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EMlighten

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Honors Research Project Report

Biomedical Engineering

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EMlighten™

EmergencyMedicine

Introduction to the Problem

The healthcare industry today is becoming more and more profit focused and driven. As a result hospitals are being run on business models where profit generation is stressed just as much as the quality of patient care. Because of this mindset, staffs are being pushed to do more with fewer resources, and measurable values like Key Performance Indicators (KPIs) are being implemented to quantify hospital performance. A major KPI for most hospitals is patient satisfaction. The patient satisfaction scores of a department are directly tied to the amount of additional funding granted to the department by the administration. In order to be granted a larger budget, hospitals want to find ways to increase their patient satisfaction KPI. The problem then is how to provide a system that will increase patient satisfaction without placing outrageous burdens on staff members, such as paperwork, time commitment, etc.

Client Description

The emergency department (ED) of Akron General came to the biomedical engineering department with an idea from Dr. Michael Beeson to solve this problem. Dr. Beeson's idea was for a tap light system located outside of an ED room that illuminates after a preset amount of time to indicate to staff members the patient has not been visited for the preset amount of time. Any staff member (nurses, techs, surgeons, etc.) passing by would then be expected to visit that patient. Visits are meant to be quick, friendly and efficient, showing the patient they have not been forgotten about but not adding additional work to the ED staff. We would expect a typical visit to consist of the staff member saying hello, inquiring if the patient is comfortable and if they need anything, and then exiting the room. Upon exiting the tap light is then reset by pushing on the light and restarting the timer. By continually visiting patients in the ED, Dr. Beeson hopes they will feel more cared for and less forgotten about, which will in turn increase their patient satisfaction scores. Ultimately, by implementing this system, we hope to achieve two things: 1 – providing a more comfortable experience for Akron General's patients, and 2 – the ED patient satisfaction scores will increase, resulting in an increased annual budget.

Project Objective

Our goal is to take the tap light system described by Dr. Beeson and merge it with our knowledge as engineers in order to develop a design which best solves the problem, meets the requirements set by Akron General, and is feasible to build before graduation. After developing and verifying a complete design, we agreed to provide Akron General with 35 functional units by the end of spring semester, 2016. These units will be immediately implemented in the ED at Akron General for a proof-of-concept study. Dr. Beeson agreed to list all students on the design team as co-authors on the clinical research paper generated from the study. One additional unit will also be made and left with the Biomedical Engineering department here at the University of Akron, for a total of 36 units. Any changes to the initial design based on the results of the proof of concept study are outside of the scope of our project because we will have graduated before results come back. Through working with Dr. Beeson and Frank Fire at Akron General, we have come up with the product name EMlighten, and are using the logo on the cover page of this report.

Design Process

The three main steps to the design process are brainstorming, testing and manufacturing. Our design team was in an interesting situation where we had a client waiting for us to finish and provide a product. We made the decision early on to make a change to the design process and brainstorm, build a prototype then test. Our design process ended up being an iterative trial and error based process. In essence, we allowed the customer, not the design process to drive our timeline instead of following the accepted design method of modeling first and manufacturing second. This caused a major halt in progress because a problem with the battery was identified during the week of delivering the 35 units to Akron General. This will be covered in detail throughout the report as our process for brainstorming, manufacturing, and testing will be outlined in the following sections.

Brainstorming

The suggested tap light design provided initial bias to our design and brainstorming process. It was unacceptable to take solution presented by Dr. Beeson focused on a mechanical interface and white light, and move forward without evaluating it against other potential solutions. In order to evaluate other solutions, the system was broken down into a functional diagram to show the components of the system. The components comprising the EMlighten system are:

- alerting mechanism
- electrical components
- data acquisition and storage
- external housing
- method to reset alerting mechanism
- battery

Assuming we directly followed the solution proposed by Dr. Beeson, each component would be described as follows: the alerting mechanism is the light, the electrical components are the circuitry which control the light, external housing holds the circuitry and mounts to the wall, the method to reset the alert mechanism is a physical “tap”, and the battery powers the system. Both this described system and the final prototype do not have a data acquisition and storage component. Data acquisition and storage refers to logging the system activity and transferring it over WiFi to some device where it can be accessed in spreadsheet form for analysis of patterns in

EMlighten activity. WiFi transfer was planned to be an additional feature we added to add to the units after they had been proven successful in hospital trials. This feature is no longer being added by our design group because of battery complications which will be described hereafter. Instead we are recommending data acquisition and storage to be something Akron General considers adding after a successful proof-of-concept study.

After identifying the six components of the functional diagram we brainstormed different ways each component could be implemented. For instance, the alerting mechanism could be a light, a sound, a phone or email notification, etc. Appendix A contains the tables we used to evaluate all of these solutions and select the best one for each component of the functional diagram. The options for each component received a score for every customer requirement, (see customer requirements in Appendix D). For example, the alerting mechanism needs to be effective over long distances like down the hallway. An auditory alert would be least effective over long distances, a digital alert would be most effective, and a light would be somewhere in the middle. A score of 5 means the option best meets the requirement criteria, and 1 means it does not meet the criteria. In the example given, over long distances auditory received a score of 2, digital received a score of 5, and a light received a score of 4. Scores for every listed requirement were then totaled and the option with the highest score was selected for our final design. The final alerting mechanism is a visual display utilizing a red LED matrix which does not flash and has a steady intensity. We proposed to Akron General that the method to reset the alerting mechanism be a radio frequency identification device (RFID), so staff could use a card or key chain to reset the timer. Akron General wanted to start with a motion sensor to reset the timer and then switch to RFID after proof of concept. We agreed and bought parts for both the motion sensor and RFID and wrote software code for both methods. The selected method of running the internal circuitry is an Arduino Mega board (SunFounder Mega 2650). The battery chosen at this stage was a standard 9V. Lastly the external housing is a pre-made plastic electrical box which we cut holes in to fit our application.

Design is an iterative process, so the brainstorming step was revisited as the process progressed and we learned more about the product and what was possible. Additional brainstorming is covered in subsequent sections of this report.

