Argus: Indoor Tracking for First Responders

Matthew Delude, CSE. Logan Emerson, EE. Aaron Linz, CSE. Zachary Little, CSE.

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. Table 2 shows the specs that were our goal for FPR.

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

No larger than ½ cubic foot & no more than 5 lbs	🟢
Retain 95% of the data sent over XBee devices	🟢
Accurate up to +/- one foot 95% of the time	🟡
Operate for minimum of 2 hours	🟢
At least 250ft Range	🟢

Table 2: FPR Specs

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.

In our MDR report we included a stepper motor in our design. It was used to obtain more angle points so we could take in more data points and measurements. After extensive testing we realized that points of data that were on an angle did not give accurate or useful data. So the stepper motor was removed from the final design. This allowed for more accurate readings of walls and a decrease in power consumption.

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]. Now in our final prototype we have removed the stepper motor and so the device only pulls 100 mAh of current so the uptime has increased to about 8 hours for our device.

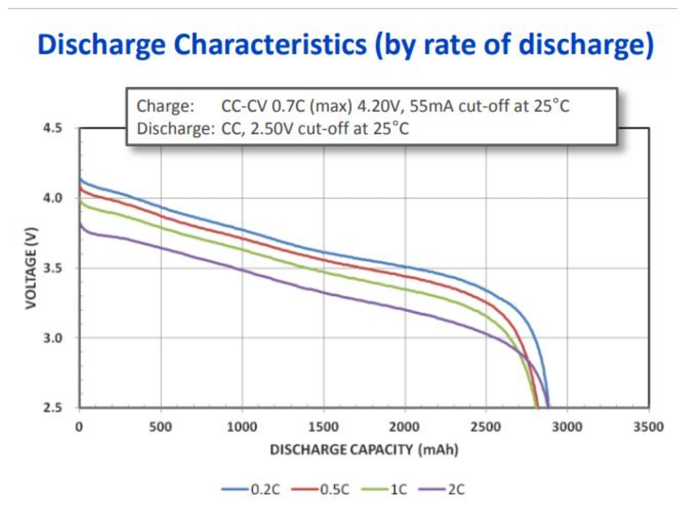


Fig. 1 Rate of consumption of our device is roughly 0.2C (C is the discharge rate compared to its maximum capacity, a 1C discharges the battery in 1 hour) so the graph shows the device will stay above 3.5V for about 8 hours. [1]

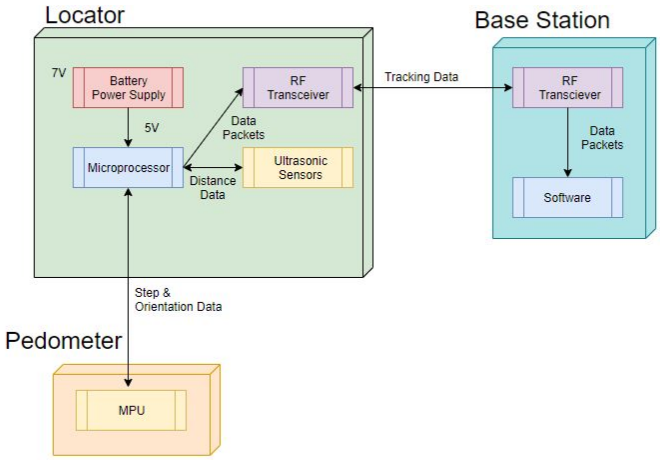


Fig. 2 System Block Diagram

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.

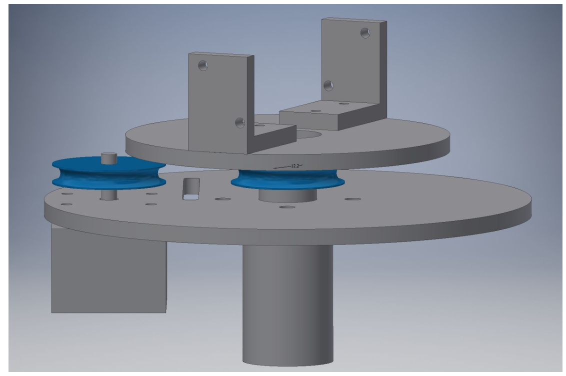


Fig 3. Mechanical assembly of Locator

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.

