Radiation Distance Safety Meter

BME 200/300
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Department of Biomedical Engineering
December 11th, 2013

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Abstract

Patients who are diagnosed with thyroid complications are commonly treated with radioactive iodine (I-131). Patients that are discharged after undergoing this treatment must avoid excessive contact with individuals in order to protect others from radiation exposure. Those at risk of radiation exposure include: family members, individuals close to the patient, health workers and the environment. The International Commission on Radiation Protection (ICRP) recommends that radioactive iodine patients receive thorough instructions to avoid direct and indirect contact with infants and young children following the treatment [1]. Currently, there is no device that alerts the patient or the nearby individuals that they are in danger of radiation exposure. Our client, Dr. Sarah Hagi, an Assistant Professor of Medical Physics, Diagnostic Imaging, and Radiation Protection at King Abdulaziz University in Jeddah, Saudi Arabia, has proposed the design of a device that alerts the patient and others around them of their proximity. A device was designed that couples a heat and distance sensors to detect a human provide both visual and auditory feedback systems when a human is within a designated distance.

Problem Statement

After a patient treated with therapeutic doses of radioactive iodine (I-131) is discharged, the radiation from the doses can be potentially harmful to those in close proximity to the patient. Greatest concern is given to family members, individuals close to the patient, as well as health care professionals and the environment. It was found that those who are close to the patient should not exceed 5mSv of cumulative radiation exposure per treatment episode [1]. Our client Dr. Sarah Hagi from the radiology department at King Abdulaziz University Hospital requested a device that alerts the patient and others if the patient is within one meter of a human.

Background

The thyroid gland, illustrated in figure 1, produces hormones that affect heart rate, blood pressure, body temperature, and weight. One in 92 men and women will be diagnosed with thyroid cancer during their lifetime [3]. 60,200 new cases of thyroid cancer will be diagnosed in 2013, with an estimated 1,850 deaths [3]. Of the estimated 60,200 new cases of thyroid cancer, it is estimated that 45,310 will be women, and 14,910 will be men [4]. The median age for thyroid cancer is 50 years of age [4].

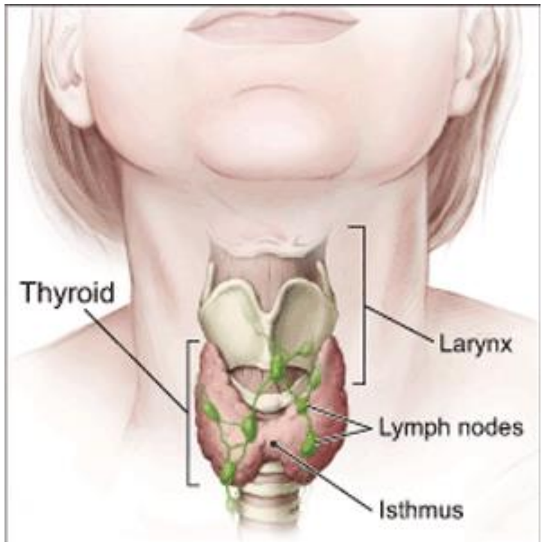

Figure 1. Location of the thyroid gland. The use of I-131 is very effective for curing thyroid problems such as thyroid cancer or hyperthyroidism [2].

Another common thyroid disorder, hyperthyroidism, occurs when the patient has excessive amounts of thyroid hormones due to several different diseases such as Graves' disease, toxic multinodular goiter, or toxic adenoma [5]. Common symptoms of hyperthyroidism include excessive sweating, heat intolerance, increased bowel movements, tremor, nervousness, rapid heart rate, weight loss, fatigue and irregular menstrual flow. Hyperthyroidism is much more common than thyroid cancer, with approximately 2% of women and 0.2% of men experiencing cases of hyperthyroidism at some point in their lifetime [5].

Doses of I-131 as a method of systematic radiation therapy has successfully treated hyperthyroidism and thyroid cancer for more than 60 years [3]. Radioiodine is the treatment of choice for radiation therapy in the United States, United Kingdom, and Canada because it is relatively inexpensive and very effective compared to other treatments [1]. Radioactive iodine works well for thyroid treatment because the thyroid cells naturally take up iodine, allowing the radioactive iodine to damage the DNA of the cancerous cells.

One of the risks of radioactive iodine therapy is that the patient becomes temporarily radioactive after treatment. While most of the radioactive iodine is excreted through urine, the patient can radiate gamma rays from the decaying I-131 [1]. These gamma rays can be particularly harmful for pregnant women and children standing near the iodine therapy patient due to their higher risk of developing cancer. The chance for developing fatal cancer due to exposure to radiation increases by 5% per Sievert of radiation accumulated, and the odds of developing cancer are 2-3 times higher for children [2]. Although the dosage of radiation to second persons from radioiodine therapy patients is to the order of micro Sieverts per hour, patients must be sure that exposure to children and pregnant women is minimized due to their increased chance of developing cancer after exposure to radiation.

In order to minimize radiation to second persons, doctors set forth strict guidelines for patient behavior following treatment. Patients should stay one meter away from persons at home and two meters away from someone if they are near them for an extended period of time. Also, it is recommended that children under two-years of age are cared for in a separate household if the parent received radioiodine because children often require physical attention, which the parent cannot give following treatment. Patients must follow more extensive guidelines regarding public interactions, including avoiding public transportation, avoiding work if it is necessary to stand or sit near coworkers for an extended time, and disposing of tissues or other waste items properly [2]. The timeframe that a patient must follow these guidelines varies from 24 hours to six weeks depending on the dosage of radioactive iodine [2].