Coding

The first thing we tackled was to write a functioning software code. The team divided into two groups focused on either the Arduino coding or the external housing and machining. The software developers finished the code well ahead of schedule and it was working with a motion sensor at the beginning of October 2015. The RFID code soon followed and was completed at the beginning of November 2015. Tutorials of other successful Arduino code and many other resources were used to accelerate code development[1].

Our initial goal was to write a third code to incorporate data acquisition and storage. Development of this code has begun but has not been completed. Storage of EMlighten data and transfer to a website is beyond our capability at this point, and we do not have time before graduation to learn everything required to successfully push the data to an online spreadsheet or remote computer for Akron General to access. The software code we have developed for the data acquisition will be compiled and given to Akron General at the end of the semester. They will likely continue the project if proof-of-concept is successful.

Assembly Methods

After finalizing a design of the initial prototype, assembly began immediately in order to receive design approval from Akron General as soon as possible. After receiving approval on one prototype we were cleared to purchase parts for, and then assemble the remaining 35 units. The biggest challenge during assembly was the mass production element of EMlighten and developing an efficient process. We took an assembly line approach to constructing the units so tasks could be done in parallel. There were three main steps to assembly: machining the boxes, connecting the circuitry, and mounting everything within each box.

Before any machining was started, group members were responsible for building seven circuits. We divided the work in this fashion so one person would not be responsible for connecting each unit, and so every group member would learn the circuit building process. After connection, all units were gathered by the group member who was not working on machining and they tested each unit for functionality. This product quality assurance testing was done in parallel with the machining and allowed us to identify and replace faulty parts before components were mounted into the boxes. Five RFID chips and three motion sensors were replaced as a result of this quality check. During the quality check, the motion sensor code (set to a 20 minute timer) was uploaded to each Arduino board.

Machining the boxes refers to cutting three holes in a plastic electrical box. Holes were for: a motion sensor, a light and the on/off switch. All of these holes were cut using the computer numerical control (CNC) machine in the engineering machine shop at the University of Akron with assistance from Mr. Dale Ertley (Senior Engineering Technician). In order to work with Mr. Ertley on the CNC machine and safely be in the lab, group members needed to complete online training modules. The minimum requirement to work in the lab was 14 modules. To use the CNC machine there were an extra 5 modules specific to the CNC interface. Of the five group members, four completed at least the 14 modules needed to work in the lab. These training modules were the first major delay in our production because we could not work on any of the boxes until the approximately 20 hours of training were completed per group member. After CNC machining, the switch and sensor hole needed to be filed down either manually or with a rotary tool to fit the switch and sensor properly. Both methods were utilized and four out of five

[1]http://www.instructables.com/id/Arduino-attendence-logger/?ALLSTEPS
http://www.instructables.com/id/Arduino-Controlled-Motion-Sensor/
http://www.instructables.com/id/LED-Matrix-with-Arduino/

group members participated. All boxes were completely machined by the second week in February 2016. We initially planned to have all boxes machined by the beginning of January (see Gantt Chart in Appendix E) but winter break, the training modules and other projects using the CNC machine delayed our schedule.

After machining, external housing and internal circuitry were completed and only assembly and connection of the power source were left to do on each unit. During the quality testing and code uploading, the board was powered by the attached computer supplying the code. Subsequently at this stage we switched from computer power to battery power. This was done by wiring a 9V battery to the board and interrupting the circuit with an on/off switch. The switch allows the hospital to turn each unit off from the outside when it is not in use to conserve power. These battery connections required two removable connectors (on one side they make a connection between the metal male end of the switch, and on the other side they clamp down on a wire making a lasting connection) and one soldering connection. Four group members completed at least one of these connections in order to learn the process. Before components could be mounted, the lighting dome, motion sensor and switch were inserted into their respective holes. The lighting dome and motion sensor were glued using a bathroom sealant and adhesive. The lighting domes were glued, held in place with clamps for 12 hours before moving. The motion sensors were glued on top of o-rings to make a liquid proof seal, and to lower the motion sensor below the edge of the box. If the motion sensor were to protrude from the plane of the box, the likelihood of it being accidentally activated dramatically increases. A liquid proof seal makes the unit more durable and able to be cleaned by the ED with a spray cleaner. In terms of mounting the components we chose to use nylon adhesive backed mounts. Each electrical component came from the manufacturer with at least four holes for mounting. The nylon mounts locked into these holes and on the reverse side adhered directly to the box. With adhesive backed mounts we avoided drilling into the box, and avoided using a mounting board which would reduce available vertical space. The group finalized the layout to maximize available space and to leave the Arduino board accessible for uploading new software. Lastly, all components were mounted to the boxes. Each group member mounted the parts for at least one unit. Zipties (Electriduct, Fort Lauderdale FL) were used to restrict wire movement and keep them out of the light path. Without zipties, the wires were visible through the dome and ruined the aesthetic cleanness of the design. Appendix B has solid works drawings of the box with holes and images of completed units with all of the parts mounted in place for reference.

Performance Testing/Battery

As mentioned previously, we made the decision to save the majority of testing until after assembly was completed. Some tests had to be run before assembly, for instance testing the code and verifying each unit was functional. The tests we planned to run after completion were power calculations on the battery, a drop test, usability test and a test with the cleaning solution the hospital will use on the units. This plan was interrupted because the week we delivered all of the units to Akron General, we discovered the 9V batteries we selected, did not last 12 hours and the hospital was expecting them to last for weeks. The initial customer requirement for battery life was a month, and we believed the 9V battery would meet this requirement with no trouble, but we did not test the system to prove so. The belief that a 9V battery would be sufficient existed due to a lack of understanding in the group caused by inexperience with the consumption of electrical systems and battery capacities. Because we chose to alter the design process and not run tests and power calculations prior to assembling units, we did not catch this fundamental error and ended up wasting time and resources. If we would have not altered the design process, this mistake would have been caught before assembling any units.

