Argus: Indoor Tracking for First Responders

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Abstract— The problem we are solving is that of indoor tracking. This is in response to the Worcester fire that occured back in 1999 in which several firefighters died due to one being lost, while others went back into the building and failed to find them. Our solution is using sonar sensors, a pedometer, and the buildings blueprint in order to track someone inside on a digital representation of the building from a base station. The device will have to be small and light as to not interfere with firefighters abilities. The system includes a Locator, Base Station, and a Pedometer. Both the Locator and Pedometer send measurements of distance to walls, walking distance, and orientation to the base station. The base station uses this data to calculate the position of a person. This map will then be replicated on an application for a smartphone.

I. Introduction

Indoor tracking has been a problem that many people have tried to solve. The main reason we are trying to face this problem is because of firefighter safety. In one incident back in 1999 there was a fire at the Worcester cold storage and warehouse. The layout of the building was very confusing and the firefighters themselves were unfamiliar with it. There were reports that people may be trapped inside so firefighters went in to search for them. One firefighter became trapped inside and the others went to try to find and save them. Since they did not know where he was trapped or the layout of the building, the result of the incident was that several firefighters died [2].

Many others have tried to resolve this issue of indoor tracking. Some solutions in today's time include GPS, beacons, RFID systems. There are several problems with these solutions though. GPS is not accurate enough because the signals can be easily obstructed when indoors [10]. Beacons were used by a previous SDP team [7]. After analyzing their design, we could see issues involving heavy infrastructure being put in place prior to any emergency. Several beacons needed to have line of sight on the target to get a reading. Beacons use signal strength to calculate distance which is not reliable. RFID systems are very accurate and used in equipment tracking[9]. They do not work in emergency situations though because the tags that are placed on equipment could be compromised in a fire and therefore become useless.

The specifications of our project were determined after our interview with professional firefighter Gabe Chapley. When talking with Gabe he said that firefighters already carry a good amount of equipment when going into a fire, stating it is about fifty pounds of equipment. That being the case it was determined the device could be no more than five pounds as to not add a large amount of extra weight to them. Also the device could not occupy a large amount of room as it would interfere with firefighters movements and actions. The range of the device is two hundred and fifty feet from the Locator to the base station. This is needed for our demonstration in Marcus Hall since the building is two hundred and fifty feet long. The connection will need to have a ninety-five percent uptime from the Locator to the base station otherwise too much data will be lost and we can't accurately and confidently say where a person is located. Also while talking with Gabe we asked about how long an emergency situation lasts. He said they go between one to two hours. The specifications and values can be seen in Table 1.

Requirement	**Specification**	**Value**
Portable	Weight	< 5lbs
	Size	< 0.5 cuft
	Battery powered	2hr between charges
Responsiveness	Data transfer	<5% packet loss
	Range	>= 250ft
	Accuracy	within 1ft

Table 1: Specifications

II. Design

A. Overview

The solution that we have come up with is using ultrasonic sensors, a pedometer, and the building blueprint to create a System to help navigate a building and keep track of location.The pedometer gives us step data and tells us how far we have traveled. It also gives the orientation of the Locator so that we know which direction it is traveling in. The blueprint will give us measurements of the buildings rooms and hallways. This will be used with the sonar sensors to give more precise measurements of where the Locator is within a room or hallway.

Other alternatives that we have researched were lidar sensors that use light to get measurements instead of sound waves. One positive aspect of lidar is that it has a long range, narrower cone for object detection, and a higher polling rate. However in our scenario with firefighters, light would be obscured within smokey buildings and create inaccurate readings.

The block diagram for our system can be seen in figure 2. The Locator collects the distance from walls and sends it to the base station. This is the part of the device that specifically will be less than five pounds and half a cubic foot. The Pedometer collects step and orientation data which is sent to the Locator and then to the Base Station. The base station takes in this data and determines an output on the digital map. The connection between the base station and Locator will lose no more than five percent of data sent. The phone will have an application that replicates the map that the base station displays.