Motivation

Due to the fact that patients must be conscience of their distance to others, especially children and pregnant women, for up to six weeks, our clients Dr. Eng. Sarah Hagi, Dr. Nazeeh Alothmany and Dr. John Webster proposed a device that would remind patients of others' presence. A simple feedback mechanism such as an auditory or visual reminder if a second party was within one-meter of the radioactive iodine patient would keep the patient aware of the need to minimize radiation to second parties.

Client Requirements

The client requests that the device be able to detect a human within a one-meter range and correspondingly alert the patient if a human is at an unsafe distance. The device must be comfortable for the patient to wear on a day-to-day basis and must be light enough for people of all ages to wear all day for up to six weeks.

Existing Devices

There are currently no devices that specifically meet the clients' requirements; however, there are different types of distance and heat sensors that exist on the market today, as well as security alert systems and sonar systems that are used to detect presence of a body. There are also radiation detection meters that are programmable to detect radiation exposure. There are no existing devices of this type that have any alert feedback mechanism. Also, these radiation detectors are analyzed after the fact by inserting a storage card into a computer [6].

Ethics

In order to encourage the patient to wear the device for the entire duration recommended by their doctor, the device must be very comfortable and not cumbersome to wear in public. The device must also be within the patient's tolerance to provide feedback that is appropriate to the situation by not alarming anyone to an unnecessary extent. The safety of second parties is largely affected by the responsibility of the radioactive patient; our device serves as a simple reminder system to aid in the protection of second parties.

Ergonomics

Ergonomics play a significant role in design considerations. A good design should incorporate both user comfort and user acceptability. This includes making the device blend in with common articles of clothing so it is not an eyesore. A feedback mechanism needs to be designed to provide the least amount of irritability to the wearer and others in close proximity. A light is subtle and an easy visual alert for the wearer to recognize, which makes it ergonomically acceptable. Other options for ergonomically feasible feedback mechanisms include vibration, sound, and phone notifications.

Design Proposal Overview

Dr. Eng. Sarah, in collaboration with Professor John Webster, proposed the original design of the RaDistance Safety Meter. The proposal calls for the design of one or many devices that will aid radioactive iodine therapy patients with interactions with family members and others in their home settings after hospital discharge. The initial idea was a form of headwear that contains both a distance and heat sensor. If a patient is to get within 1 meter of another person, the patient will receive an acoustic, vibratory, or optical feedback. The client proposed the use of a pyro-electric infrared sensor for the heat sensor, and an ultrasonic time-of-flight sensor for the distance sensor.

Component Design

Our selected design will combine two heat sensors –4x4 D6T MEMS Thermal Sensor by Omron –and two distance sensors –PING))) ultrasonic distance sensor by Parallax –on a belt, as shown in figure 2.A and figure 2.B. There are two attachment possibilities: one will be attached with a buckle and the other with Velcro. One heat sensor and one distance sensor will be paired together and placed on the ventral side of the belt, whereas the other heat-distance sensor pair will be placed on the dorsal side of the belt. This will allow the sensors to perform detection anterior and posterior to the user. The output from the sensors will be processed by an Arduino microcontroller. The microcontroller will send outgoing signals to a dual-feedback mechanism located on the belt. This dual-feedback mechanism will include a visual alert via a LED and an auditory alert via a small speaker. The LED will begin to flash when the sensors immediately detect a person within one meter of the user, while the auditory alarm will sound when this person has remained in the one meter zone for more than twenty-five seconds.

In order to find the amount of time that a person may stand within a one-meter radius, a few assumptions are necessary. First, a typical interaction of a family member within one-meter lasts an average of 30 seconds. Overall, a person close to the patient interacts with the patient 20 hours a week. Therefore, the person interacts with the patient an average of 4800 times within a two week period. It has been shown that the standard for radiation in a two week period cannot exceed one mSv. Also, the same study showed that children accumulate 1.2 mSv per two weeks from a close adult [1]. Therefore, within this two week period, the child cannot exceed more than 33.33 hours around the patient. That means that each interaction with the patient should not exceed 25 seconds. The code will be set for the buzzer to go off 25 seconds after the LED is turned on.

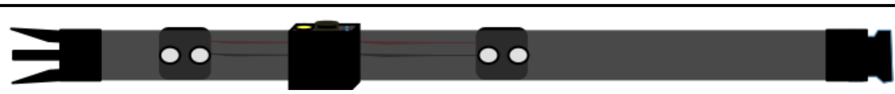

Figure 2.A. Buckle attachment for proposed device

Figure 2.B. Velcro attachment for proposed device.

Evaluation and Matrices

The final design was chosen from three main design features; the location of the sensors, the location of the sensor feedback, and the type of sensors. The three main features were separated into three design matrices (tables 1, 2, and 3) and evaluated individually based on relevant criteria. The criteria used for each evaluation matrix were selected and weighted according to their importance. Each design feature could receive a maximum of 100 points.

Criteria (weight)	Belt		Wrist		Cap		Vest		Ankle	
Function (20)	3	12	2	8	4	16	4	16	1	4
Comfort (20)	4	16	2	8	1	4	3	12	3	12
Aesthetics (15)	4	12	3	9	1	3	2	6	3	9
Accessibility (15)	4	12	5	15	2	6	4	12	2	6
Fabrication (10)	4	8	3	6	2	4	2	4	3	6
Safety (10)	4	8	3	6	3	6	3	6	3	6
Cost (10)	5	10	4	8	3	6	3	6	4	8
Total (100)	**78**		**60**		**45**		**62**		**51**	

Table 1: Sensor Location Evaluation Matrix

The first design feature was where to place the sensors on the user's body to optimize performance and comfort. The criteria used to determine the best location, in order of importance, were functionality, comfort, aesthetics, accessibility, ease of fabrication, safety, and cost. These criteria were considered for sensors located on a waist belt, a wrist bracelet, a head cap, a torso vest, and an ankle bracelet. The waist belt was the highest scoring design feature with 78 points, and was selected for our final design.

