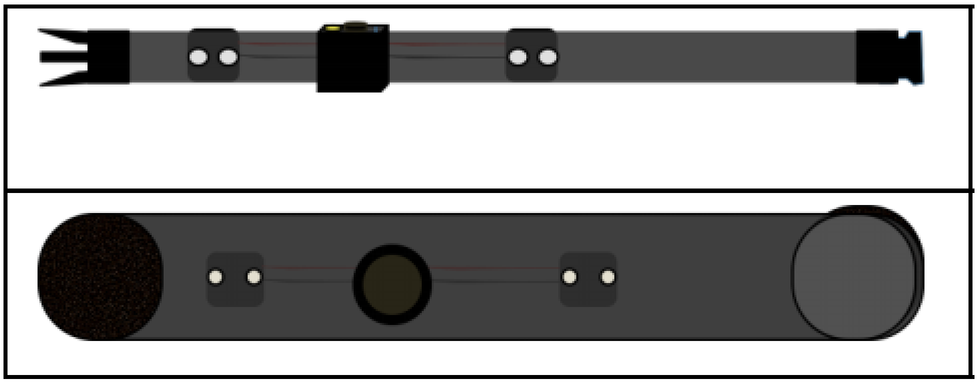


Figure 2. Previous design. Belt apparatus w/ sensors.[6]

2.5. Design Specifications

Design requirements can be found in the Product Design Specifications section located in the Appendix.

3. Designs

3.1. Design 1 - Multiple Sensors

The Multiple Sensors design was created as a very simple approach to solve the client's problem. The main function of a successful device is to accurately detect a human within a one meter range, and provide feedback if and when that moment occurs. This design idea is an extension of the previous (Fall 2013) year's design where a distance and thermal sensor were paired together in the front of the patient and secured on a belt like apparatus. In this design, there would be the same sensors in the front of the patient as well as a pair of sensors posteriorly and on the left and right sides of the patient. This would increase the device's total field of view by a factor of four.

A D6T-44L MEMS Thermal Sensor from Omron and a Ping))) Ultrasonic Distance Sensor from Parallax were used together in the previous design with very high timing, distance, and temperature accuracy. In the Multiple Sensors design, there would simply be three more of the same thermal sensors, and three more of the same distance sensors. Along with the sensors, there would be a primary visual feedback system as well as a secondary vibratory feedback system to warn the patient of a human within one or two meter proximity.

The flowchart on the right gives a general walkthrough of how the design would actually function. First, all four of the distance sensors will continuously be taking distance measurements and storing the most recent values in a matrix. The average value would be stored in a variable called Range. If Range for all four sensors is greater than one meter, the warning variable is false and the feedback system will not turn on. However, if any of the four sensors have a Range value of less than or equal to one meter, the thermal sensors will take action. These sensors will begin to take many temperature measurements of any thermal radiation in its field of view and store the most recent values in a matrix. Just as before, the average value would be stored in a variable called Temp. If Temp is less than 23C which is the average ambient temperature of the radiation given off by the body, then the warning variable will again be false, the feedback system will remain off, and the distance sensors will start taking measurements again. However, if Temp comes back as greater than 23C, then a human being is being detected inside of one meter proximity, and the feedback system will turn on.

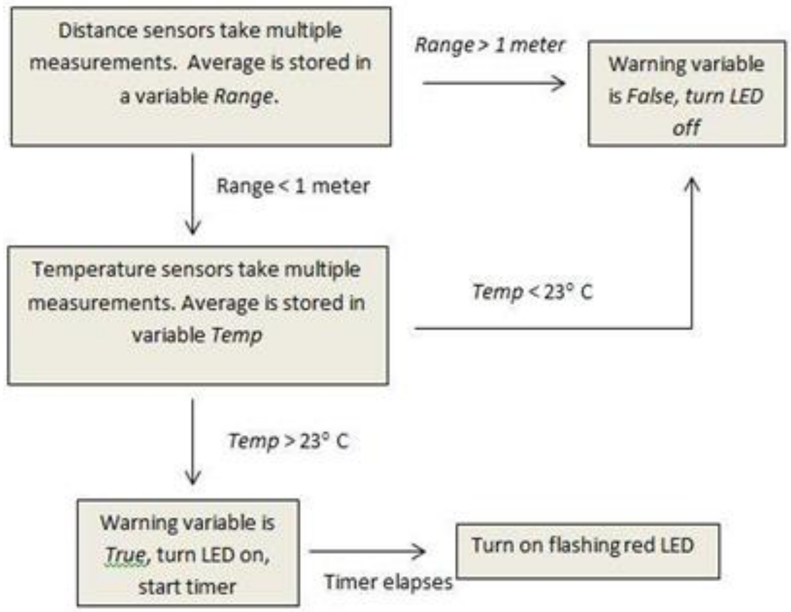


Figure 3. Design One Software Flowchart

The initial feedback will consist of a green LED that will turn on once the sensors detect someone within 1 meter of the patient and remain on until the sensors stop detecting someone in the same range. There will also be a secondary feedback system to give further warning of dangerous exposure. Once the LED first turns on, a timer will turn and elapse while the human remains within a one meter distance. Once the duration reaches 25 seconds, a flashing red LED warning will be given to the patient and continues to be given until the distance between the patient and subject is greater than one meter. A time of 25 seconds was chosen as an optimal time based on estimations that take into account about how many interactions (within one meter) the patient will have with family members in the six week period and how much exposure should each interaction be limited to.

3.2. Design 2 - RFID Tags

In the second design alternative, the team decided to switch gears a little bit to employ the use of radio communication between devices through RFID tags, where RFID stands for Radio Frequency Identification. Just as RFID is used in industry to track the whereabouts of an item through an assembly line, for example, it would track the location of the patient's family members with respect to the patient. Ideally, there would be a receiver tag on the patient and beacon-like signaling tags on each of the family members in the household.

Looking at the code, the tags that belong to each family member other than the patient will first send out an RF signal to be read by the receiver tag on the patient. When the signal finds the patient's tag it would then be turned into a distance measurement by analyzing both the signal strength and the time the signal took to get there. Just as in design 1, the most recent distance measurements would be stored in a matrix and the average of these would be stored in a variable Range. If Range is greater than a 1 meter distance, then the feedback system would remain turned off and the beacon would begin to re-signal for the receiver. If Range is less than or equal to 1 meter, the feedback system would turn on since a family member is within the proximity of exposure danger.