Discovering the batteries would not live up to customer expectations halted our progress because we have to backtrack and replace the 9V battery. For the past three weeks all of our focus has been on finding a battery with ample capacity to meet the new required duration. After we informed Akron General of the mistake, they told us the absolute minimum battery life is one week; therefore a week became our new customer requirement (Appendix D). Our first step was then to assess how much power the system was consuming. We did this with a voltmeter and found that the LED pulls a huge amount of current when it is lit. We first looked for ways to reduce the power consumption like not utilizing the whole LED matrix, and reducing the LED intensity. Leaving some of the matrix unlit saves immensely on power consumption, while not adversely affecting LED visibility. However reducing the intensity did cause a visible difference and the light was difficult to see from a distance in a well lit room. We were able to reduce the current draw from 320mA to 155mA when the LED is lit up; which is over a 50% reduction in current draw on the component consuming the most power.

After the initial consumption reduction, we completed power calculations (see Appendix C) and based on those, we are aiming to have a battery capacity of 20,000mAh. We can give a minimum and maximum timeframe for battery life, but in reality the battery will last somewhere in between the two. The actual battery life will depend on how long it takes staff members to respond to the light coming on. Without being able to perform a usability test at Akron General before implementing batteries, we are conservatively estimating it will take staff members an average of 30 minutes to respond to and to turn the light off each time it comes on. From the power calculations in Appendix C you can see 30 minutes of the light left on corresponds to 7.4 days of life for a 20,000mAh battery, 5.5 days of life for a 15,000mAh battery and 3.7 days for a 10,000mAh battery. Akron General can replace the batteries at most every week, so we have to use a 20,000mAh battery to meet their requirement. The 20,000mAh battery is still a slight overestimate because the power calculations assume each ED room is operating at full capacity 24/7. We know the EMlighten units will not be on 24/7, but we and the client would rather overestimate then adjust a maintenance schedule based on a usability study, rather than have the batteries die too quickly.

When researching to find a 20,000mAh battery to fit this application, we were balancing cost with size and quality. Generally speaking cheaper batteries are larger and of more questionable quality, whereas more expensive batteries can be smaller and of a higher quality. We want to provide the best product for Akron General within a reasonable budget. Therefore for our first attempt at reaching a 20,000mAh capacity, we chose to buy two smaller 10,000mAh batteries and connect them together to reach 20,000mAh. The batteries fit within the boxes we already have constructed, and we were able to successfully connect them. However all of the batteries we were considering have a voltage output of 5V, so connecting two in series bumped up the voltage of the system to 10V. The higher voltage of the circuit increased the current draw significantly, and we no longer met the customer requirement. The increased consumption of the system meant the two batteries connected in series will only last for 5.1 days assuming the light is left on for 30 minutes each cycle; compared to the life of 7.4 days with only one 20,000mAh battery running the system at 5V. In addition to the battery life, we also learned the two 10,000mAh batteries were manufactured in China. After speaking with our instructors, we learned lithium ion batteries manufactured in China and sold at a lower price and quality are prone to catching on fire. The hoverboard (Hoverboard Technologies, Mountain View CA) batteries which have been making headlines for catching on fire did so because they were poor quality lithium ion batteries.

The requirements we were then left with were using one 20,000mAh battery, a relatively small battery size because of the space available in each box, and ideally a battery made in the United States of America. Back to researching, the only batteries meeting these three requirements are significantly more expensive than we were expecting to pay. We identified an ideal battery from Anker with a capacity of 20,100mAh. This battery is currently on sale on Amazon for approximately \$40. Anker's website (https://anker.com) also mentions their willingness to reduce price for bulk orders and for educational applications. We reached out to Anker in an attempt to negotiate a better price for the batteries as we are students ordering 35. Anker responded and was unable to offer us any break in price. So we presented the cost breakdown to Akron General with the \$40 batteries and it was approved. Batteries and parts to mount them in the boxes as well as charging cords were purchased online from Amazon on April 19th, 2016. The parts arrived April 22nd, 2016 and we started fixing the units the next day

Future Work

Now that we have the parts, we must complete and deliver the units to Akron General before graduation on May 15th, 2016. Ideally we will have the 35 units finished before finals week (May 9th – 13th) in order for group members to focus on final exams and papers. Each unit needs to be gutted and components rearranged and reattached to make room for the battery. This 20,100mAh battery is much larger than the original 9V we planned for, so all of the components have to be rearranged to make space for the Anker battery. This gutting and re-layout of each unit is what we are doing now. The adhesive backed mounts are not easy to remove and have to be carefully pried up without damaging any electrical components. We are using another assembly line process to finish the units, and group members are working in the lab during their free time.

The one other part of the design we do not have completed at the time of this report is the logo. Akron General ideally wants an “EMlighten” logo on each unit as well as an Akron General/Cleveland Clinic logo. Additionally we want to have a symbol to show staff members where to wave cards to activate the RFID chip for when the units switch from motion sensor activation to RFID activation. After researching cost and availability during the first week of April, a trial set of logos was purchased on April 11th, 2016 from VistaPrint. The logos stick well and do not peel off easily. But before ordering more we need client approval which we are currently working on getting.

When all of the units have been completed and delivered to Akron General, we are going to provide them with all of our software codes and information regarding the project. The codes will be at their disposal to manipulate and change the timing of the units as they see fit after usability tests in the hospital environment. All additional information provided, we expect to be used after the proof-of-concept study. Installing the units for the first time and seeing how they work will most likely reveal improvements which could be made to the system. If the system looks promising, we expect Akron General to come back to UA next year to partner with another senior design group and make second generation improvements. Examples of these improvements are data transmission over WiFi, further reducing system power consumption, and combining components to reduce space. By giving Akron General all of our information we hope to accelerate their work with future senior design groups.

Reflection

This senior design project was geared toward learning the design process, interacting with a client, practicing time management skills, working together as a team, and being challenged technically. I believe the EMlighten project has taught me all of these things as well as many more. We made a huge mistake in how we approached the design process in a trial and error manner, allowing the client to dictate the timeline and not following the traditional design process. We have all learned firsthand why this is a mistake, and now we are in the process of trying to rectify the error. The backtracking is not pleasant, but it is what has to happen in the real world when mistakes occur. Akron General has been very understanding of the battery problem, but we are still experiencing dealing with an unhappy customer and trying to mend and maintain that relationship. Technically, we picked an electrically heavy project and only have one group member in the biomedical engineering instrumentation track. So the rest of the group has learned a significant amount of technical information and skills. Overall if we were to do the project again, things would definitely be done differently to avoid our mistakes and the issues we are now facing. But the complications are what have forced us to learn and adapt so they have still been beneficial.