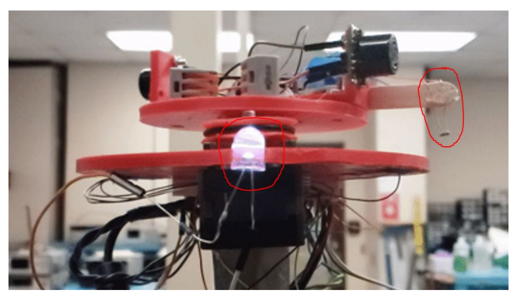


Fig 4. *Picture of drift correction hardware*

In our final design, the use of the spinning platter with the sensors affixed atop was removed. This decision came about from our testing, as when the sensors were spinning, the distance points had a large spread. When the spinning was stopped, the spread went down drastically, increasing the confidence in our reading to use in our correcting algorithms. See figure 5 below to see the difference between the two. What is important to look at in this figure is the purple dots down the left and right of the hallway, which represent the left and right ultrasonic data sensor data.

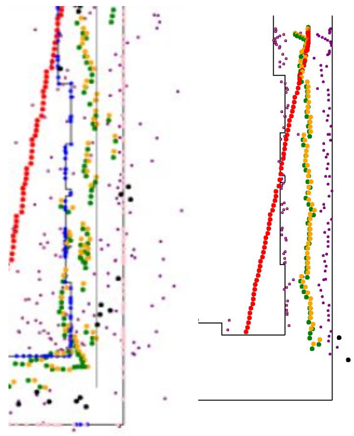


Figure 5: Comparison of Spin vs No Spin

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.

Moving into FPR we moved the design from being on the pole as a prototype, to a real helmet that very closely resembles what a firefighter might wear. The final assembly of the project can be seen below in Figure 6. The design is sleek, with all the electronics hidden on the inside, with the ultrasonic sensors sticking out the sides to get the readings. On the back of the helmet is the antenna for the RF Transceiver, which in our case is a XBee Pro XSC. This choice is transceiver was made with some knowledge from field and waves (ECE333), where i knew that a lower frequency would give us less attenuation through the concrete wall, increasing our maximum distance. One aspect that was left out when we moved forward was the bluetooth, as when faced with some challenges, we decided to go against it for the mean time to try and alleviate a time crunch we were in. This meant that for our final design, we still had a cable running down from the helmet to the shoe. Moving forward, we would have wanted to tackle this issues again to make that connection wireless.

Figure 6: Finalized design on helmet

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 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.

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

Now the Scripts on the Base Station have been updated and can be run in live mode instead of reading from the data.txt file. The serial bit stream is read in through the USB port directly to the python script which then processes the data.

The processing of the data has also gotten considerably more complex. Before, the algorithm would simply display the location that was calculated by the angle of the IMU and the step count. Now, the algorithms take into consideration the sonar-sensor data and the digitized list of walls in order to correct the calculated location.

Additionally, a new graphics library is in use called TKinter. While this graphics library is considerably faster and more robust, it is also more difficult to implement. Nonetheless, with the new graphics, we can reduce the time it takes to draw the map from fifteen seconds, to less than one second, with only a slight drawback of suboptimal graphics display frequencies.

The following figure 7 shows the display that is generated by the python scripts. The red line represents the location that would be calculated without this correction algorithm, and the green line represents the position that is calculated with our correction algorithm.