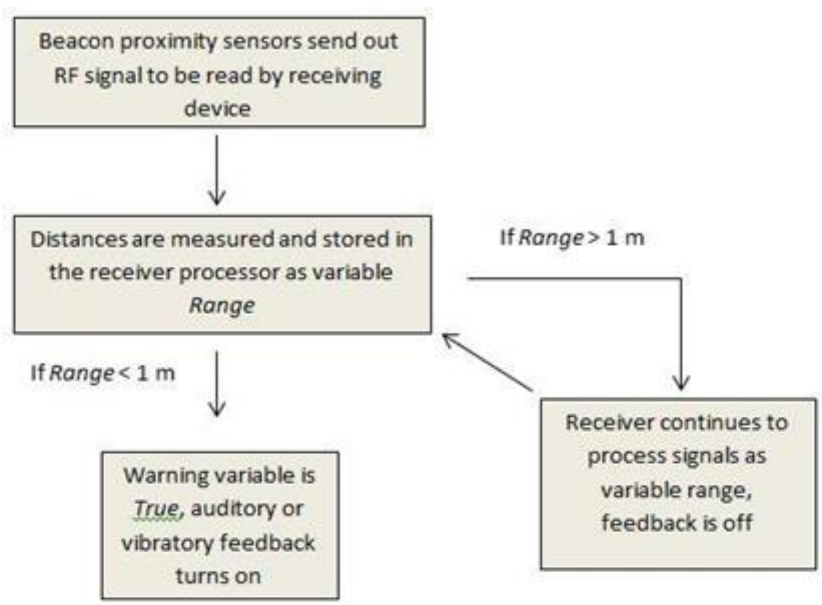


Figure 4. Design Two Software Flowchart

The primary feedback would be a vibratory or auditory signal located on the patient for initial warning, and it would remain on until the family member is greater than a one meter distance away from the specific family member. The primary feedback system has high variability in its design and could therefore be a lit LED too if that were to hold a better chance of the patient recognizing the warning. The secondary system would again start after a timer and give a second warning after the 25 second duration elapses.

This design would ideally require only one microcontroller connected to the receiving tag on the patient in order to analyze the radio signal from the family members for its strength and speed in order to convert to a distance measurement. These signals would also be omni-directional which would eliminate the concern for a limited field of view which was seen in the previous device and in design one.

3.3. Design 3 - Bluetooth Beacon/ Receiver with Tracking

The final design idea employs the use of Bluetooth technology which, like the RFID, can accurately calculate distances.[7] With this design, the patient would have a Bluetooth beacon sending out signals, with each family member having Bluetooth receivers. This system would allow not only a feedback system alerting the patient when a family member is too close (within one meter) but would also effectively measure total accumulated radiation for each family member.

With this design, the code would work as follows: The patient's chip sends out a signal, which triggers timers to simultaneously start (one for each receiver). Next the family members' Bluetooth chips will receive the signal and react by sending a signal back, with each receiver carrying a different identification tag being sent back. When this signal returns back to the Bluetooth chip, one of the timers is stopped (the timer being stopped identified based on what tag is received by the beacon) and the beacon will record the time it took for the original signal to be accepted by the receiver and then sent back to the beacon and will record this time in the variable "*time 1, time 2, time 3*" etc. with each time representative for each receiver (therefore keeping track of the time for each individual family member). To keep the rest of the code easier to understand, the code will be examined for an individual receiver from here on out, with the assumption that the same code will be applied for each receiver, with tags to keep track of each individual receiver.

With the time recorded for the signal to pass back and forth between the receivers and the beacon, the time variable can be inputted into an algorithm that outputs the variable "*distance*". Thus, the distance between the receiver and the beacon is accurately determined. "*Distance*" will then be inputted into a new algorithm called rad-distance that is by itself recording time that the beacon has been paired with the receiver (thus total time since the patient became radioactive) and receives "*distance*" and outputs "*radiation*". Thus, current radiation exposure to the receiver is calculated. This radiation calculation is then sent back to the receiver, which then will add this new radiation variable to the receiver's own variable "*totalrad*" which is a measurement of the total radiation exposure of the particular receiver, and thus the total radiation exposure of a particular family member.

Each receiver will have a feedback system consisting of 5 LED lights. Each LED light will be correlated to five variables: "*LED1, LED2...LED5*" with the values of *LED1*, *LED2*, *and LED3* consisting of increasing incremental values correlated to "low accumulated radiation" all the way up to "dangerous radiation exposure" of .0238mSv. If "*totalrad*" exceeds LED1's threshold, then the first LED light will flash. If "*totalrad*" exceeds LED2's threshold, then two LED lights will flash, and so on. Each day, "*totalrad*" will be reset to 0. Thus, if the family member hits .0238mSv (all 5 LED lights flashing) everyday, they would be receiving just below 1mSv within the six week period. Since the goal is for each family member to be exposed to less than 1mSv for the whole 6 week period, it would be highly advised to avoid reaching to 5 LED lights flashing each day. Microcontrollers would be implemented in each receiver to communicate the incoming "*totalrad*" value to the feedback system.

Figure 5. Multi-LED feedback system to be worn on each family member

In addition to this feedback in each receiver, "distance" will also be inputted into a feedback system (mediated by another microcontroller) in the beacon. Should "distance (measured in meters) be greater than 1, a feedback loop will cause a light on the beacon to turn on, and vibrate, thus alerting the patient and family member that they are within one meter of the patient and should distance themselves as soon as possible.

3.4. Design Matrix

Criteria (Weight)	Multiple Sensors (belt)		RFID Tags		Beacon/receiver w/ tracking	
Functionality (25)	2/5	10	3/5	15	5/5	25
Comfort (20)	2/5	8	4/5	16	4/5	16
Safety (15)	3/5	9	3/5	9	3/5	9
Reliability (15)	3/5	9	4/5	12	4/5	12
Ease of Fabrication (15)	5/5	15	3/5	9	2/5	6
Cost (10)	3/5	6	4/5	8	3/5	6
Total (100)	57		69		74	

Table 1. Design Matrix of three evaluated designs

When comparing the three separate designs to determine which best fits the client's expectations outlined in the product design specifications, each design was evaluated by six separate criteria. The design choice was ultimately determined from these six weighted-criteria. The main categories were functionality and comfort followed by safety, reliability, ease of fabrication and cost as seen in Table 1.