Appendix A: Brainstorming Tables

Alerting Mechanism 1: Signal Type						
Signal Option	**Signal needs to be effective over a long distance away from the system. Allows signal to be registered by busy staff far away from patient rooms.**	**Signal needs to have a low disruption level. The ED enviroment is already chaotic, our system shouldn't make that worse.**	**Feasibility of design; the alpha version needs to be designed and built before spring semester. An overly complicated signal won't fit into this timeline.**	**What does the client want to have? They're paying for the units so they have a major say in this decision.**	**Has to integrate into the existing ED environment and way patients are monitored.**	**Overall Score**
Auditory: alarm or beep	2	1	5	1	5	14
Visual: light	4	5	5	5	4	23
Digital: app, computer program, etc.	5	5	1	4	1	16

Alerting Mechanism 2: Visual signal display						
Display Option: Color	**Ideally would have multiple color options. Buying lights which can be more than one color.**	**What does the client want?**	**Needs to catch staff attention.**	**Need the color to be visible but not associated with a different meaning.**	**Overall Score**	
Red	5	5	5	2	17	
Green	5	4	4	2	15	
Blue	5	4	4	4	17	
White	1	5	3	4	13	
Display Option: Beam type	**Ability to grab staff attention.**	**Needs to not cause annoyance to patients or staff.**	**Combined effect of 30+ units needs to not be a major annoyance.**	**Ability to represent the few depressed rooms in the ED.**	**What does the client want?**	**Overall Score**
Steady	4	5	4	3	5	21
Strobe/Flashing	5	1	1	5	1	13
Display Option: Intensity	**Ability to provide the most information possible to staff at a glance.**	**Easy to train staff on how to use.**	**Feasibilty of integrating into our code in the accelerated timeline.**	**What does the client want?**	**Overall Score**	
Steady	3	5	5	5	18	
Intensity changes as time passes	5	4	2	4	15	
Display Option: Light Hardware	**Option to swith between colors if needed.**	**Want to use the least amount of wiring possible to save space in our circuit.**	**Lowest cost is ideal.**	**Want to have flexiblity with the amount of light produced.**	**Easily measureable voltage consumption.**	**Overall Score**
Individual Bulbs	5	1	2	4	2	14
LED Matrix	5	5	4	1	5	20

Method to Reset Alert Mechanism 1: Methods										
Method Option	Easy to train staff (is it intuitive?), this is one of the major requests from the client.	Should be specific to staff members. Don't want patients or family members reseting the system.	Should be hands off to be as germ free as possible. Want to reduce infection/bacteria spread, or at least not make it worse.	Needs to be durable and hold up over multiple resets by potentially angry or rushed staff.	Has to integrate into the existing ED environment and the room designs, (curtain rooms).	Want to have potential for data transmission in the beta design.	Want to minimize accidential activation. Should be activated only by a deliberate action or decision.	Want method to be as easy as possible for staff, we don't want to add extra work to their already full load.	What does the client want to use?	Overall Score
Doorway motion sensor (similar to a security system)	4	1	5	5	1	1	1	5	1	24
RFID (Radio Frequency Identification Device Badging in/out)*1	5	5	4	5	5	5	5	4	4	42
Mechanical ("tap" light, asked for by the client)	5	2	1	2	5	1	5	3	5	29
Localized Motion Sensor/PIR Sensor (similar to an automatic soap dispenser)*2	5	2	5	5	5	1	3	4	5	35
RFID over a longer distance (works like the door motion sensor but with RFID tags)	4	5	5	5	1	5	2	5	1	33

*1 presented this to the client as our best option, but they only wanted to do RFID for the beta design
*2 decided with the client this is the next best option and simple, so a PIR sensor is being used for the alpha design

Method to Reset Alert Mechanism 2: Method Location on System External Interface						
Alpha: PIR Sensor	How intuitive is this location?	Will all staff members be able to access this location?	Ability to minimize accidental activation.	Want simple manufacturing, does this location require additional housing?	Needs to be easily accessed by staff members.	Overall Score
Front of system	5	5	1	5	5	21
Top of system	3	4	5	5	4	21
Bottom of system	4	5	4	2	4	19
Beta: RFID Reader	How intuitive is this location?	Will all staff members be able to access this location?	Need to minimize accidental activation.	Want simple manufacturing, does this location require additional housing?	Needs to be easily accessed by staff members.	Overall Score
Front of system	5	5	5	5	5	25
Top of system	3	4	5	5	3	20
Bottom of system	1	5	5	5	4	20

Internal Electrical Components 1: Type of Open Source Circuit						
Circuit Brand	Technology group members have used before and have some experience coding.	Free software download	Units are relatively inexpensive.	Popular in the community, lots of tutorials of similar projects.	Has size options if we need to bump up to more in/out-puts.	Overall Score
Arduino	5	5	5	5	5	25
Tiny Circuits	2	4	4	4	3	17
Any other brand	1	?*	?*	?*	?*	1

*decided because we already had experience with Arduino searching for a better alternative wouldn't be a good use of time with our accelerated schedule

Internal Electrical Components 2: Size of Arduino				
Arduino Size	Has enough in/out-put channels for the alpha design.	Estimate of if it will have enough in/out-put channels for beta design.	Units are relatively inexpensive.	Overall Score
Mega*	5	5	4	14
Uno	5	3	5	13
Mini	3	1	4	8

*decided to plan ahead for the beta design so we don't need to buy all new internal and external components

External Housing Components 1: Manufacture of housing					
Manufacturing Option	**Cost effective option. Need to keep in mind will need ~35**	**Time it takes for part to arrive after ordering. Want this to be as short as possible.**	**Repeatable to find and order. If client wants to make more units after graduation.**	**Multiple options of dimensions and materials if plans change.**	**Overall Score**
Pre-made (order something being mass produced by company)	5	5	4	5	19
Designing and manufacturing our own unique housing	2	2	3	3	10