The sensors ability to function at the proposed locations was given the largest weight of 20 points because it was the most important criteria for the device. In order to accurately detect people within one-meter of the user, the sensors must be placed in a location that optimizes their field of view and minimizes the risk of obstruction. The cap and vest design received the highest scores in this category while the ankle was scored the lowest. The cap provides 360 degrees of vision, which is why it received the highest score. Comfort for the user was given the same weight of 20 points. It was decided that the device needed to be as comfortable and natural feeling as possible to not inhibit the user from everyday activity. The belt design received the highest score in this category while the cap received the lowest.

The next two criteria, aesthetics and accessibility, were given the same weight of 15 points. Aesthetics were given middle level of importance because the user will have to wear the device for multiple weeks. The belt again scored the highest in this category while the cap was the lowest. Accessibility of the sensors was taken into consideration for instances when adjustments needed to be made by the user to improve comfort or function. The wrist was considered the most accessible while the ankle and cap were deemed relatively inconvenient to access.

The final three design criteria, ease of fabrication, safety, and cost, were equally weighted at 10 points each. We believed all of the sensor location designs were similarly feasible to fabricate, safe to the user, and affordable, which is why these criteria received the lowest weighting. The belt received the highest marks in ease of fabrication and cost because we would not need to miniaturize any of the components to attach them to a belt. On the wrist, however, the size of the sensors would have to be much smaller and therefore more expensive and difficult to fabricate. The belt also received the highest score in safety because if the sensors were to malfunction and overheat they would not be in direct contact with the skin unlike sensors on the wrist, ankle, and cap would be.

Criteria (weight)	**Belt**		**Wrist**		**Cap**		**Phone**		**Vest**		**Ankle**	
Comfort (25)	4	20	2	10	1	5	4	20	3	15	3	15
Accessibility (25)	3	15	5	20	2	10	1	5	3	15	2	10
Aesthetics (15)	4	12	4	12	1	3	5	15	2	6	3	9
Fabrication (15)	5	15	3	9	2	6	1	3	4	12	3	9
Safety (10)	4	8	3	6	2	4	4	8	3	6	4	8
Cost (10)	3	6	3	6	2	4	2	4	2	4	3	6
Total (100)	**76**		**63**		**32**		**45**		**58**		**57**	

Table 2: Feedback Location Evaluation Matrix

Our team determined a dual-feedback mechanism incorporating light and sound would be the best design option. This is because it provides different levels of alerts, ensuring that the patient was notified of an individual that is in an unsafe distance. This was determined due to the fact that our client requested a dual-feedback system.

The second design feature considered was where to place this feedback mechanism on the user's body to optimize comfort and functionality. The criteria used to determine the best location, in order of importance, were comfort, accessibility, aesthetics, ease of fabrication, safety, and cost. These criteria were considered for feedback mechanisms located on a waist belt, a wrist bracelet, a head cap, a cellular phone application, a torso vest, and an ankle bracelet. The waist belt was the highest scoring design feature with 73 points, and was selected for our final design.

The comfort and accessibility of the location of the feedback mechanism were given the highest weight of 25 points each. User comfort again was a major concern to ensure the device did not restrict the user's daily life. Placing the feedback mechanism on the belt or from a phone received the highest scores, while the cap was the lowest. The belt was highest because the sensors will already be located on a belt, so adding the feedback mechanism to it would not add any additional discomfort to the user. A notification from a smartphone application or text message was also considered not to add any discomfort to the user. Accessibility of the feedback system, which includes an 'acknowledge' button the user will have to press, was a top priority for two reasons. First, we wanted to ensure the user does not struggle to disarm the device, and second we wanted to make sure the feedback was somewhere easily noticeable to the user. Having the feedback mechanism located on the wrist was decidedly the most accessible location, while the phone was considered difficult to notice.

The next two criteria, aesthetics and ease of fabrication, were given the same weight of 15 points. Aesthetics were given this middle level of importance because the user will have to wear the device for multiple weeks. The phone, being a device most users already own and use daily, scored the highest for aesthetics, while the cap was the lowest. The belt received the highest ease of fabrication score because the feedback system could be hardwired to the sensor system in one component. The other feedback locations all would have required the use of wireless Bluetooth signaling or uncomfortable wire connections.

The final two design criteria, safety and cost, were equally weighted at ten points each. We believed all of the feedback location designs were similarly safe to the user and affordable. The belt was amongst the highest marks in both of these categories confirming it as our final design location for the feedback mechanism.

Criteria (weight)	Ping (((Ultrasound		Max Robotix Ultrasound		Infrared PIR		Mouser PIR	
Integration/ Fabrication (25)	5	25	4	20	2	10	2	10
Field of View (25)	2	10	1	5	2	10	4	20
Accuracy (20)	4	16	4	16	2	8	3	12
Cost (20)	3	12	3	12	4	16	5	20
Safety (10)	4	8	3	6	3	6	3	6
Total (100)	**70**		**59**		**50**		**68**	

Table 3: Distance Sensor Evaluation Matrix

The third design feature was determining which distance sensor to use in the device to ensure proper functionality. The criteria used to determine the best sensor, in order of importance, were ease of fabrication/integration, field of view, accuracy, cost, and safety. These criteria were considered for the Ping))) ultrasonic sensor, the Max Robotix ultrasonic sensor, the infrared PIR sensor, and the Mouser PIR sensor. The Ping))) ultrasonic sensor was the highest scoring design feature with 70 points, and was selected for our final design.