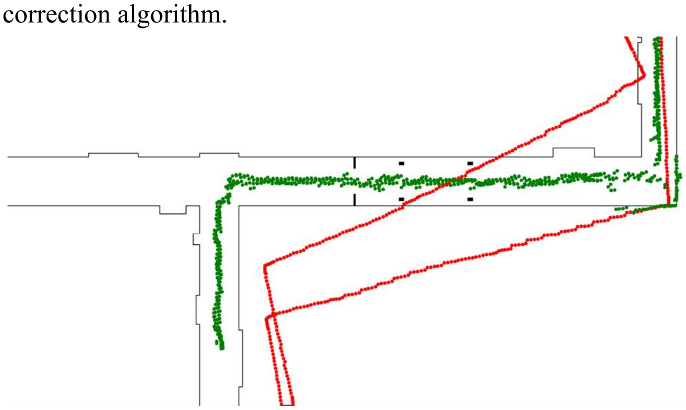


Fig 7. Output display of Base Station

What this figure shows, aside from the graphics interface itself, is the importance of these correction algorithms in fixing the drift that is inherent in the IMU.

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 any 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.

After a great deal of testing and a strong rewriting of some major parts of the code, we were able to get rid of all the synchronization issues between the base station and locator. By using live mode, we can stall the base station code until a signal is received by the Xbee.

Additionally, the new correction algorithms have increased the accuracy of our base station dramatically. The following figure 8 represents the distribution of of error that we recorded from our calculated location (before the correction algorithms) and the ground-truth location.

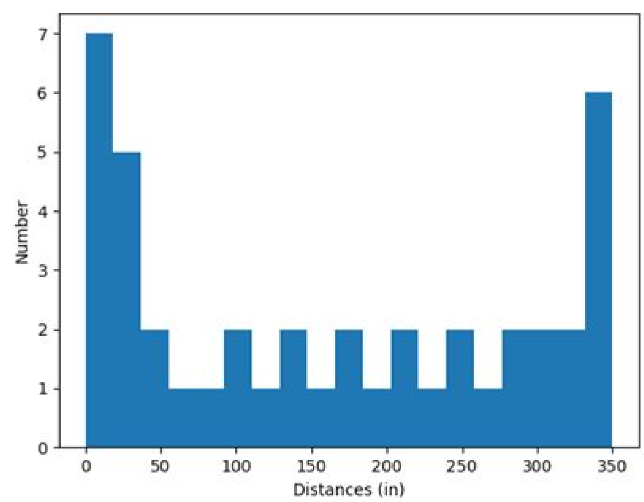


Fig 8. Error Distribution Without Sonar Correction

This distribution shows a huge margin of error, ranging between 0in and 350in with a mean value of 200in. The next figure 9 shows the distribution of error with the new correction algorithms, and we can see that with a range of 1in to 78in and a mean of 38in, we can see a dramatic improvement.

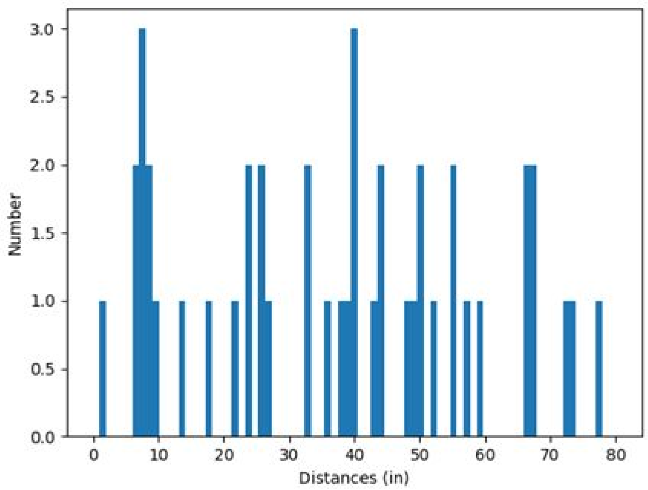


Fig 9. Error Distribution With Sonar Correction

Although we were unable to meet our system spec of accuracy within one foot, we were able to make a considerable improvement towards this goal.