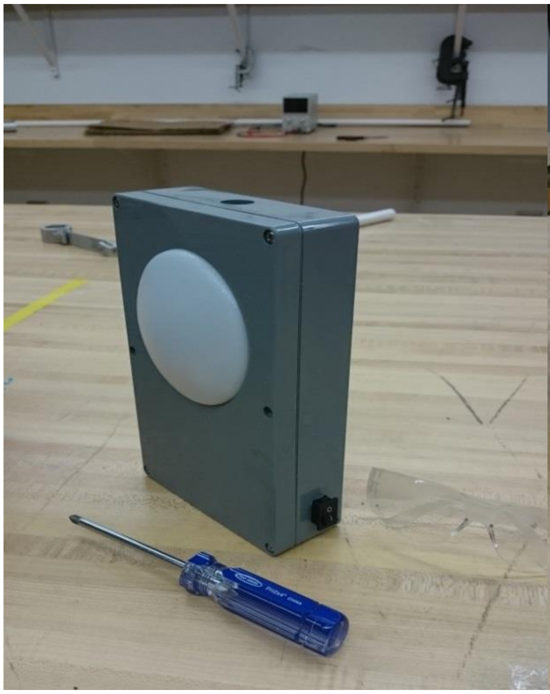
External Housing Components 1: Material of housing								
Material Option	**Cost effective.**	**Availability of parts and different box sizes.**	**Fits well in the environment of the ED. No sharp corners.**	**Durable material, needs to withstand bumps and wiping down with antiseptic.**	**Weight, a lighter box will be easier to mount.**	**Ability to incorporate a logo in a beta design.**	**Ability to vent heat away from electrical components. Don't want the circuitry to overheat and fail.**	**Overall Score**
Metal*[1]	4	5	1	5	2	5	4	26
Plastic*[2]	3	3	5	5	5	4	3	28

*[1] initially we purchased a metal box because we were worried about heat generation, and we had trouble finding plastic alternatives

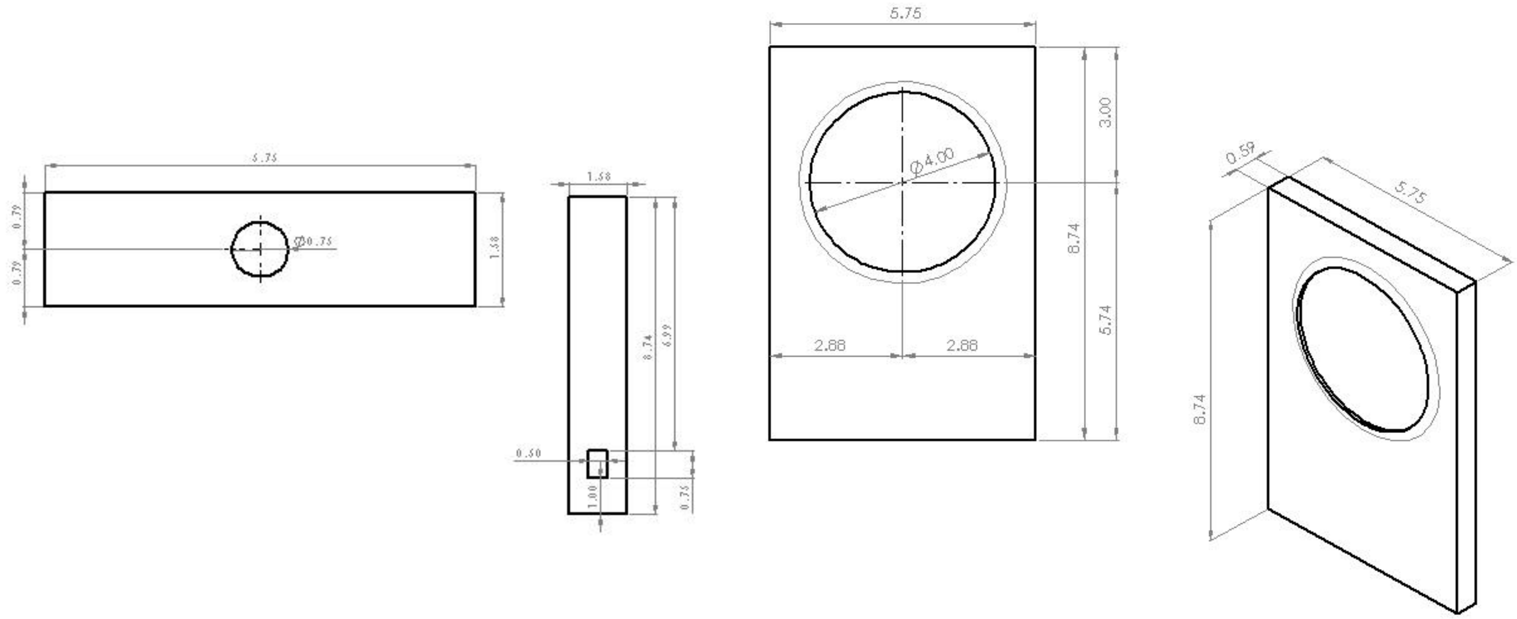
*[2] switched to plastic as an because heat production is not a problem and plastic better meets the client's environmental needs