B. Power Consumption

So our device needed to last two hours minimum and when testing our device we found that it pulls 433mA of current so we would need a battery that had at least double that capacity. The battery we have chosen for our device has a capacity of 2750mAh and stays above the minimum voltage of seven volts required to run the device at peak performance for about four hours. Using two of these batteries in series provides the seven volts we need for the device. The rate of consumption can be seen in figure 1 [1]. The device also needs to be accurate within a foot so we are able to tell which side of the wall we are on since walls are not more than a foot thick.

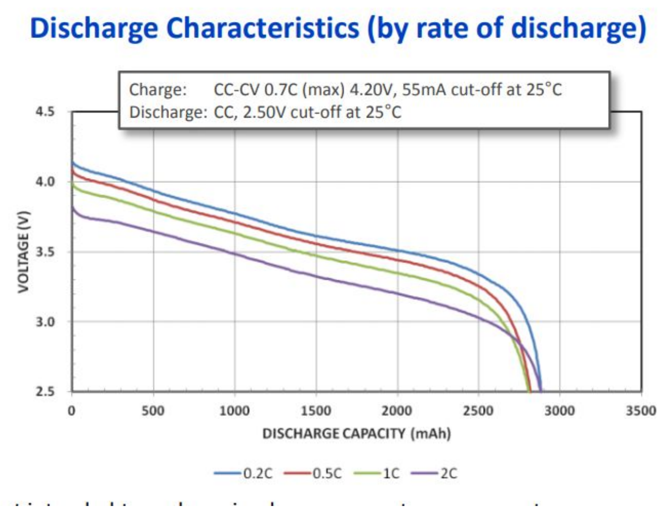

Fig. 1 Rate of consumption of our device is roughly 0.2C (C is the discharge rate compared to its maximum capacity, a 1C discharges the battery in 1 hour) so the graph shows the device will stay above 3.5V for about 4 hours. [1]

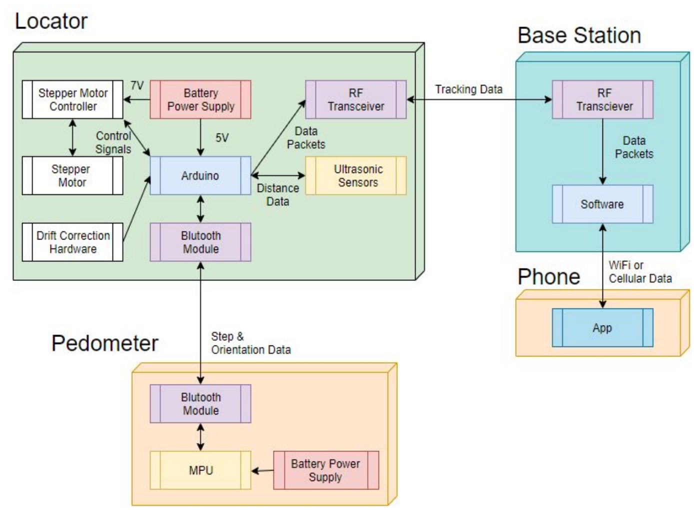

Fig. 2 System Block Diagram

C. Locator

The Locator subsystem is what is responsible for collecting the data from both the ultrasonic sensors and the pedometer and sending it to the base station. This subsystem as of MDR is mounted on top of a 6.5’ pole, to simulate being on a person's head. At the heart of this there will be an ATMEGA328-PU [8] microcontroller, and its job is to take the data collected, do a small amount of local processing, and send send the data packets to the base station via RF communications.

The ultrasonic sensor that were picked for this project were the Maxbotix LV-Z3 [3] because of its favorable characteristics. For taking in its measurements, it has a range of about 20', and the cone of which objects are detected is narrow compared to other sensors, about a 60cm diameter cone. On top of this, it can be sampled at 20Hz, and with two of these atop a rotating platform, we have flexibility in collecting the data. The reason we want a narrow cone for object detection is to try and only measure the distance to a wall and nothing else. This narrower cone decreases the probability of measuring the distance to "obstacles".

With these two sensors in mind, we have them mounted on a rotating platform. This platform was made with the inspiration of a SLAM (simultaneous localization and mapping) device, recommended to us by Shira Epstein. The two major components to our DIY SLAM device was a ball bearing and a slip ring. The slip ring is a device that allows an electrical connection to be maintained in spinning use cases, and for us it in mounted in the center of the rotating platform as seen in Fig 3.