The ease of which the sensor could be integrated into the design and the sensor's field of view was given the highest importance of 25 points each. The ability of the sensor to be integrated into the system was scored based off of the outputs given by the sensor and the available literature on the sensor. The Ping))) ultrasonic sensor received the highest score due to multiple open source communities available around the product. The sensor's field of view was given considerable importance because fewer sensors could be used to achieve 360 degrees of vision around the user if the sensor has a larger field of view. The Mouser PIR sensor was given the highest score due to it having the largest field of view.

The next most important criteria considered when selecting a sensor were accuracy and cost, weighted at 20 points each. Accuracy received a high weight because the success of the overall device was heavily dependent on the accuracy of the sensor. Accuracy was not weighted the highest because we believed we could overcome some of the potential inaccuracies with efficient processing. The Ping))) ultrasonic sensor and Max Robotix sensor received the highest accuracy scores because they had the most precise specifications. Cost was given equal importance because multiple sensors will be needed for our final design. The Mouser PIR was the least expensive of the sensors and therefore received the highest score for cost.

The safety of the sensors was the last criteria considered for our sensor selection. It received the lowest weighting, 10 points, because of the almost exact safety concerns and warnings for each sensor. The Ping))) ultrasonic sensor was ultimately deemed the safest due to its low input voltage and small size.

The final design was chosen according to the summation of the three design matrices outlined. A device with a Ping))) ultrasonic distance sensor and a 4x4 D6T MEMS Thermal Sensor integrated with a dual–feedback mechanism, both located on a belt, was selected as the final design. A system with sensors and feedback on the user's wrist, in the form of a bracelet, will be considered our back-up design as we move forward.

Prototype Components

The thermal sensor that will be used in the prototype is the D6T-44L MEMS Thermal Sensor by Omron, shown in figure 3 [7]. This thermal sensor provides high-precision area temperature detection with low cross-talk field of view characteristics. Unlike similar pyro-electric heat sensors, the D6T MEMS thermal sensor is able to sense change in ambient temperature without the motion of the warm body in the field of view. This will be advantageous for our design because the patient may be sitting too close to another human that is not moving, but is still being overexposed to radiation.

The Omron D6T MEMS thermal sensor is composed of a silicon lens, MEMS thermopile array, custom designed sensor application-specific integrated circuit, and a signal processing microprocessor and algorithm. The silicon lens gathers infrared (IR) radiation emitted by a warm body and directs it onto the thermopile. The IR radiation produces an electromotive force on the MEMS thermopile array, which transduces the IR light into an electrical signal. A temperature conversion algorithm converts the sensor signal to digital temperature, which is output through an I2C bus [11]. The following is illustrated in the figure below.

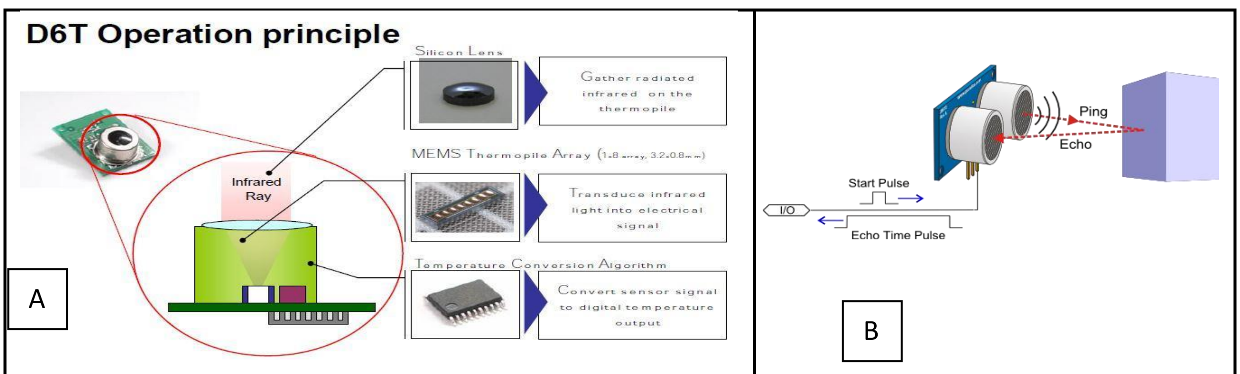

Figure 3: (A) Omron D6T thermal sensor. (B) D6T-44L-06 MEMS temperature sensor operating principle. [11]

A thermopile in the Omron D6T thermal sensor consists of multiple thermocouples connected in series. A thermocouple generates voltage when any conductor (i.e. metal) is subjected to a thermal gradient. This is known as the Seebeck effect. A thermocouple nurtures a Seebeck effect via cold junctions and hot junctions. At a cold junction, temperature is the same as ambient temperature because Silicon is highly conductive. At a hot junction, temperature is dependent on the flow speed [11].

The distance sensor that we will be using for our prototype is the PING))) ultrasonic distance sensor by Parallax [8]. This distance sensor is capable of measuring distances from two centimeters to three meters, which includes our desired range. The microcontroller activates the distance sensor by sending a short 5V signal to the sensor. The sensor sends an ultrasonic wave and records the time of flight for the wave to hit a close object and return to the sensor, as shown in figure 3. The sensor sends a high voltage signal back to the microcontroller lasting the same length as the time of flight of the ultrasonic wave. This time of flight can be easily converted to a distance. The sensor is advantageous because it works in any lighting condition and has a narrow field of view, so it will get the distance of a specific object.

As decided by our design matrices, an LED and buzzer serve as the feedback mechanisms. If the Arduino senses the presence of a person, the LED turns on immediately. The LED is connected in series with a 270Ω resistor. An 85-dB piezo buzzer from RadioShack® was used because it worked very well for our purposes and was inexpensive.

Although not ideal for long-term use, a 9V battery was selected for the prototype due to price and convenience. The 9V battery directly powers the Arduino, which controls the power to the other components. The 9V battery worked well for testing and for use throughout the semester. The 9V battery is connected with switch so that the user can conserve the batter by turning off the system when not in use.