Effectively ensuring that family members and those near the patient remain below safe levels of radiation is the largest priority, and wrapped into the functionality category. The device needs to function in a way that allows the user to know they are receiving harmful radioactive emissions. The functionality scale in this context can range from a simple warning to a complex radiation exposure calculation. The multiple sensors design did not score well in this category because although a proximity warning is given, there is no way to track exposure radiation. It also has a very limited field of view for detection. The Bluetooth beacon with tracking scored very well in this category, incorporating the ability to dynamically give feedback on the amount of radiation each user is taking in. RFID tags scored in between the first and third designs as they only detect distance and do not track exposure; however it has a much greater field of view than the Multiple Sensors design.

The devices, being physically worn by the users for a six week period, need to be comfortable as well as aesthetically pleasing.[8] The patient will likely already be feeling emotionally drained and tired of hospitals and medical equipment, so the device was designed to have as mundane an appearance as possible. With the intent of not forcing the patients to deal with another piece of medical hardware, all three designs are geared around looking like every day accessories. The multiple sensors device, fashioned as a belt, takes last place in this category because it can be seen from all sides and cannot be covered up due to sensor limitations. Despite this visibility, it will look similar to anything normally worn about the waist, and not be visually distracting. Both the RFID and the Bluetooth designs scored evenly because they both utilize the same basic template, a wristwatch-like item. It was assessed that users will not be inconvenienced by the device's presence, as wearing a wristwatch is already common practice.

Safety is a large factor in most products made today, and for all electronics there is an inherent possibility of electrical shock. However small the chance of shock may be, there needs to be a consideration for it. The multiple sensors device, being worn around the waist, has a higher chance of electrical shock due to the possible exposure of electrical components. However, this device is only worn on the patient and therefore only the patient is at risk. The second and third designs were scored the same because, though they may have a smaller chance of shock, they are both worn by each of the family members in the household, not just the patient.

Treatment lasts six weeks, so the device has to be designed to operate correctly and reliably for a long period of time. The device also has to reliably sense others and give feedback, from all angles. Modern RFID and Bluetooth technologies operate very efficiently and consume little energy, allowing them to stay on a single battery charge much longer than 8 individual sensors and a microcontroller could. This added points to the second and third design scores over the first. The multiple sensors design is also limited by its ability to detect persons from odd angles. The proposed sensors will offer a 15 degree field of view evenly spaced in four azimuths from the patient, realistically allowing for blind spots that pose a chance for the device to allow someone to go unnoticed. The RFID and Bluetooth designs are not limited by FOV and therefore can reliably perform their intended tasks without interruption.

Ease of fabrication plays a significant role in the design project with limited resources, skills, and a condensed semester long schedule. Multiple sensors is an expansion on previous work, and thus could be produced fairly easily. Code will need to be modified and replicated to allow for the added sensors; however, they will operate in the same capacity. RFID is a common medium used in the industrial world, and many devices exist to act as a learning point for the RaDistance Safety Meter system. Despite the commonplace of the RFID technology, a new device would still need to be created from the ground up, lowering its fabrication score relative to the first design. Implementing Bluetooth in the sense of connecting devices should be relatively easy since there are already a plethora of consumer proximity sensor products already available.[10,11,12] However, the software portion of this design would be much more intense since exposure would be tracked for each individual family member as well as accurately measuring distance which led to the final design having the lowest ease of fabrication score.

Cost is always a concern when working with a limited budget. The multiple sensors design was cost analyzed based off of the previous semesters design report. The single sensor from last year had a pre-determined price, and that price was just estimated to be roughly four times larger for design one. RFID is used on a giant scale in the industrial world, thus making it commercially cheap to purchase. Bluetooth is also relatively cheap in itself and uses very little power, however this design also requires several microcontrollers which brings the overall cost grade down.[9]

4. Final Design Modifications

Modifications were made to the design in accordance with production abilities, commercial product availability, current limitations of wireless technologies, and cost efficiency. The Bluetooth Receiver with Tracking model was modified to utilize a single central receiver, held by the patient, and small individual beacons, to be held by family members. The small beacons are capable of emitting an omni-directional Bluetooth signal continuously. A central Android device based application will be used as a receiver that can “listen” for the signals from the beacons and calculate range. The range variable can then be inputted into an algorithm to determine radiation exposure. The accumulated exposure will be stored and displayed individually for each beacon on the android application.

Estimote, a commercially available Bluetooth emitter, was used for the beacons.[13] The Estimote beacons are capable of emitting an omnidirectional Bluetooth Low Energy (BLE) signal continuously without interruption, for roughly two years on a single coin style battery. Three beacons were purchased for use in the project but a virtually unlimited amount could be applied, allowing the client or user to add a customized number of beacons per the patient’s situation. The beacons have a simple design consisting of a small IC board with embedded antenna and attached battery all encased in a removable silicone protective shell. The size of the entire device is less than one inch by one inch by two inches (WxHxL) and easily fits in the palm of a hand. No software is required to be user programmed on the beacons, and will emit a constant signal in the Bluetooth (~2.4Ghz open licensed ISM) band whenever it is receiving power from the battery. The functionality and simplicity of the Estimote products made them the perfect fit in our beacon receiver model.

The central receiver was designed on a smartphone platform to utilize the already built functionality of a user interface, processor, and Bluetooth antenna that could speak with each other. Deciding to move the receiver model over to a pre-designed smartphone model resulted in lower production cost, moved all fabrication to software only, and ensured that the physical hardware would work as required without excess time spent correcting it. Production smartphones are built with high grade receivers and processors that have been designed to communicate effectively and efficiently, so choosing to adopt this platform was an obvious improvement over developing an in-house receiver with individual antennas, communicators, and processors.

The software for the receiver was developed using Java on an Android operating system due to the easy to use and publish development environment as well as our prior experience in the Java programming language. Apple's iOS was considered for the development environment but lack of prior knowledge in the Swift language (Apple modified version of C and Objective-C) and app publishing costs resulted in our decision to not choose it. However, after finalizing the design and plan completely, the app could be easily adapted for iOS and/or other platforms.