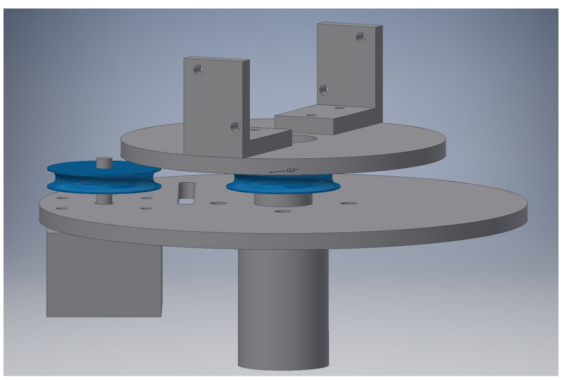

Fig 3. Mechanical assembly of Locator

With our rotating platform made using 3D printing, we chose to use a stepper motor [11] to control the rotation. This was done for the ability to move the sensors to any angle accurately. An issue that came up from this design was every rotation the platter would seem to drift by a few degrees. Although the problem was never identified, we added a photoresistor [12] and an LED [13] to fix this. The LED was attached to the stationary bottom platform and the photoresistor on the rotating platter. The stepper motor will rotate normally for 335 degrees, then on the last 45 it will move one step at a time until the photoresistor was overhead the LED. This is determined by an analog in pin on the ATMEGA328-PU. This can be seen in Fig 4.

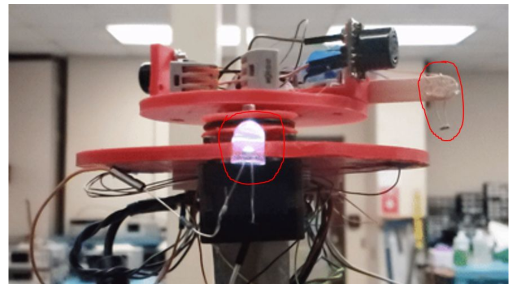

Fig 4. *Picture of drift correction hardware*

For the communication of data between the subsystems, there are currently two types in place. There is a Bluetooth connection between the Pedometer and the Locator for transmitting the step and angle data. This was chosen because the Pedometer will always be in range of the Locator, and will use less power. Next, a RF Transceiver [14] will be used to transfer the complete data packet between the Locator and the basestation. The final product has not been chosen yet, as we have been working toward getting the tracking part of the project working first. For CDR we plan to have at least the bluetooth communication working.

D. Base Station

Once data has been gathered by the Locator, it is sent to the Base Station, a computer powerful enough to run the python scripts that we have written; i.e., a laptop. Here the data is processed and fed into algorithms which calculate an absolute position based off of the pre-initialized blueprint.

Additionally, the Base Station contains a script that takes a text file of ones and zeros representing the blueprint, and generates an efficient list of walls that are contained in this blueprint. The script then outputs this list to a text file so that it can later be used by the primary base station code. This process is done separately because in order to make high resolution maps (one digit per square inch), the computation must be long and intensive. This means that it makes more sense to do that computation just once per blueprint and then reuse the results over and over.

The script processing the data must first read from the data.txt file generated by the Locator and Pedometer, and then store all of the sensor data from the pedometer and the ultrasonic sensors into the structure that the code can process. Then, the current position is updated based on the step and orientation information received by the pedometer. Then, the map is updated with all of the ultrasonic sensor data, in accordance with the new position. All of this is then displayed to the graphics panel in addition to the walls which were previously generated with a separate code. The initial position and orientation can be pre-set, but must be manually input.