Final Prototype Code

The program initially runs the pingDistance() function [10], which signals for the Ping to take a distance measurement. To do this, the sensor measures the time it takes for an ultrasonic echo to return to the sensor after it has been emitted, and converts the time of flight to a distance in centimeters. This distance measurement is placed in an array of the 21 most recent distance measurements. An array of size 21 was chosen because it provided sufficient accuracy, and a larger array would create a longer delay in the program.

If the median value of the distance array is below 100cm, the Arduino uses I2C communication to request the temperature values from the thermal sensor. I2C is a form of communication where the master requests certain information from a slave. The microcontroller is the master and the thermal sensor is the slave with the 7 bit address of 0x0A. If any of the 16 temperature values from the 4X4 grid corresponding to the field of view of the thermal sensor is above 23ºC, the variable highTemp is true and the loop checking the thermal readings is broken.

If the median of the distance measurements is less than 100cm and *highTemp* is true, then the variable *closeWarm* is also true. If *closeWarm* is true, the LED is immediately turned on and the buzzer timer begins. This timer runs for 25 seconds before activating the buzzer signal and restarting. If *closeWarm* becomes false because the median of the distances is above 100cm or the temperature values are all below 23ºC, the LED is turned off and the timer for the buzzer is disabled. Appendix C contains the full final code and figure 4 illustrates the main loop of the code.

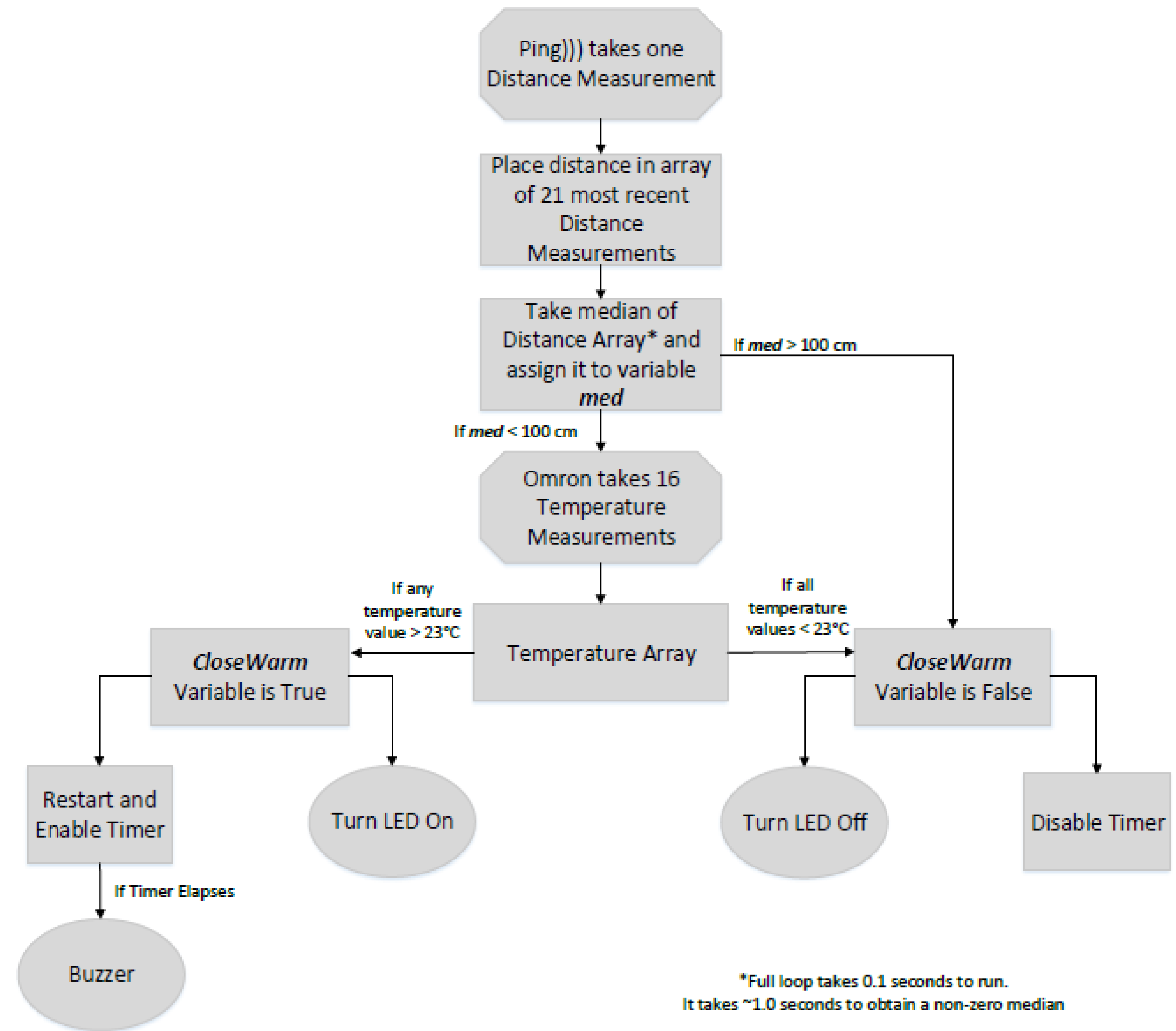

Figure 4: Final code diagram

Final Prototype Construction

The final belt was constructed of polyester and a nylon belt. The polyester was cut to 8.5" wide to fully cover the microcontroller. Styrofoam holds the LED and sensor in place within the belt. Two grommets expose both the thermal sensor and the LED. To prevent the grommet from conducting with the thermal sensor, electrical tape separates the grommet from the thermal sensor. The wiring was threaded through the inner parts of the belt before the components were stitched into place. The patient can still access the battery, switch, and microcontroller, but all other components are enclosed in the belt.