5. Design Fabrication

The final design involved off the shelf hardware components, so the bulk of fabrication was software development. The first step in software development involved establishing the necessary development environment. The Eclipse IDE was used, with the Android Development Kit plugin installed. An additional Estimote development kit was provided with the Bluetooth beacons, and this software was imported to the application source files. The Estimote SDK (Software Development Kit) was invaluable for development, as it included a library of classes for interacting with the beacons as well as demo code for performing various Bluetooth functions. Connecting via Bluetooth on an Android device requires implementation of the Bluetooth associated programming interface. The Estimote kit included its own implementation of this interface, abstracting the complexity and packaging it inside simple objects. One of the objects necessary for our application is the beacon class, which effectively represents a single Estimote beacon and all relevant information like RSSI, Mac address, and name. Another object we implemented is the *BeaconManager* class, which handles a variety of operations that can be performed on surrounding beacons, like connecting and transmitting data. To gather distance information from beacons in range, the *startRanging()* method within *BeaconManager* must be called, as demonstrated by the following code:

```
beaconManager.connect(new BeaconManager.ServiceReadyCallback() {
        @Override
        public void onServiceReady() {
                try {     beaconManager.startRanging(ALL_BEACONS);
                } catch (RemoteException e)
        }
});
```

This method continuously attempts connections with all available beacons, and periodically bundles this information as an event. An event handler must be defined to catch this information and utilize in a useful way. The event handler, called a ranging listener, is defined in the following code block:

```
beaconManager.setRangingListener(new BeaconManager.RangingListener() {
        @Override
        public void onBeaconsDiscovered(Region region, final List<Beacon> beacons) {}
```

Inside the *onBeaconsDiscovered* method is the bulk of our code for gathering distance information from a list of found beacons. This includes utilizing another Estimote method, *Utils.computeAccuracy*(Beacon b), which returns a double value of the distance measurement in meters. For multiple beacons in range, the Mac address is used to distinguish them and assign a specific distance. Another feature of the application is a vibration feedback mechanism. Whenever a beacon is detected within one meter of the device, the phone will vibrate to give the user a warning.

The previous description of code effectively captures a distance measurement for a single Estimote beacon, but more calculation is required to convert this into a quantity of radiation exposure. All of the complexity for this conversion calculation is contained inside of the *RadTracker* class.

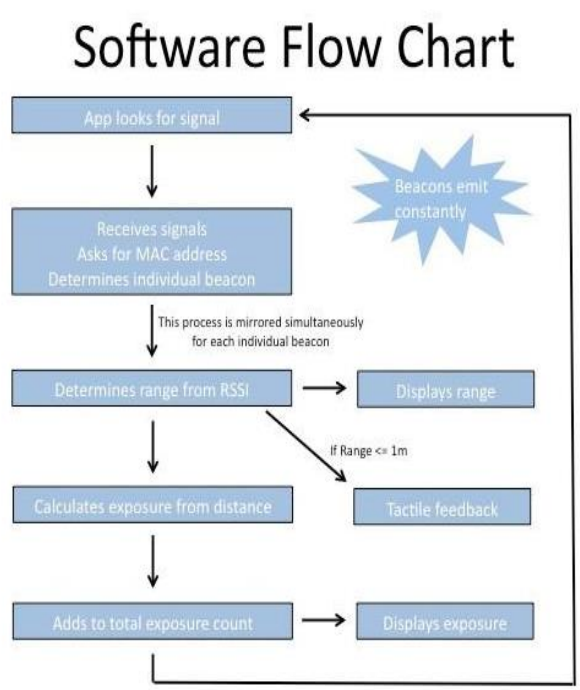


Figure 6. Flow chart of final code

One *RadTracker* class is instantiated for each local beacon, and stores the total amount of radiation exposed over the lifetime of the beacon.

The radiation exposure calculation is based on data found on a very well-reviewed gamma exposure calculator found online.[14] This equation takes into consideration three things, the radioactivity of the patient which is based on a simple half-life equation for I-131, as well as the distance between the patient and the specific family member, and finally the time spent at that distance.

$$A = 600 \cdot \left(\frac{1}{2}\right)^{\left(\frac{T}{8.02}\right)} \qquad R = \left(\left(\frac{A}{2.065404475}\right) \cdot (100\,d)^{-2}\right) \cdot t$$

The radioactivity represented by *A* is based solely on a half-life timer and an initial radioactivity level, in this case 600 Megabecquerels (MBq) of radiation. This initial level is based on the dosage that the patient received at the treatment time and so it may be variable among others. The time variable (*T*) accounts for the decrease in radioactivity over time due to the decay of I-131, and is handled by a days counter that is incremented once per 24 hours by the use of a built in Android class called *AlarmManager*. Once the radioactivity of the patient is known at a certain time, it is then used in conjunction with the distance between the patient and family member to calculate the patient’s radiation exposure represented by *R*. This equation also requires a time spent at each distance which is based on a dedicated timer class that uses the device’s system millisecond time to measure the exact time between each distance measurement (*t)*. Each exposure amount is continuously added to the previous, and the overall accumulation is then shown on the application’s interface.

Our application is only effective when constantly measuring radiation throughout the day, so the ranging code must be running indefinitely. This task proved to be difficult within the constraints of the Android operating system, but could be accomplished in most standard circumstances. The bulk of an Android application runs as an Activity, a special Android designation for a process that runs in the primary UI thread. An *Acitivity*, however, is usually destroyed by the operating system after an application is closed. In the context of our application, if an Activity was used the distance measurements and radiation calculation would not occur unless the application was open at all times. To maintain the radiation calculation even when the phone is asleep or the application closed, we implemented a background thread, called a Service, to run the bulk of the program. The Service will run constantly even when the application is closed, the phone is asleep, or a different application is in use. This Service will never be closed under normal conditions, allowing essentially indefinite measurement. The issue with the Android operating system, however, is that under extreme conditions such as memory shortage or heavy processor usage, the kernel can kill any non-default application in a vaguely defined manner. This is a limitation of the platform that cannot be truly solved without excessive tampering with the internal workings of the operating system. To partially solve this problem, we implemented an auto saving feature to periodically save the total radiation data. Every 15 minutes of monitoring, this saved data is updated. Upon restarting the app, this saved data will be automatically loaded if available, and the monitoring will continue where it left off.

The main user interface of the program is still run as an Activity, but this code only involves establishing user interaction with the background service. The background service is connected to the UI Activity by means of an *IBinder*, allowing for data transfer between threads. Contained in the code for the main Activity is a simple user interface allowing for starting and terminating the background service, viewing the total radiation values, and gathering real time distance information for testing.