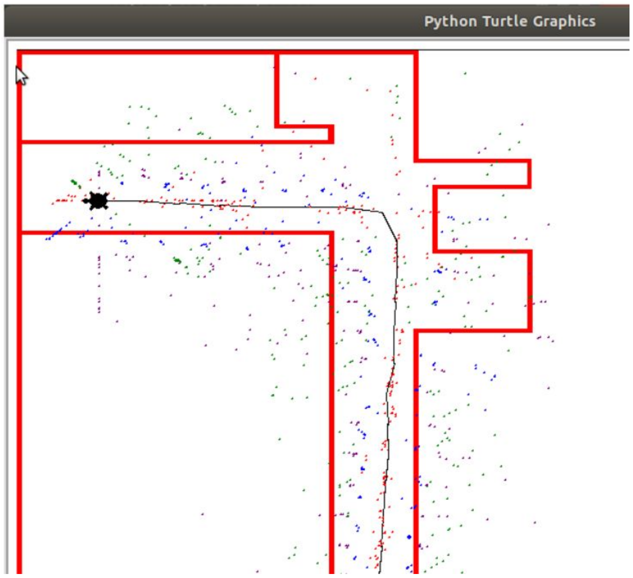

Fig 5. Output display of Base Station

The scripts on the Base Station utilize the efficiencies of object oriented coding as taught in Intro to Java. Two objects, Locations and Walls, have been created not only to simplify the code and make it more efficient, but also to allow for a more robust and expandable structure. with these objects in place, we can easily access a list of walls with detailed attributes, or we can find out all there is to know about a particular location.

In addition to these objects, the code includes several data structures and optimized search algorithms that were taught in our Data Structures class. A digital map is created using nested lists, and is traversed on several occasions using techniques harnessed and practiced in ECE 242.

Further testing and data accumulation must be done before the synchronization issues between the Base Station and the Locator are fully eradicated. Unfortunately, as the capabilities and function of the Locator changes, so must the Base Station change in order to meet these new specifications.

Additionally, the algorithms on the Base Station must become more complex and robust so that they can accommodate a successful data fusion between the Locator and Pedometer data. There will need to be lots of research and development in order to figure out when and in what way to take some data instead of others. For this reason, the team is considering using machine learning algorithms to increase the Base Station's ability to interpret the data. We hope that these algorithms might help eliminate error from tilt, or perhaps even allow us to get rid of false data points. We realize that while we are currently taking data from eight different directions, only a few of those directions will be worth taking at a time. For this reason, we are looking into figuring out how to best decide when to take data from one direction and not another.

In order to test this block we must use the graphics interface as our tool to calculate effectiveness. Although it may not be the most accurate tool. It is quick and provides many troubleshooting opportunities. To truly test this block, several tests will need to be done with different room sizes and shapes as well as several unique walking paths. currently there is a small amount of information that we can get from testing this block--either it works or it doesn't; but as the code matures, there will need to be lots of testing along the way

E. Pedometer

The pedometer block will increment a step counter for tracking linear movement. It will also keep track of orientation, to determine in which direction this movement is taken. This information is extremely valuable, as when given a starting point, we can know where the user goes from that point.

To gather this information, an IMU called the MPU-6050 [6] is used. This device uses an accelerometer and gyroscope together, to collect acceleration and orientation data. This is done by attaching said IMU to the user's foot, and sending walking data collected to the Locator's microcontroller for additional processing. Figure 5 displays how we place the pedometer prototype on the user's foot.

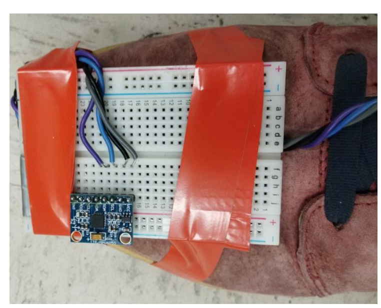

Fig 6. Pedometer fixture

Taking the Maker Space Design Project course (ECE 297DP) greatly helped with designing algorithms on the arduino. In the future when we switch to a new microcontroller, no doubt the knowledge from Computer Systems Lab I & II (ECE 353 & 354) will be helpful as well. Figure 5 displays how we place the pedometer prototype on the user's foot.

To count steps, a simple counting algorithm has been implemented. Using the IMU's gyroscope, pitch is calculated and monitored to observe a walking pattern. When the user takes a step, the foot is angled, raised up, then lands flat. By watching for this pattern on the pitch axis, steps are accurately calculated. To monitor orientation, again the IMU's gyroscope is utilized. This time, yaw is monitored, which may effectively track orientation when placed flat on the user's foot. By tracking this information, we know which direction steps are taken, and when significant turns have been made. For example, when a user takes a left turn at the end of a hallway, a 90 degree change in orientation is expected.