Two 12" nylon straps with D rings secure the belt to the patient. Two straps were used to secure both the top and the bottom of the belt and the D rings ensure that the belt is adjustable. The belt could be easily altered to fit larger patients if the nylon strap was longer, but 12" of nylon strap accommodates a large range of patient sizes.

The battery, connected to a switch, directly powers the Arduino, which in turn powers the other components. The 5V power supply from the Arduino is split between the Ping))) sensor and the D6T thermal sensor, which are both connected to the Arduino's ground. The D6T thermal sensor uses I2C communication so it is also connected to the Arduino's analog 4 and 5 pins, which serve as the Arduino's SDA and SCL lines respectively. The buzzer and LED are both powered by digital pins, and connected to the Arduino's ground.

Testing

Two tests were performed to test the accuracy of the code: a field of view test and a time accuracy test.

Field of View

The belt was placed on the floor against the wall with the sensors pointing away from the wall. Next, 5 inch (0.127 m) increments were placed from the sensors up to 1.0 meter. A test subject entered into the field of view at one increment from both sides of the sensors. When the LED turned on, the subject placed a marker on the spot where they were detected. The following procedure was repeated at every increment. The results can be seen in the diagram below.

The diagram, figure 5, shows the horizontal field of view from a bird's eye view. The results show that the right side of the field is wider; this is due to the fact that the ultrasonic waves from the Ping sensor exit from the right side. As the distance from the sensor increases, there is an increase in the distance from the midline on both sides, which is expected for both sensors. The field of view angle for the combination of sensors is 15.71 degrees.

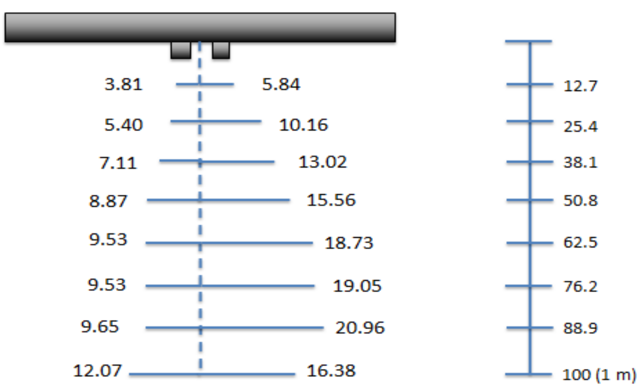

Figure 5: Field of view diagram

Timer Accuracy

The belt was propped up on a countertop so that the sensor and LED faced in the same direction. A tape measure was used to measure the distance from the countertop to a position of 1.0m away from the sensors on the line that the sensors were facing. The belt was turned on via power from the usb port of a laptop. The code was uploaded onto the Arduino and the Serial Monitor on the Arduino software was opened so that the distances measured by the distance sensor could be observed as a live feed. Next, a human subject stepped in front of the sensor with their ankles lined up with the 1.0m mark on the ground.

Once the LED turned on, another team member started a timer in an iPhone. After the initial onset of the LED, flashes (on-off-on) of the LED were counted. A flash of the LED corresponds to the resetting of the feedback timer (if the LED is on for 10 consecutive seconds, the buzzer will tone). Zero flashes corresponds to 1 cycle, one flash of the LED corresponds to two timer cycles, etc. The timer on the iPhone was stopped when the buzzer toned. Two sets of ten trials were performed at 1.0m. The first trial used the code without the median array (table 4), whereas the second trial included the code with the median array (table 5). The following tables show the result for both 1m tests.

Trial	Time (s)	Cycles
1	11.7	3
2	23.1	9
3	FAIL	FAIL
4	14.3	3
5	95.8	25
6	105.8	33
7	135.1	59
8	14.5	2
9	27.7	7
10	43.2	14

Table 4: First testing trial

Trial	Time (s)	Cycles
1	10.23	1
2	13.40	2
3	10.21	1
4	10.10	1
5	9.95	1
6	16.73	2
7	10.15	1
8	10.10	1
9	10.21	1
10	10.16	1

Table 5: Second testing trial with running median code

It was observed that including the median code noticeably decreased the amount of cycles that the belt took before signaling the buzzer.

Statistical Analysis

The null hypothesis for the time accuracy test is the time between the onset of the LED and the sound of the buzzer is 10 seconds (μ=10). The alternative hypothesis is the time between the onset of the LED and the sound of the buzzer is not 10 seconds (μ is not equal to 10). The sample size was 10 trials. The sample average for the final attempt on this test was calculated to be 11.124 seconds. The standard error was found to be 0.70262s. Therefore, the t-statistic was calculated to be 1.5997. Since the degree of freedom was 9, the p-value was 0.14412. This value is much greater than the significant value of 0.5. Table 6 provides a summary of the variables calculated:

Calculations	
Mean	11.124 sec
Variance	5.706 sec
Standard Error	0.7026 sec
T test value	1.5997
P-value	0.14412

Table 6: Statistical Analysis

Since the p-value is greater than the significant value, there is not enough evidence to reject null hypothesis. Although this test does not assure us that the null hypothesis is true, we do not have evidence to confidently justify that it is false. Therefore, we can conclude that the system successfully detects a human within a one meter radius and alerts the patient after 10 seconds.

Discussion

The prototype meets the clients' requirements for several reasons. The combination of the heat and distance sensors was successful in detecting a human within a one-meter radius and alarming the patient in the allotted time (which was ten seconds for testing purposes). In reality, the buzzer will go off 25 seconds after a human is detected within the sensor's field of view. The final field of view for the combination was found to be 15.71 degrees.