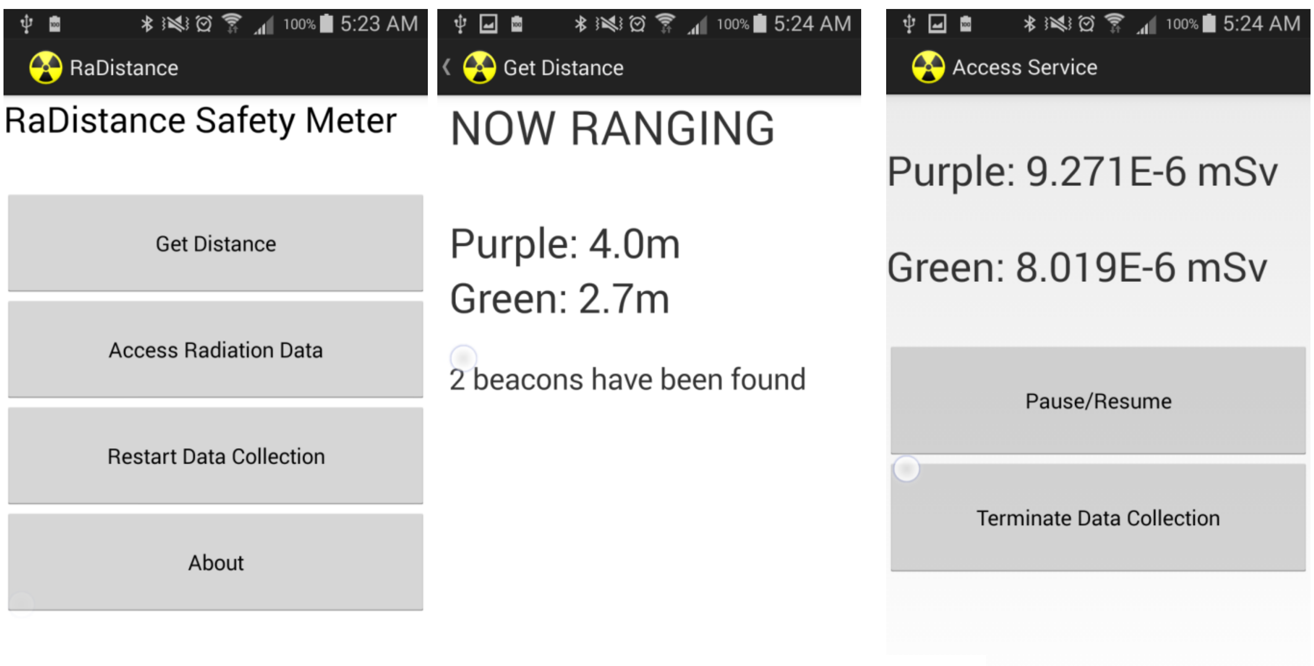


Figure 7. Screenshots of RaDistance Application. Home screen (left). Ranging app (middle). Radiation accumulation (right).

6. Testing

Two tests were performed to assess the accuracy of the Bluetooth applications, distance testing using a single Estimote (with both iOS and Android apps), and distance testing using two Estimotes with just iOS to represent an ideal situation of a small conversation between a family.

6.1. Testing with one device nearby

Both the Estimote Bluetooth device and the phone acting as the receiver were placed onto a table with distances of 10 cm to 100 cm, in increments of 10 cm, marked out by a ruler. The phone was positioned with its top side facing the Estimote, and the Estimote was positioned with its long face on each respective distance marker. Once the reading on the phone's app was steady, the distance was recorded and the Estimote was moved 10 cm further away. This was repeated up to 100 cm away. 10 trials of this procedure were performed using both the iOS application as well as the Android application in order to evaluate the accuracy and consistency ofeach application. The results for each trial, as well as some statistical analysis can be found in the appendix.

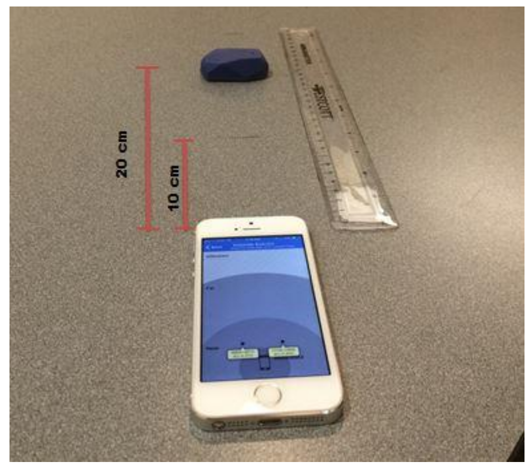


Figure 8. Test setup for one Estimote

6.2. Testing with two devices nearby

The experimental set up for this procedure was the exact same as the first experiment, except for the additional Estimote beacon. The secondary Estimote beacon was placed 70 cm away from the phone, at a 45 degree angle with respect to the other Estimote beacon. The primary Estimote beacon was again placed at 10 cm away while the secondary beacon remained 70 cm away, and the reading for both beacons was recorded. This was again repeated at each 10 cm marker up to 100 cm, all while the secondary beacon remained at 70 cm. 10 trials was repeated for this procedure as well, but only using the iOS application due to the better accuracy as compared to Android, as discussed later in the discussion