With a bit more time, we would aim to have the correction work not only for the east and west directions, but also forward and back. This is something that we had not been doing because our sensors are often not able to reach the end of long hallways and that data would only cripple us if we were to use it for corrections. in addition to this, we found that the sonar data that was not pointing directly perpendicular to a wall, did not return an accurate value. Despite all of these issues, if we were to use the forward and back correction, we would also be able to correct the step length issue of the pedometer. This would increase the accuracy of the system and make it far more robust.

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 bottom of the user's foot, and sending walking data collected to the Locator's microcontroller for additional processing. In figure 10, the IMU is fixed to the bottom of the shoe, with a plug on the side.

Fig 10. Pedometer fixture

Taking the Maker Space Design Project course (ECE 297DP) greatly helped with designing algorithms on the arduino and the knowledge from Computer Systems Lab I & II (ECE 353 & 354) has been helpful as well.

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.

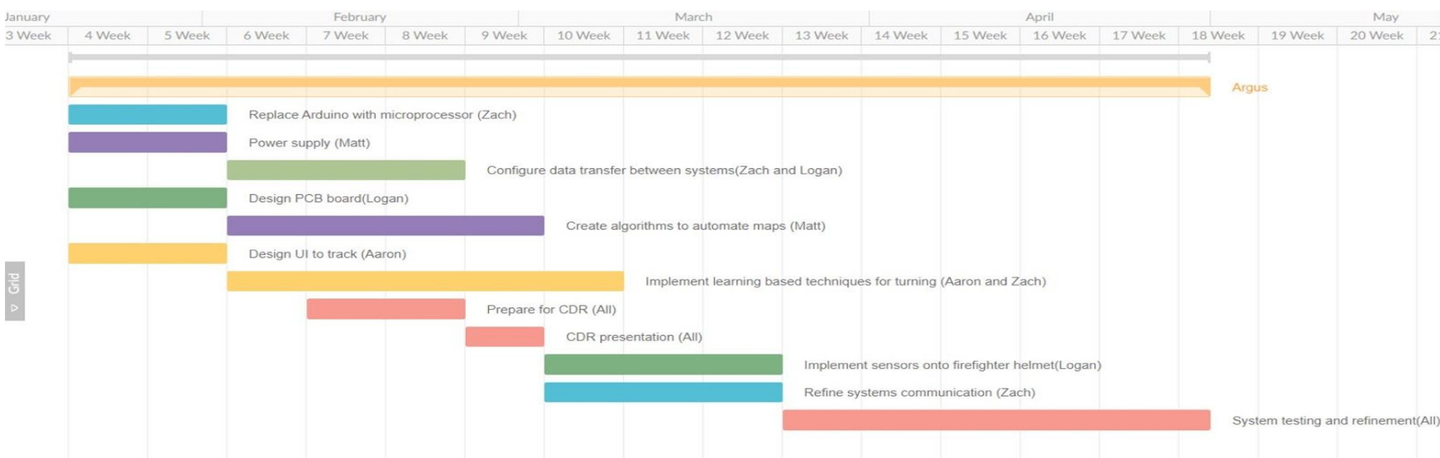
For future work, we could learn how to make the most robust algorithms possible for accurate tracking. Currently, we've based the algorithms off data collected by primarily one person's average stride. To make the device more robust, an experiment must be conducted on the pedometer by different sized 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. We wanted to implement these methods before FPR, but we needed to set the goal aside to work on more crucial features.