The material used allows the prototype to be lightweight and comfortable. The Styrofoam allows for the protection of the electrical equipment while the fabric allows the patient to comfortably where the device around their waist.

Future Work

The primary focus of future work on this project is to utilize the capability of the Ping))) and D6T sensors by optimizing the microcontroller code, as well as incorporating wireless tracking capability to monitor exposure of people in frequent contact with the patient, increasing the field of view, including more complex feedback mechanisms, and making the device ready to be manufactured by adding sturdy housing materials. Currently, the main flaw in the code is that the timer for the onset of the buzzer is reset if one distance median in the distance array is greater than 1m. The Ping))) distance sensor is not an extremely accurate distance sensor and is prone to missing a distance measurement if the echo is reflected in a direction that is not back towards the sensor, or if it is absorbed by the material that it hits. To account for this, it is may be possible to add another timer that goes off when the object leaves the field of view (the distance median is greater than 1m). By creating this time window tolerance, it can be assured that the buzzer timer does not turn off if the person near the patient is still in danger. This idea has its own unique flaw: the belt will not be able to determine if the person that leaves and enters the field of view, within the new timer's window, is the same person or a different person. If it is a different person, the buzzer will go off and warn them prematurely. The overriding goal of the device is to ensure the safety of others, it is better to warn them prematurely than to fail to warn them in an appropriate time frame.

To minimize the risk of failing to inform someone that they are in danger of excessive radiation exposure, the design can potentially include a Bluetooth-like device that can record the accumulation of radiation over time to the people that are going to be near the patient frequently or for extensive periods of time. If a person continually enters and leaves a dangerous distance between them and the patient, the belt described in this paper will not be able to warn them of the overall accumulation. It only detects if a person is too close at one moment. This feature would be extremely beneficial to the patient and the people that surround him/her.

One reliable solution to the resetting of the timer when a person leaves the field of view of the belt is to create a larger field of view. Multiple pairs of the same sensors that we have been using can accomplish this. The Ping))) distance sensor has a smaller field of view than the thermal sensor so it may be necessary to have more distance sensor than thermal sensors. Multiple sensors and multiple measurements may also be helpful in determining if there are multiple people in the field of view.

A greater number and different feedback mechanisms can be implemented to provide more information to the patient. For example, different color lights could be used to indicate the danger level of a person that has been in the field of view for certain amounts of time (green, yellow, red). Different beep rhythms, tones, and volumes can also be used for different amounts of time exposed to radiation.

A stronger material than Styrofoam can be used to protect the sensors and feedback. Different plastics can be molded to secure the sensors and feedback. A cover for the temperature sensor will be necessary to protect it and to maintain its functionality. The efficacy of the thermal sensor is greatly altered by elements such as stress and dirt (especially oil from skin contact). It has been shown that high-density polyethylene (HDPE) is a good material to use to protect the thermal sensor while maintaining its functional integrity [11].

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Appendix A: PDS

RaDistance Safety Meter PDS

Updated: December 9th, 2013

Client:
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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 will create a device that provides acoustic and optical feedback to alert the patient of their proximity to others.

Client Requirement:
- 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 where on a day-to-day basis

1. Physical and Operational Characteristics

a. Performance requirements: Must detect human presence within one meter for at least 6 weeks. Must provide feedback to alert user of human presence. Must function under mild radioactive conditions.

b. Safety: The device must have a 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 around the waist of the patient. The device should weigh no more than one kilogram.

j. Materials: The materials must not be affected by radiation from 131-I. 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.

Appendix B: Timeline

Task	October				November					December
	4	11	18	25	1	8	15	22	29	6
Project R&D										
Lit. Research	X	X								
Manufacturing			-	-	X	X	X			
Cost Estimation				X	X	X	X			
Prototyping							X	X	X	
Deliverables										
Progress Reports	X	X	X	X	X	X	X	X	X	X
PDS	X	X	X	X	X	X	X	X		
Midsemester	X									
Final Poster										X
Meeting										
Client	X	X		X		-		-		X
Team	X	X	X	X	X	X	X	X	X	X
Advisor	X	X	X	X	-	X	X	X	-	X
Website										
Update	X	X	X	X	X	X	X	X	X	X