Appendix B: Drawings and Photos

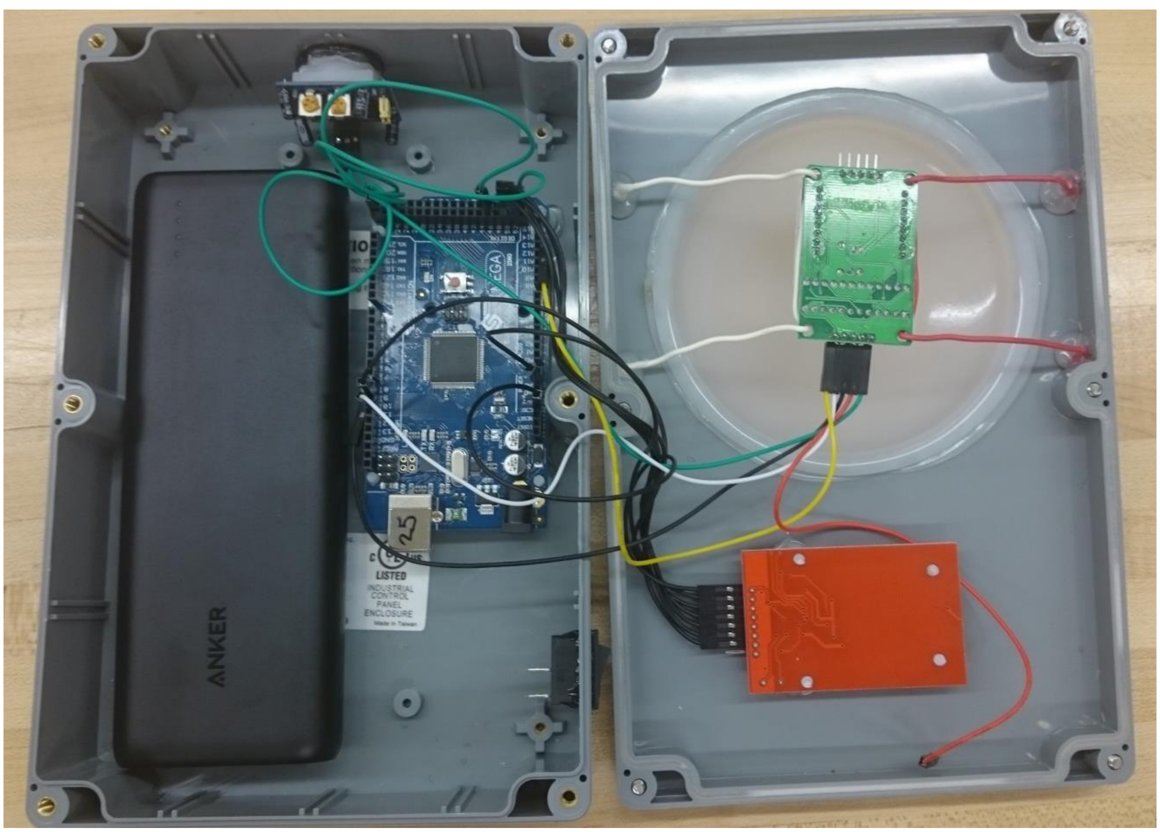
Physical Unit



SolidWorks Drawings: Body and Lid



Physical Unit Inner Layout



Appendix C: Power Calculations

Senior Design Battery Calculations 20,000 mAh Battery
Portable Charger costs anywhere from $20 - $100. We found one for $20 and have ordered one to test.
battery life (h) = battery capacity (mAh) / device consumption (mA)

@ 15 brightness and half LED consumption = 155mA									
LED left on (min)	cycle time (min)	Total Hrs in a Week	Hrs/week LED on (h)	LED off consumption (mA)	LED on consumption (mA)	capacity needed for one week of battery life (mAh)	battery capacity (mAh)	total battery life (h)	total battery life (days)
0% MINIMUM	20	168	0	50	155	8400	20000	400	16.7
5	25	168	33.6	50	155	11928	20000	281.7	11.7
10	30	168	56	50	155	14280	20000	235.3	9.8
15	35	168	72	50	155	15960	20000	210.5	8.8
20	40	168	84	50	155	17220	20000	195.1	8.1
25	45	168	93.3	50	155	18200	20000	184.6	7.7
30	50	168	100.8	50	155	18984	20000	177	7.4
35	55	168	106.9	50	155	19625.5	20000	171.2	7.1
100% MAXIMUM	never cycles	168	168	50	155	26040	20000	129	5.4

@ 11 brightness and half LED consumption = 128mA									
LED left on (min)	cycle time (min)	Total Hrs in a Week	Hrs/week LED on (h)	LED off consumption (mA)	LED on consumption (mA)	capacity needed for one week of battery life (mAh)	battery capacity (mAh)	total battery life (h)	total battery life (days)
0% MINIMUM	20	168	0	50	128	8400	20000	400	16.7
5	25	168	33.6	50	128	11021	20000	304.9	12.7
10	30	168	56	50	128	12768	20000	263.2	11.0
15	35	168	72	50	128	14016	20000	239.7	10.0
20	40	168	84	50	128	14952	20000	224.7	9.4
25	45	168	93.3	50	128	15680	20000	214.3	8.9
30	50	168	100.8	50	128	16262	20000	207	8.6
35	55	168	106.9	50	128	16738.9	20000	200.7	8.4
100% MAXIMUM	never cycles	168	168	50	128	21504	20000	156	6.5

Senior Design Battery Calculations 15,000mAh Battery
Portable Charger costs anywhere from $20 - $100.
battery life (h) = battery capacity (mAh) / device consumption (mA)

@ 15 brightness and half LED consumption = 155mA									
LED left on (min)	cycle time (min)	Total Hrs in a Week	Hrs/week LED on (h)	LED off consumption (mA)	LED on consumption (mA)	capacity needed for one week of battery life (mAh)	battery capacity (mAh)	total battery life (h)	total battery life (days)
0% MINIMUM	20	168	0	50	155	8400	15000	300	12.5
5	25	168	33.6	50	155	11928	15000	211.3	8.8
10	30	168	56	50	155	14280	15000	176.5	7.4
15	35	168	72	50	155	15960	15000	157.9	6.6
20	40	168	84	50	155	17220	15000	146.3	6.1
25	45	168	93.3	50	155	18200	15000	138.5	5.8
30	50	168	100.8	50	155	18984	15000	133	5.5
35	55	168	106.9	50	155	19625.5	15000	128.4	5.4
100% MAXIMUM	never cycles	168	168	50	155	26040	15000	97	4.0

@ 11 brightness and half LED consumption = 128mA									
LED left on (min)	cycle time (min)	Total Hrs in a Week	Hrs/week LED on (h)	LED off consumption (mA)	LED on consumption (mA)	capacity needed for one week of battery life (mAh)	battery capacity (mAh)	total battery life (h)	total battery life (days)
0% MINIMUM	20	168	0	50	155	8400	15000	300	12.5
5	25	168	33.6	50	155	11928	15000	211.3	8.8
10	30	168	56	50	155	14280	15000	176.5	7.4
15	35	168	72	50	155	15960	15000	157.9	6.6
20	40	168	84	50	155	17220	15000	146.3	6.1
25	45	168	93.3	50	155	18200	15000	138.5	5.8
30	50	168	100.8	50	155	18984	15000	133	5.5
35	55	168	106.9	50	155	19625.5	15000	128.4	5.4
100% MAXIMUM	never cycles	168	168	50	155	26040	15000	97	4.0