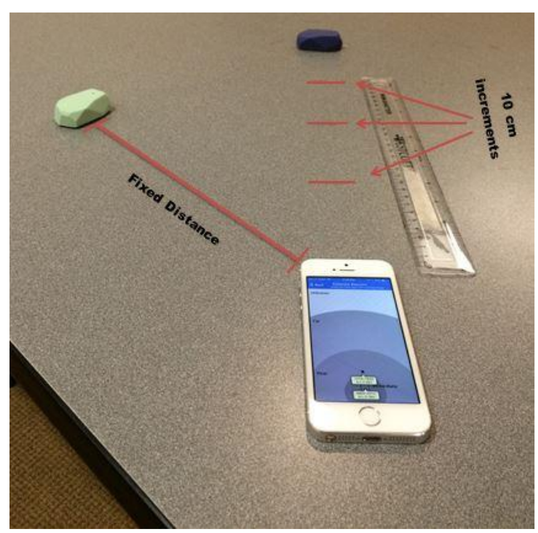


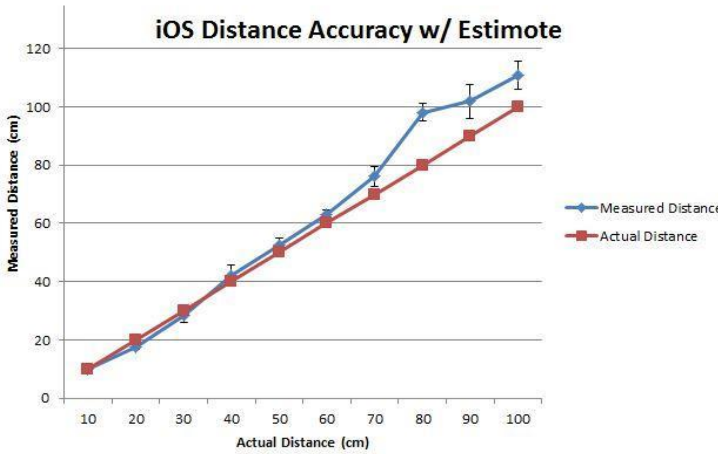
Figure 9. Test setup for two Estimotes

The team also performed a simple test to check the reliability of the vibratory feedback. The setup was simple, we had one person hold a beacon and approach the phone while another person held a timer. Once the beacon entered the 1 m range, the timer was started. Finally, when the vibration was first felt, the timer stopped. The average response time was about 2.5 seconds and a standard deviation that would consistently give us a response time between 2 and 4 seconds.

7. Results & Discussion

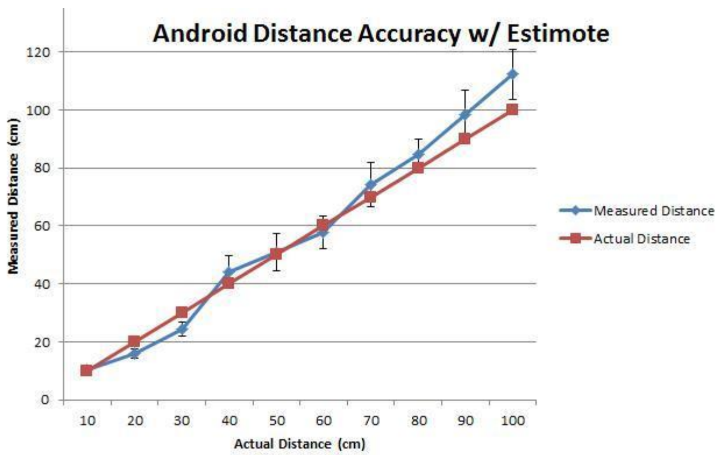
7.1. Testing with one device nearby

After gathering the data for the first test, the ten trials were averaged to give a single value, and then plotted on the graphs shown. The measured distance, as in the distance recorded from the apps, is represented by the blue line and is plotted versus the actual distance. The actual distance, the distance measured by a ruler, is represented by the red line and is also plotted versus the actual distance to give a linear model to compare to.



The first graph shown plots the averages of the ten trials for each increment recorded by the iOS application BLExplr.[15] The averages follow the actual linear path all the way up to 60 cm for the most part, but begin to fall off beyond that, reaching a maximum error of about 20 cm at an actual distance of 80 cm, but improves afterwards.

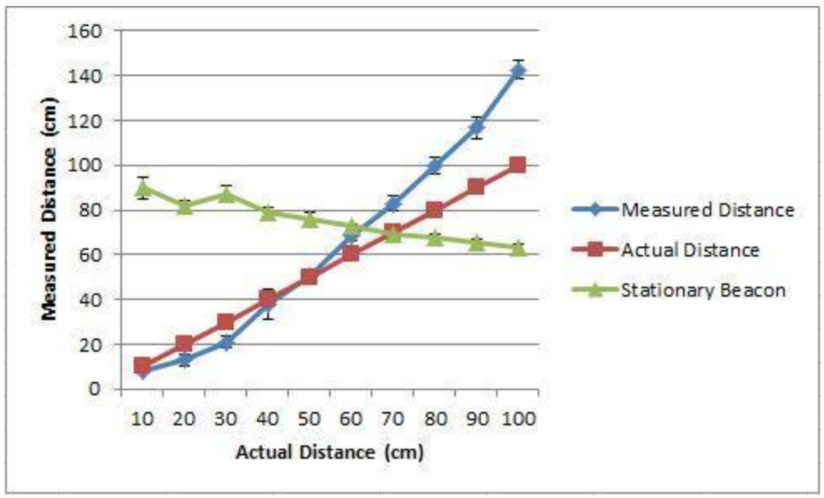
The second graph shown again plots the averages of the ten trials, but for the team's own Android application instead. In this case, the averages don't follow the linear path as precisely as the iOS, but rather almost oscillates above and below the actual distance up until about 60 cm. Beyond that, the measured distance average was a bit higher than the actual distance, but with much larger error bars at each distance than the corresponding iOS measurements, reaching a maximum error of 30 cm when at the actual 1 m mark.



Comparing the two platforms, it appears that by just looking at the error bars, the Android app is more precise than the iOS overall. However, the error bars must be taken into great consideration as well. Since the radiation exposure is on the power scale and not linear, any sort of error gets largely multiplied at any range, but especially at shorter distances. This could lead to prematurely falsely warning the patient that their family member is in risk , or even worse, failing to warn a family member because the application thinks the total exposure is less than the actual amount. The latter case may occur due to the averages at 20 and 30 cm where the measured distances are a smaller than the actual. Therefore, the iOS is the more desired platform as it gives less error at the smaller ranges, as well as less error overall across the entire length of testing, leading to less error in the exposure calculation. There may still be error at higher distances, but based on the data, the measured is higher than the actual which would prematurely warn a patient should he or she receive enough exposure. However, if there is any error, this type would be the desired type, rather than not giving any warning at all and putting the family members at risk.

7.2. Testing with two devices nearby

For the second test, the team again plotted the measured distance averages versus the actual distance, but also included the average distance of the fixed beacon represented by the green line. Recall that this beacon was originally fixed at 70 cm. As shown in the graph, the measured distance of this beacon hovered around its actual distance of 70 cm while ranging between roughly 60 and 90 cm as the mobile beacon was incremented further and further. Looking at the incremented beacon shown by the blue line, there is clearly error occurring at all distances, with the largest being beyond the 60 cm mark and reaching up to a 40 cm error when only 1 m away. This test was performed to model a close interaction between the patient and more than one of their family members. Based on the results, the Estimotes. in conjunction with the iOS application, are not very effective when there are multiple beacons in range because there is significant signal interference between each beacon and the phone. Therefore, the device currently will have trouble calculating accurate exposure levels when there are two or more people in very close range. However, given the circumstances that the patient is dealing with, they shouldn't be within close range of multiple people for an extended period of time anyways.