Appendix C: Final Code

```
/* Fall 2013 BME 200/300 Radiation Distance Safety Meter Program   Last Updated 12/5/13   Team Members: Jack Goss, Michael Quirk, Adam Strebel, Tommy Zipp, Emily Carroll Code written for Ping))) Ultrasonic Distance Sensor by Parallax inc. and   Omron MEMS D6T Thermal Sensor   Code detects human presence within 1m distance of sensors and provides auditory and visual feedback.
*/
#include <RunningMedian.h> // Include the library that allows us to measure the median of
                                   //an array of distance measurements
#include <SimpleTimer.h> // Include the timer library
#include <Wire.h> // Include I2C library
SimpleTimer timer;
RunningMedian samples = RunningMedian(21); // Create array of size 21 to hold the 21 most
                                                       //recent distance measurements
double values[16]; //Double holds precision floating point numbers.
                    //values is a 16 value array holding the temperature values of 4X4
//thermal sensor grid double ambient;
int distance;
  boolean closeWarm = false;
int timerId;
int med;

//Assign Pins
int pingPin = 7;
int speakerpin = 2;
int ledpin = 13;
int buzzpin = 4;

/* The ping is triggered with a short 5V signal for 5 ms.   The return signal from the ping lasts the time of flight of the ultrasonic wave. The signal is then converted   from milliseconds to cm. The distance in cm is   placed in the RunningMedian array in order to   eliminate outliers.
*/
void pingdistance() {
long duration, inches, cm;
pinMode(pingPin, OUTPUT); //code to trigger ping
digitalWrite(pingPin, LOW);
delayMicroseconds(2);
digitalWrite(pingPin, HIGH);
delayMicroseconds(5);
  digitalWrite(pingPin, LOW);
pinMode(pingPin, INPUT); //code to read ping
duration = pulseIn(pingPin, HIGH);

// convert the time into a distance
cm = microsecondsToCentimeters(duration);
distance = microsecondsToCentimeters(duration);
//Add Distance to Median Array
samples.add(distance);
med = samples.getMedian();
}
```

```
long microsecondsToCentimeters(long microseconds) {
// The speed of sound is 340 m/s or 29 microseconds per centimeter.
// The ping travels out and back, so to find the distance of the
// object we take half of the distance travelled.
  return microseconds / 29 / 2;
distance = microsecondsToCentimeters(microseconds); }


/* The OMRON thermal sensor uses I2C communication.   The arduino serves as the master and the address   of the
sensor is 0x0A. Once we request the temperature   values from the sensor, the values are placed in a 16 value   array
corresponding to the 16 temperature readings of the 4x4 grid.
*/
void readTemperatures() {
Wire.beginTransmission(0x0A);
Wire.write(0x4C);
int writeStatus = Wire.endTransmission();
if (writeStatus != 0) {   Serial.println("Writing command failed"); // A return value of 0 means that the
                                                                    //communication with the sensor worked
return; }
Wire.requestFrom(0x0A, 34);
if (Wire.available() > 1)   ambient = Wire.read() + Wire.read() * 256;
int i = 0;   while (Wire.available() > 1) {
double value = Wire.read() + Wire.read() * 256; values[i] = value / 10;   i += 1;
} }


//Function that runs when timer elapses
void testingtimer(){
//Serial print used to monitor timer if using serial communication
Serial.println(" ");
Serial.println("TIME UP");
Serial.println(" ");
pinMode(buzzpin, OUTPUT);
digitalWrite(buzzpin, HIGH);
delay(200);
digitalWrite(buzzpin, LOW);
delay (200);
digitalWrite(buzzpin, HIGH);
delay(200);
digitalWrite(buzzpin, LOW);
delay(200);
digitalWrite(buzzpin, HIGH);
delay(95);
digitalWrite(buzzpin, LOW);
 delay(95);
digitalWrite(buzzpin, HIGH);
 delay(95);
digitalWrite(buzzpin, LOW);
}


void setup() {
Wire.begin();
Serial.begin(9600);
```

```
timerId = timer.setInterval(25000, testingtimer); //Timer for buzzer set to 25 seconds
}

void loop() {
timer.run();
 pingdistance();
//Serial Print used to monitor accuracy of distance median
Serial.print("median distance = ");
  Serial.print(med);
Serial.println(" cm");
delay (10);
//delay 10 ms for accuracy of ping
if (med < 100) {   readT emperatures();
}
int bodytemp = 23; //Thermal sensor determined people were between 24-26 degreees C. int space = 100;
                         //100cm radius around patient
pinMode (ledpin, OUTPUT);
boolean highTemp = false; //Initially, highTemp is set to false
//if any of the 16 temperature values is above bodytemp, high temp is true
for (int i = 0; i < 16; i++) {
if (values [i] > bodytemp) {   highTemp = true;   break; //Break loop if any value is above bodytemp
} }
//If a person is within range, closeWarm is true,
//LED turns on, and timer for buzzer begins
 if(highTemp && (med < space)) {
if (!closeWarm) {
Serial.println(" ");
Serial.println("Starting buzzer timer");
Serial.println(" ");
timer.enable(timerId);
timer.restartTimer(timerId);
closeWarm = true;
}
digitalWrite(ledpin, HIGH);
}

//If no person is within range, closeWarm is false, LED turns off, and the timer for buzzer is disabled
else {
closeWarm = false;
digitalWrite(ledpin, LOW);
 timer.disable(timerId);
}
delay(100);  //delay 100 ms before running loop again
}
```

Appendix D - Costs of Prototype Construction

Item	Quantity	Date Purchased	Purchased from	Purchased by	Price	Subtotal	Shipping and Tax	TOTAL
Ping))) Distance Sensor	1	10-21-2013	Mouser Electronics	Tommy	$29.99	$79.52	$7.99	$87.51
Omron MEMS Temperature Sensor	1				$49.53			
Arduino Uno	1	11-01-2013	Radioshack	Tommy	$31.49	$31.49	$1.73	$33.22
JST GH Connector Housing 4 position 1.25mm	1	11-04-2013	Digi-Key Corporation	Tommy	$0.13	$0.24	$10.20	$10.44
JST GH Connector Terminal 30-26 AWG	1				$0.11			
JST GH Connector Terminal 30-26 AWG	20	11-08-2013	Digi-Key Corporation	Tommy	$2.10	$2.10	$0.12 (*free shipping because they messed up the order*)	$2.22
White Styrofoam Block (5" x 12" x 1 1/4")	2	11-15-2013	Hobby Lobby	Jack	$5.98	$9.01	$0.50	$9.51
Sewology 1" Nickel D-Rings	1				$1.99			
Navy Polyester (1 yard)	1				$1.04			
Arduino Uno Case	1	11-19-2013	MCM Electronics, Inc.	Adam	$7.64	$7.64	$9.49	$17.13
9V Alkaline Enercell Battery	1	11-22-2013	Radioshack	Adam	$4.49	$7.18	$0.39	$7.57
5 pack 9V battery clips	1				$2.69			
Medium coaxial DC power plug	1	11-22-2013	Radioshack	Adam	$3.14	$8.53	$0.47	$9.00
85dB Piezo Buzzer	1				$5.39			

Total Expenditure: $176.60

Money Spent by:

Tommy: $133.39
Jack: $9.51
Adam: $33.70

Appendix E - Arduino Circuit Diagram