Senior Design Battery Calculations 10,000mAh Battery
Portable Charger costs anywhere from $10 - $80.
battery life (h) = battery capacity (mAh) / device consumption (mA)

@ 15 brightness and half LED consumption = 155mA									
LED left on (min)	**cycle time (min)**	**Total Hrs in a Week**	**Hrs/week LED on (h)**	**LED off consumption (mA)**	**LED on consumption (mA)**	**capacity needed for one week of battery life (mAh)**	**battery capacity (mAh)**	**total battery life (h)**	**total battery life (days)**
0% MINIMUM	20	168	0	50	155	8400	10000	200	8.3
5	25	168	33.6	50	155	11928	10000	140.8	5.9
10	30	168	56	50	155	14280	10000	117.6	4.9
15	35	168	72	50	155	15960	10000	105.3	4.4
20	40	168	84	50	155	17220	10000	97.6	4.1
25	45	168	93.3	50	155	18200	10000	92.3	3.8
30	50	168	100.8	50	155	18984	10000	88	3.7
35	55	168	106.9	50	155	19625.5	10000	85.6	3.6
100% MAXIMUM	never cycles	168	168	50	155	26040	10000	65	2.7

@ 11 brightness and half LED consumption = 128mA									
LED left on (min)	**cycle time (min)**	**Total Hrs in a Week**	**Hrs/week LED on (h)**	**LED off consumption (mA)**	**LED on consumption (mA)**	**capacity needed for one week of battery life (mAh)**	**battery capacity (mAh)**	**total battery life (h)**	**total battery life (days)**
0% MINIMUM	20	168	0	50	128	8400	10000	200	8.3
5	25	168	33.6	50	128	11021	10000	152.4	6.4
10	30	168	56	50	128	12768	10000	131.6	5.5
15	35	168	72	50	128	14016	10000	119.9	5.0
20	40	168	84	50	128	14952	10000	112.4	4.7
25	45	168	93.3	50	128	15680	10000	107.1	4.5
30	50	168	100.8	50	128	16262	10000	103	4.3
35	55	168	106.9	50	128	16738.9	10000	100.4	4.2
100% MAXIMUM	never cycles	168	168	50	128	21504	10000	78	3.3

Senior Design Battery Calculations 2X 10,000mAh batteries in serie
Portable Charger costs anywhere from $12
battery life (h) = battery capacity (mAh) / device consumption (mA)

@ 15 brightness and 39 LEDs on, consumption = 218mA										
LED left on (min)	**cycle time (min)**	**Total Hrs in a Week**	**Hrs/week LED on (h)**	**LED off consumption (mA)**	**LED on consumption (mA)**	**capacity needed for one week of battery life (mAh)**	**battery capacity (mAh)**	**total battery life (h)**	**total battery life (days)**	**compared to one 20,000mAh battery**
0% MINIMUM	20	168	0	78	218	13104	20000	256	10.7	16.7
5	25	168	33.6	78	218	17808	20000	188.7	7.9	11.7
10	30	168	56	78	218	20944	20000	160.4	6.7	9.8
15	35	168	72	78	218	23184	20000	144.9	6.0	8.8
20	40	168	84	78	218	24864	20000	135.1	5.6	8.1
25	45	168	93.3	78	218	26171	20000	128.4	5.3	7.7
30	50	168	100.8	78	218	27216	20000	123	5.1	7.4
35	55	168	106.9	78	218	28071.3	20000	119.7	5.0	7.1
100% MAXIMUM	never cycles	168	168	78	218	36624	20000	92	3.8	5.4
*In order to last a week, the light can only be on 5-10 mins compared to just one 20,000mAh battery where the light can be on 35 mins.										
*Current draw goes up with batteries in series because the voltage goes up too.										

Appendix D: Customer Requirements

Customer Requirements			
Project Start		**Project Finish**	
Required	**Desired**	**Required**	**Desired**
Catch staff attention in well lit hallway	Rechargable batteries	Catch staff attention in well lit hallway	Rechargable batteries
Set to reliable timer	On/Off switch	Set to reliable timer	Battery charging station
Easy and intuitive to operate	Adjustable timer on unit	Easy and intuitive to operate	Lid secured while removing battery
Battery operated (no cords)	WiFi transmission capability	Battery operated (no cords)	*WiFi transmission capability*
Aesthetically pleasing	Data push to Excel	Battery lasts one week	*Data push to Excel*
No sharp corners	Data tracks employees	Hospital able to change code	*Data tracks employees*
Battery lasts one month	Data push logs time light left on	No sharp corners	*Data push logs time light left on*
Requires effort to reset timer		Hospital able to change timer	*Adjustable timer on unit*
Low profile mounted on a wall		Aesthetically pleasing	
		Low profile mounted on a wall	
		Requires effort to reset timer	
		On/Off switch	

Legend
High Priority
Medium Priority
Low Priority
Our group is not attempting to meet this criteria before graduation

Appendix E: Gantt Chart

To see the whole Gantt Chart we have to scroll through multiple screens in the GanttProject software. Every task is posted below in three screenshots as if we were scrolling through the Gantt Chart vertically. Color coordination corresponds to the people completing the listed task. The first section of lines is a legend: Nicole – purple, Emily – green, Lexie – red, Angel – yellow, Mike – dark blue, Everyone – bright light blue, More than one person but not the whole group – dull light blue. We did our best here to include all quantifiable tasks and responsibilities with their respective timelines.