Our client requested a device that can detect a human within a 1 meter range, provide some sort of feedback if too close, and to possibly have the ability to keep track of the radiation exposure of each family member. This device has no trouble doing any of these three tasks when there is just one beacon in range of the phone, however, it runs into a little bit of trouble when there are multiple people in range because of signal interference. This is definitely an issue to keep in mind moving forward, and is a big part of motivation for future work.

8. Future work

Future work with incorporating Bluetooth technology for the *Radistance* project can be generally split up into two sections: device modifications, and programming modifications. In terms of future work with development of the device, one major next step is going away from the premade Estimote beacons and creating self-made beacons and receivers. This way there could be much greater control over the programming, the design, and the accuracy of the device. In addition, it would be more convenient if the beacon was not a phone but rather a simpler device with a longer lasting battery, and if the beacons could be incorporated into a user friendly and comfortable wristband as proposed earlier.

One programming modification to be worked on involves making the interface more user-friendly and aesthetically appealing. In addition, the programming should be incorporated into iOS (which is more accurate), or into a self-made system that would be more accurate if possible. If a self-produced system could be produced with similar accuracy as iOS, this would be preferred as there would be more freedom to adjust the programming and the general properties of the device. Finally the range calculations should be improved and the algorithm adapted if and where is necessary.

9. Conclusion

It would be beneficial to discharge patients, who have been treated with radioactive iodine, immediately. This requires a device that can warn family members who live with the patient at home when they are at risk for dangerous radiation exposure. A previous design group proposed a belt with a thermal and proximity sensor. By instead using Bluetooth technology for constant distance measurements between the patient and family members, a design that can readily calculate accumulated radiation exposure can be crafted. The validity of using Bluetooth for distance measurements, and then calculated radiation exposure, between a patient and a family member has been confirmed with testing on an android and iOS interface using an Estimote Bluetooth device. Although the results are promising and suggest that

Bluetooth technology is a viable and improved option from the previous design group, further development and testing is required to make the model completely effective.

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11. Appendix

11.1. Product Design Specifications

Radiation Distance Safety Meter

Product Design Specifications

Nick Gilling (Leader), Alex Mccunn (Communicator), Michael Wolff (BSAC),
Joe Benthein (BWIG), Keith Dodd (BPAG)

Problem Statement: Patients treated with therapeutic doses of radioactive iodine (I-131) can be potentially harmful to those in close proximity when discharged. The radiation from the doses can be a threat to those less than one meter away from the patient, especially family members and healthcare providers who are in frequent contact. Our client, Dr. Sarah Hagi, from the radiology department at King Abdulaziz University Hospital, requested a device that alerts the patient if individuals are within one meter. We would like to create a device that will provide feedback to alert patients of their proximity around others, and also to alert the patient's family members of overall radiation exposure.

Client Requirements:

- Must be able to sense a human within a one-meter range.
- Must provide a feedback to alert the patient.
- Must be comfortable enough to wear on a day-to-day basis.

1. Physical and Operational Characteristics

a. Performance requirements: Must detect human presence, and possibly pets, within one meter for at least 6 weeks. Must provide feedback to alert user of human presence. Must function under mild radioactive conditions. Device to be used on 20 patients per year.

b. Safety: The device must have sufficient feedback mechanism to warn user of unsafe distances with minimal discomfort to the user. The materials must not become radioactive in the period of use. Electrical components must be concealed.

c. Accuracy and Reliability: The device must be battery powered and function accurately for at least 6 weeks. The device must detect distances within a 0.1 meter tolerance.

d. Life in Service: When the patient is discharged from the hospital after therapeutic radioactive iodine treatment it is recommended they avoid coming within one meter of another person for 4-6 weeks. The device would have to be constantly active for this period of time. It is possible it could be recharged at night while the patient is sleeping. The device should hold a charge for at least 17 hours/day, 7 days a week for 6 weeks.

e. **Shelf Life:** The device should be able to be stored for 10 years without using any of its functionality.

f. **Operating Environment:** The device will be operated in various interior and exterior environments throughout the world. For this reason it should ideally be operational at extreme temperature (-25-50 degrees Celsius) and humidity (5-95%) ranges. It should also be water resistant in the event of rain or spilling.

g. **Ergonomics:** The device must be comfortable to wear throughout the day for up to six weeks.

h. **Size:** The device must be small enough not to intrude on the patient's daily activities.

i. **Weight:** The device must be light enough to be worn comfortably on the patient. The device should weigh no more than one kilogram.

j. **Materials:** The materials must not be affected by radiation from I-131. The device should not be made out of a common allergen, such as latex. Electrical components should maintain their electrical properties in the presence of radiation.

k. **Aesthetics, Appearance, and Finish:** The device should be aesthetically appealing so that the patient feels comfortable wearing the device.

2. **Production Characteristics**

a. **Quantity:** One Prototype.

b. **Target Product Cost:** Around $100.

3. **Miscellaneous**

a. **Standards and Specifications:** The device must meet the requirements of the National Institute of Standards and Technology.

b. **Customer:** Therapeutic iodine radiation clinics and hospitals and the patients they treat.

c. **Patient-related concerns:** The device needs to be durable and comfortable.

d. **Competition:** There are no devices currently on the market targeted towards therapeutic radioactive iodine patients.