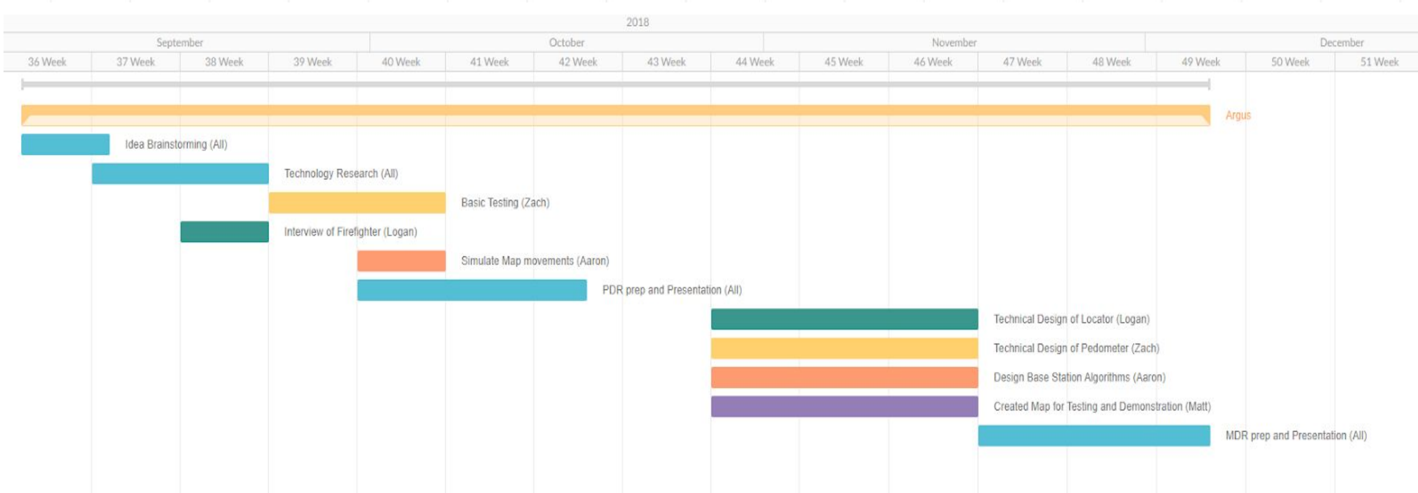
III. Project Management

Our team is quite proud of the final product. This project has been quite a challenge and we needed to adapt to the situations presented to us as we proceeded. For example, the goal was always to create a device that could be placed upon a helmet, however the further we developed the harder that goal seemed to be. It took a mechanical redesign to seamlessly integrate our hardware into a construction helmet. To do this, we had to rethink how the helmet unit gathered data, which was quite challenging and was the subject of much debate. But in the end, we had a simpler system which was much easier to work with, gather cleaner data and be more portable. Sometimes the team needs to take a step back before we could take two steps forward.

Significant project changes didn't always result in positive results. The team had a difficult time developing the project before the CDR presentation. This was due to many factors, mainly a combination of a lack of focus after winter break and the stress of job searching and interviewing. We also had some tough goals, like making out system wireless between the locator and base station, and locator and pedometer. Its at this time we learned making something wireless was not easy and involved a lot more work than anticipated. While we pushed through and implemented a wireless XBee network between the base station and locator, the same cannot be said about the locator and pedometer. We wanted to implement a wireless bluetooth connection, although it added a lot of complexity and risk for no significant features in return, besides a quality of life upgrade for the user. Before CDR, we decided to abandon the bluetooth connection goal and keep the pedometer wired to the locator. This is a prime example of the team banding together to face a hard fact and agreeing to proceed with other goals for the good of the project.

The team has worked together very well throughout the entirety of the project. We believe we found just the right mix of skills to meet our project needs. Logan was the brave solo EE of the group and without him the end product of the locator would not of been possible. Zac has a lot of embedded system experience so he could work well with both hardware and software. He designed the pedometer and refined the stepping algorithm while also assisting Logan with the locator. Aaron is very comfortable with software development and is responsible for the entire base station design. He created the algorithms which fused data received from the base station and displayed them over custom floor plan maps. Matt is responsible for all the maps and floor plans we tried and tested throughout the project. He would walk throughout buildings to gain measurements needed to create the custom floor plans for the base station.