For the future, we must learn how to make the most robust algorithms possible for accurate tracking. Currently, we've based the algorithms off data collected by primarily one person. To make the device more robust, an experiment must be conducted on the pedometer by different sized subjects. Walking patterns must be observed at different strides to get an idea of how the data behaves. Converting this raw data to statistical data may allow for a percentage, or an average based pedometer. By doing this, we could produce a pedometer which accurately tracks steps no matter the user's stride.

F. Phone application

The phone application is a stretch goal for us if we complete the functionality of the primary device first. What this would be is an application that firefighters can use on their phone to see a layout of the building similar to the base station. The application would be able to show each firefighters individual location on the map. It could also give directions to certain areas based on where the base station tells them to go.

III. Project Management

Track Locator in building hallway	🟢
Tracks walking straight and turning corners	🟢
Base station will show movement progress	🟡
Base station will display walls, open space, and tracker	🟢

Table 2: MDR Deliverables

Our team has accomplished a ton of goals throughout the semester. So far our progress has been making a mechanical fixture to simulate the device being on top of a person's head, making a program that can process the data collected from the Locator. Moving forward, our team needs to work on advancing our data processing algorithm program. Currently it runs slower than expected, and because of this it can not be run in real time of the person being tracked.

Starting this project was a very slow process for our team, mostly stemming from our uncertainty of our capabilities and our benchside meetings being somewhat demoralizing. Once we got the ball rolling on our project, things went pretty smoothly. Work on the project was being done almost daily right up until the point of MDR. We first started with building both the mechanical design and the data processing program in parallel, so that once the mechanical portion was done we could start analyzing data right away. For the mechanical design, many prototypes were made as one would be made, but we saw where we could improve it right away. Having the slow start contributed to us not having enough time to fully finish our MDR deliverables, and if we had been more confident in the beginning we could have made a more complete MDR product.

The team has been working well with each other along this process, but there have been some issues regarding time conflicts and time commitment. Once we had figured everything out, We had split the work according to each person's strengths. Since Logan had just worked an internship as a mechanical engineer over the summer, he worked on the mechanical design and integration of electronics on the Locator. Aaron has always coded quick and efficiently, so he took up the task of doing the base station. Zach has a plethora of experience with embedded systems, so he helped a lot with some finishing details of the Locator and making the pedometer. Matt was able to help fill any gaps, since he was an EE major then switched to CSE, giving him an edge with the fusion of hardware and software.