11.2. Testing Data

11.2.1 Testing w/ One Estimote using BLExplr and Android App

iOS testing using BLExplr (cm)										
	Trial 1	Trial 2	Trial 3	Trial 4	Trial 5	Trial 6	Trial 7	Trial 8	Trial 9	Trial 10
10 cm	10	9	11	10	9	10	11	10	10	10
20 cm	18	17	17	17	19	18	18	16	18	19
30 cm	25	28	30	33	32	28	28	25	30	27
40 cm	36	35	44	42	44	45	46	43	42	43
50 cm	52	47	51	53	54	55	55	52	54	54
60 cm	61	62	63	64	65	66	63	61	62	63
70 cm	75	75	71	66	67	70	74	75	74	75
80 cm	92	96	92	96	98	101	99	102	101	97
90 cm	108	110	105	99	103	107	102	98	93	93
100cm	114	110	114	110	105	101	113	118	111	112

Android testing using RaDistance (cm)										
	Trial 1	Trial 2	Trial 3	Trial 4	Trial 5	Trial 6	Trial 7	Trial 8	Trial 9	Trial 10
10 cm	9	10	12	10.6	8.6	14	8.6	8.6	12	10
20 cm	17.3	17.3	14	14	17.3	14.06	17.3	14	17.3	17.3
30 cm	27	23.7	20.2	23	23	27	23	27	23	27
40 cm	41.8	41.8	41.8	55	50	41.8	50	41.8	36.3	41.8
50 cm	55	50.7	55	50.7	64	42	50.7	50	50.7	42
60 cm	64	55	55	55	64	51	64	51	55	64
70 cm	77	77	77	64	87	77	64	77	64	77

80 cm	88	77	88	88	89	87	77	87	87	77
90 cm	98	88	88	98	109	109	99	98	109	88
100cm	130	109	109	99	109	120	109	109	120	109

Calculations						
Distance	**Average (cm)**		**Variance**		**Stdev**	
	iOS	**Android**	**iOS**	**Android**	**iOS**	**Android**
10 cm	**10**	**10.34**	**0.44**	**3.34**	**0.67**	**1.83**
20 cm	**17.7**	**15.9858**	**0.90**	**2.88**	**0.95**	**1.70**
30 cm	**28.6**	**24.39**	**7.16**	**5.89**	**2.67**	**2.43**
40 cm	**42**	**44.21**	**13.33**	**31.21**	**3.65**	**5.59**
50 cm	**52.7**	**51.08**	**5.79**	**40.48**	**2.41**	**6.36**
60 cm	**63**	**57.8**	**2.67**	**30.84**	**1.63**	**5.55**
70 cm	**72.2**	**74.1**	**12.18**	**58.10**	**3.49**	**7.62**
80 cm	**97.4**	**84.5**	**12.49**	**27.17**	**3.53**	**5.21**
90 cm	**101.8**	**98.4**	**35.73**	**73.60**	**5.98**	**8.58**
100 cm	**110.8**	**112.3**	**23.29**	**74.90**	**4.83**	**8.65**

11.2.2 Testing w/ Two Estimotes

Two Estimotes testing using BLExplr (cm)										
	Trial 1	Trial 2	Trial 3	Trial 4	Trial 5	Trial 6	Trial 7	Trial 8	Trial 9	Trial 10
10 cm	7 (94)	8(85)	9 (86)	9 (89)	9 (96)	7 (94)	7 (85)	8 (86)	8 (89)	8 (96)
20 cm	13 (85)	17 (81)	9 (79)	13 (81)	14 (83)	12 (85)	15 (81)	11 (79)	13 (81)	13 (83)
30 cm	21 (88)	20 (83)	16 (84)	22 (93)	24 (88)	25 (88)	20 (83)	20 (84)	19 (93)	23 (88)
40 cm	36 (82)	35 (80)	34 (76)	51 (78)	33 (80)	48 (82)	33 (80)	35 (76)	35 (78)	36 (80)
50 cm	47 (75)	46 (78)	47 (80)	51 (44)	51 (72)	49 (75)	53 (78)	56 (80)	54 (74)	47 (72)
60 cm	68 (73)	67 (72)	69 (74)	71 (71)	70 (73)	71 (73)	68 (72)	65 (74)	67 (71)	68 (73)
70 cm	80 (72)	86 (70)	83 (68)	82 (66)	80 (69)	84 (72)	87 (70)	78 (68)	86 (66)	80 (69)
80 cm	97 (68)	98 (65)	101 (67)	95 (70)	103 (68)	106 (68)	95 (65)	99 (67)	102 (70)	97 (68)
90 cm	114 (65)	116 (66)	112 (64)	113 (65)	116 (68)	121 (65)	127 (66)	118 (64)	113 (65)	114 (68)
100cm	142 (61)	147 (63)	151 (64)	142 (65)	139 (63)	144 (61)	140 (63)	137 (64)	142 (65)	142 (63)

Calculations						
Distance	**Average (cm)**		**Variance**		**Stdev**	
	Primary	**Secondary**	**Primary**	**Secondary**	**Primary**	**Secondary**
10 cm	**8**	**90**	**0.67**	**20.89**	**0.82**	**4.57**
20 cm	**13**	**81.8**	**4.67**	**4.62**	**2.16**	**2.15**
30 cm	**21**	**87.2**	**6.89**	**13.96**	**2.62**	**3.74**
40 cm	**37.6**	**79.2**	**40.93**	**4.62**	**6.40**	**2.15**
50 cm	**50.1**	**75.8**	**11.88**	**9.07**	**3.45**	**3.01**
60 cm	**68.4**	**72.6**	**3.60**	**1.16**	**1.90**	**1.07**

70 cm	**82.6**	**69**	**9.60**	**4.44**	**3.10**	**2.11**
80 cm	**99.3**	**67.6**	**13.12**	**2.93**	**3.62**	**1.71**
90 cm	**116.4**	**65.6**	**21.16**	**2.04**	**4.60**	**1.43**
100 cm	**142.6**	**63.2**	**16.04**	**1.96**	**4.01**	**1.40**

11.3. Itemized Purchases

Item purchased	**Cost**
3 Estimote beacons	$116
BLExplr App from App store	$2.99
Total	**$118.99**

11.4. Timeline

Task	September				October				November				Dec.	
	7	14	21	28	5	12	19	26	2	9	16	23	1	7
Project R&D														
Background Research	X	X												
Design Brainstorm		X	X	X										
Final Design Selection				X	X	X	X							
Fabrication								X	X					
Testing										X	X	X	X	
Deliverables														
Progress Reports	X	X	X	X	X	X	X	X	X	X	X			
PDS		X	X	X	X									
Midsemester Presentation				X	X									
Midsemester Paper				X	X	X								
Final Poster												X	X	
Final Paper												X	X	X
Meetings														
Team	X	X	X	X	X	X	X	X	X	X	X		X	X
Advisor	X	X	X	X	X		X		X	X	X		X	X
Client	X	X											X	
Website														
Updates	X	X	X	X	X	X	X	X	X	X	X			X