IV. Conclusion

For our team, the Argus project is complete. What started as a vague idea in Professor Goeckel's office is now a functional indoor tracking system. As we said in our MDR report, is been a constant circle of prototyping and testing. We've gone from a spinning set of sensors and on 3-D printed platform on a pole, to a stationary system fully integrated into a construction helmet. Even though we didn't plan out this final helmet design, we're all very happy with how it turned out.

Though the team is very happy with the final result, there are certainly things we'd like to implement if we had more time. One major thing we'd want to do is make the pedometer and helmet connection wireless. This is something we wanted to do as early as CDR, however it turned into a huge hassle. It offered a host of complexities and risks to our project with no huge feature. With the pressure of other features, we abandoned the goal. However, knowing what we know now, it may be possible to find a simpler implementation. Another huge feature we considered for a while was a mobile app for the firefighter, or whoever would wear the helmet. This app would display the live updating position as seen on the base station. This would make the person being tracked a more active participant in the process, and give them valuable information just from a phone display. This was also a stretch goal for us, however we just didn't get to it due to more crucial features needing attention.

It is our hope that an SDP team next year may take up our project to implement some of those stretch goals. This project has huge potential, especially with the user wearing the helmet. Right now the helmet is completely passive, requiring no user input and just transmits data. Although if someone were to implement an app like we mentioned earlier, the user could tap buttons to indicate check points being reached, giving the base station valuable information. Instead of an app, there could be a series of switches or buttons for such things on the helmet. There could even be an augmented reality (AR) project here, augmenting the helmet to outline the floor plan in front of the user. As one can see, there are many possibilities for continued work on our project if a group is willing to try!

Overall, our team is very excited about the final product. We reached all but one of our final specs, with the accuracy spec not having a huge negative impact on the final result. The project has a lot to offer future SDP teams and other interested students as a great indoor tracking learning experience.

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.

References

[1] Panasonic Lithium Ion NRC 18650 battery data sheet https://engineering.tamu.edu/media/4247819/ds-battery-panasonic-18650ncr.pdf

[2] "Worcester Cold Storage and Warehouse Co. Fire." *Wikipedia*, Wikimedia Foundation, 21 Nov. 2018, en.wikipedia.org/wiki/Worcester_Cold_Storage_and_Warehouse_Co._fire.

[3] LV-MaxSonar-EZ Series Datasheet https://www.maxbotix.com/documents/LV-MaxSonar-EZ_Datasheet.pdf

[4] DIY LIDAR SLAM http://grauonline.de/wordpress/?page_id=1233

[5] Interview with Gabe Chapley, professional firefighter at Deerfield Fire Department

[6] Adafruit Industries LLC, "Adafruit MMA8451 Accelerometer Breakout", August 2013 [Revised August 2018]. https://cdn-learn.adafruit.com/downloads/pdf/adafruit-mma8451-accelerometer-breakout.pdf

[7] E-Pil Emergency Personnel Indoor Locator http://www.ecs.umass.edu/ece/sdp/sdp15/team21/

[8] ATMEGA328-PU Data sheet https://www.mouser.com/datasheet/2/268/Atmel-8271-8-bit-AVR-Microcontroller-ATmega48A-48P-1315288.pdf

[9] Indoor Localization with RFID https://www.infsoft.com/technology/sensors/rfid

[10] Indoor positioning system relation to GPS https://en.wikipedia.org/wiki/Indoor_positioning_system#Relation_to_GPS

[11] Polulu SY35ST26-0284A Stepper Motor https://www.pololu.com/file/0J690/SY35ST26-0284A.pdf

[12] PDV-P8103 Photocell 16-33kOhm https://media.digikey.com/pdf/Data%20Sheets/Photonic%20Detectors%20Inc%20PDFs/PDV-P8103.pdf

[13]10mm Super Bright White LED. 15000mcd http://www.mpja.com/download/15415op.pdf

[14] Parallax 433 MHz RF Transceiver https://drive.google.com/file/d/14YGz20Memf8iptmIGzNSfu_FK5peJIGW/edit