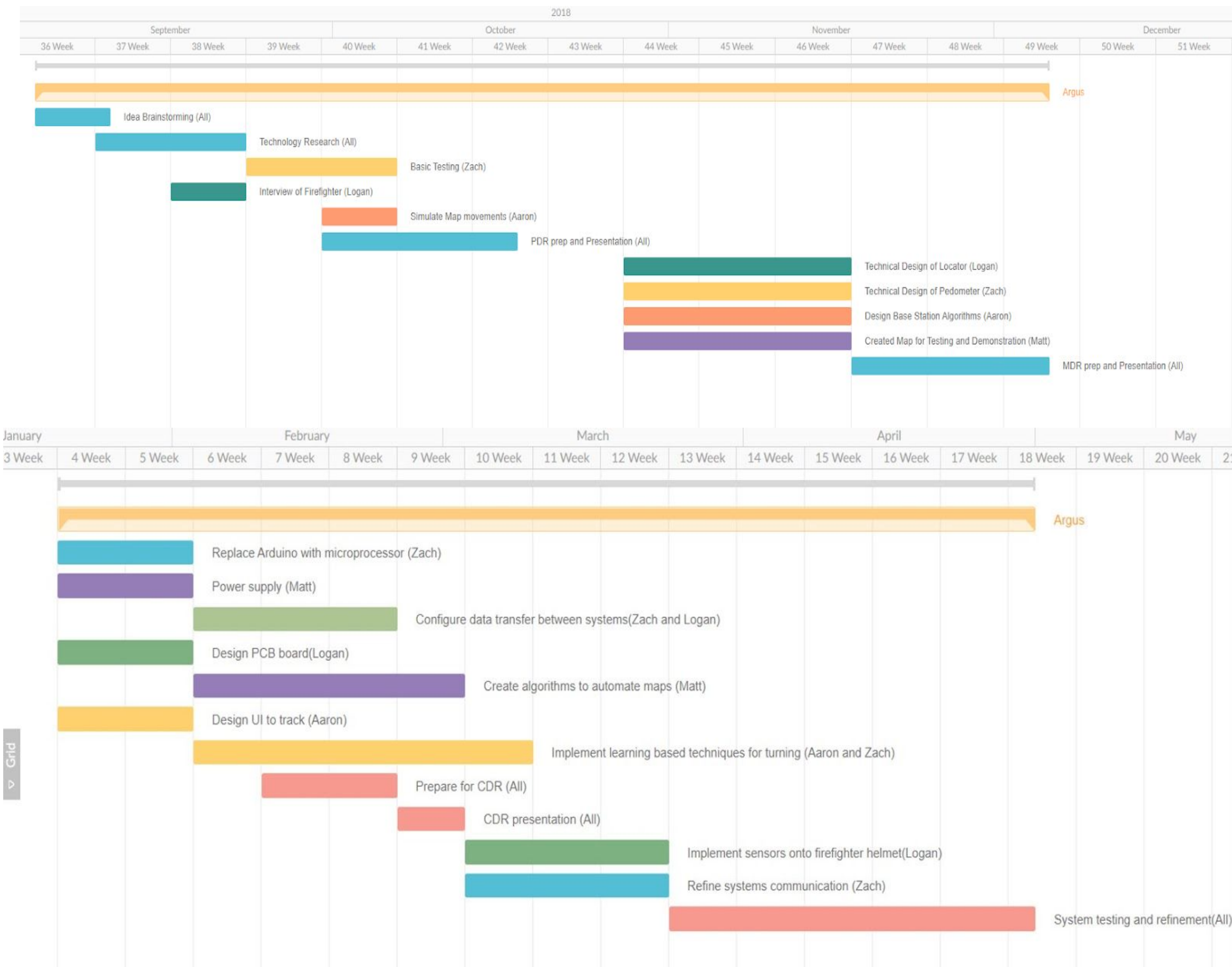

Fig. 7 and 8: Gantt chart for pre and post MDR

IV. Conclusion

Currently the Argus tracking system is far from complete. Getting to this point has been a journey of data collection & analysis, mechanical prototyping, and algorithm design. Many devices we thought we'd use at the beginning were tested, and found to be unsatisfactory, which led back to testing new devices. This circle of prototyping was time consuming, but also a journey of immense learning. The result of which, is a device which uses step and orientation data to track the user's movement, along with ultrasonic data to visualize walls and other obstructions.

From here, the primary goal is fusing the data collected by the pedometer and tracker. Currently both devices collect data, and both are used together to display movement, but neither device directly influences the other. By implementing data fusion and learning algorithms, the devices may help correct each other when some data sets are favorable over others. This would not only increase tracking accuracy, but allow for optimal visualization when tracking the user at the base station. This will undoubtedly be a difficult task, as it is like nothing our group members have done before, but if achieved, it will launch Argus towards the finish line.

In addition to data fusion, wireless communication between the pedometer and Locator, as well as the Locator and base station, must be implemented. Currently, all devices communicate through hard-wired, serial communication. This has been ideal for testing with minimal variables, but for CDR wireless communication is critical. It is important the success of Argus that wifi isn't required, so a radio frequency communication system is desired. Variables like packet loss will surely be a factor between the base station and Locator. Wall penetration capabilities will be weighed against range and data carrying capacity when we search for communication devices. All this variables will surely cause difficulties, and must be monitored during testing.

To help achieve our goals, our gantt chart laid out in project management will be followed. Enough time has been given to each task to ideally accommodate for foreseen and unforeseen difficulties. These difficulties will be handled by extensive testing of each subsystem, and ensuring any fixes we make still meet our initial project specifications.

Acknowledgment

We would like to thank the following individuals for contributing to our progress: Professor Irwin, for offering advice on wireless communication and data fusion; Professor Siqueira, for suggestions on power analysis and the kalman filter; Gabe Chapley, for sharing is experience as a firefighter; and Professor Goeckel, for encouraging, guiding, and supporting us throughout project development.

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