Name	Begin ...	End date	People
Alpha Unit	8/31/15	5/20/16	
Nicole	9/1/15	5/13/16	
Emily	9/1/15	5/13/16	
Lexie	9/1/15	5/13/16	
Angel	9/1/15	5/13/16	
Mike	9/1/15	5/13/16	
Everyone	9/1/15	5/13/16	
Part of the Group	9/1/15	5/13/16	
School Related	8/31/15	5/13/16	
Problem Definition	8/31/15	9/16/15	Everyone
First Draft of NABC	9/4/15	9/9/15	Everyone
Gantt Chart	9/7/15	5/13/16	Nicole
Assemble Binder	9/10/15	5/13/16	Nicole
Second Draft of NABC	9/11/15	9/18/15	Everyone
MOU	9/16/15	9/30/15	Emily
Mission Statement	9/21/15	9/23/15	Nicole
Sell Sheet	10/1/15	10/2/15	Emily
Problem Statement	10/2/15	10/2/15	Emily
Final Draft of NABC	10/5/15	10/5/15	Everyone
Project Proposal 1	10/15/15	10/19/15	Nicole
Project Proposal 2	11/6/15	11/16/15	Lexie
Second Draft of Missi...	11/9/15	11/16/15	Angel
Block Diagrams	11/18/15	11/30/15	Everyone
Final Project Proposal	11/30/15	12/7/15	Everyone
Spring Project Propos...	2/5/16	2/9/16	Everyone
Spring Project Propos...	3/28/16	4/4/16	Lexie and Nicole
Redo Engineering Req...	4/1/16	5/6/16	Everyone
Redo Customer Requi...	4/1/16	5/6/16	Everyone
Redo Testing protocol	4/1/16	5/6/16	Everyone
Final Project Proposal	4/1/16	5/6/16	Everyone
Final Project Presentat...	4/25/16	5/13/16	Everyone
Prototype Related	8/31/15	5/20/16	
Design Concept	8/31/15	9/18/15	Everyone
First Client Meeting	9/4/15	9/16/15	Everyone
Research Arduino Sets	9/11/15	9/18/15	Everyone
Research type of light ...	9/18/15	10/16/15	Everyone
Establish who is on ho...	9/18/15	9/18/15	Everyone
Brainstorming Housing	9/25/15	10/30/15	Everyone
Write code for Arduino	10/1/15	10/30/15	Lexie
Create Logo	10/1/15	10/2/15	Emily
Pick Arduino Set to us...	10/2/15	10/9/15	Everyone
Second Client Meeting	10/14/15	10/14/15	Everyone
Test PIR and RFID Sen...	10/15/15	10/23/15	Lexie
Solidworks Drawing	10/16/15	11/16/15	Emily
Brainstorming testing	10/16/15	12/31/15	Everyone
Pick Light (LED Panel)	10/16/15	10/23/15	Everyone
Establish PIR as sensor	10/16/15	10/16/15	Everyone
Research on Housing	10/16/15	10/30/15	Mike
Research on Light Co...	10/16/15	10/30/15	Nicole
Research on Training i...	10/29/15	11/6/15	Emily
Training in Lab	10/30/15	12/31/15	Everyone
Research Mounting	10/30/15	11/30/15	Everyone
Order Housing	11/2/15	11/5/15	Everyone
Order Light Cover	11/2/15	12/4/15	Emily
Have holes punched i...	11/6/15	11/16/15	Everyone
Third Client Meeting	11/9/15	11/10/15	Everyone
Bulk Order Supplies	11/10/15	11/30/15	Lexie
Assemble Prototype	11/16/15	12/15/15	Everyone
New Logo	11/16/15	11/30/15	Everyone
Research Battery Indic...	11/18/15	11/30/15	Everyone
Updated Solidworks D...	11/18/15	12/7/15	Emily
Research Switches	11/23/15	12/4/15	Everyone
Comment Code	11/23/15	11/30/15	Lexie
Assemble Circuitry for...	11/23/15	12/11/15	Everyone
Find New Housing Unit	12/1/15	12/8/15	Nicole
Punch Holes in Facepl...	12/1/15	12/30/15	Everyone
Punch Holes in Box	12/1/15	12/30/15	Everyone
Plan Layout of Electric...	12/2/15	1/29/16	Emily
Assemble Prototype	12/15/15	1/22/16	Emily and Nicole
Fourth Client Meeting	1/15/16	1/15/16	Everyone
Order Bulk Housing	1/15/16	1/15/16	Lexie
Finalize Design	1/15/16	1/22/16	Everyone
35 Units Assembled	1/18/16	2/26/16	Everyone
Test Code at Diff Tim...	1/20/16	1/21/16	Nicole
Punch Holes in Housi...	1/22/16	2/12/16	Everyone
Update Solidworks Dr...	1/25/16	2/15/16	Emily
Test all Electrical Com...	1/28/16	2/15/16	Lexie and Nicole
Glue Domes	1/29/16	2/15/16	Nicole
Solder Battery Compo...	2/5/16	2/19/16	Emily
Upload 1 Minute Cod...	2/8/16	2/25/16	Lexie and Nicole
Test 35 Units with Code	2/25/16	2/26/16	Everyone
Upload 20 Minute Co...	2/29/16	2/29/16	Lexie and Nicole
Test 35 Units with Code	3/1/16	3/4/16	Lexie and Nicole
Test Battery Consump...	2/29/16	3/3/16	Mike
Brainstorm New Batte...	3/3/16	3/17/16	Everyone
Research Portable Ph...	3/14/16	3/25/16	Nicole
Research Microcontro...	3/15/16	3/28/16	Angel
Test 20000mA Battery	3/17/16	3/18/16	Emily and Mike
Test 10000mA Battery	3/28/16	4/6/16	Emily and Mike
New Box Design for 1...	3/29/16	3/31/16	Emily
Test new 20000 mA B...	4/1/16	4/13/16	Emily and Mike
Order Bulk Batteries	4/1/16	4/19/16	Emily, Nicole, and Mike
New Box Design for 2...	4/5/16	4/8/16	Everyone
Test different LED hol...	4/5/16	4/28/16	Emily and Angel
Order Logos	4/11/16	4/19/16	Emily
Meet with Client	4/13/16	4/13/16	Emily, Nicole, and Mike
Upload Chip Identities...	4/13/16	5/6/16	
Test Logos	4/19/16	4/19/16	Emily
Research new logos	4/19/16	4/26/16	Nicole
Reassemble 35 units	4/19/16	5/13/16	Everyone
Order New Logos	5/2/16	5/10/16	Everyone
Test Reassembled units	5/2/16	5/13/16	Lexie and Nicole
Deliver Final Units	5/10/16	5/13/16	Everyone
Deliver New Logos	5/16/16	5/20/16	Everyone