FINAL REPORT

3-D MARKERLESS MOTION CAPTURE AND POSITIONING SYSTEM FOR ACTIVE SHOOTER RESPONSE TRAINING

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1 OVERVIEW

1.1 Executive Summary

Our project was sponsored by the Texas State University ALERRT Center. The ALERRT Center upholds the national standard to provide the best research-based active shooter response training in the nation. The Center is free for police municipalities to attend, but that does not factor in travel and man-hour expenses, which can limit the training to well-funded municipalities. With a team made up of three electrical engineering undergraduate students, we set out to find a solution to allow for their active shooter trainings to be easily accessible to all police municipalities. Our project's goal is to help provide simple access for the scenarios the training entails.

We believe this goal can be obtained by virtualizing the ALERRT Center's training scenarios. To accomplish this, motion data will need to be collected from a Golden Standard – scenario's done by professional first responder(s) – and then rendered into a virtual or augmented reality environment.

This project is designed to be a multi-team, multi-year undertaking. Our focus of the project was based around laying the foundational layer, the motion capture system. This called for a prototype system that can be easily integrated into the ALERRT Center's existing equipment and work in a complex environment. Our final product is a user-controlled system based around a mobile application that allows for the capture of data in a three-dimensional (3D) plane for pitch, roll, and yaw – rotation side-to-side, rotation front-to-back, and rotation around the vertical axis. Ultimately, this system streamlines the access of raw motion data which allows us to visualize the orientation of the first responder's tracked movement. Future work can be done to mine additional data out, obtaining data points like trajectory and displacement of the responder.

1.2 Abstract

Active shooter response training is limited in availability to smaller municipalities due to budget and access. Our senior design project aimed to eliminate as many of these availability issues as possible through the development of a virtual representation of highly trained professionals delivering a Gold Standard performance of a live shooter scenario. Our system will capture the motion data and trajectory of the trained professionals as they navigate a live shooter scenario and record motion data at key locations such as the head, chest, and gun. In addition to capturing the data, the system allows the user to upload the data to a centralized location where it can be processed and prepared for a virtual recreation of the scenario. These virtual recreations can be used as training tools for all municipalities, enabling law enforcement everywhere to receive the proper training for these unfortunate events.

Contents

2 LIST OF FIGURES

3 LIST OF TABLES

4 PROBLEM DESCRIPTION

In the United States alone there has been a total of 336 mass shootings reported, since October 15th [1]. Municipalities are facing the trouble of not having enough funding to provide the resources for proper training. Many first responders are given the basic training, but it is not enough insight to how they should physically react to an active shooter(s) scenario. For this reason, we are designing a three-dimensional motion capturing system. This motion capturing system is to record movement from well-trained first responders who will be running through different response scenarios.

Figure 1 Mass Shootings – displays mass shootings within the U.S. in October of 2019.

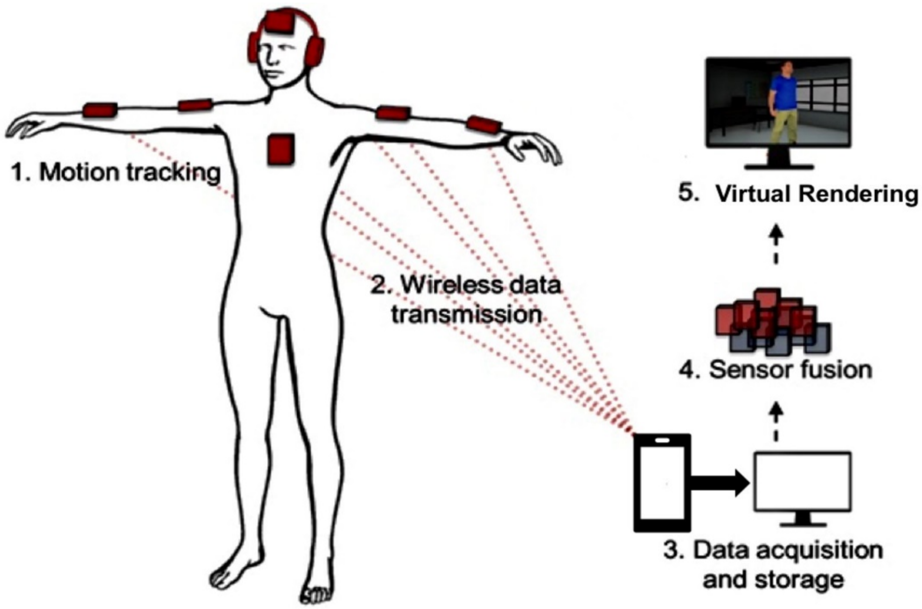

Figure 2 System Level Diagram – displays how the system operates as a whole

It should be noted, we designed the mobile application and integration of the system components. Some components, such as the sensor firmware, were open source items that were modified to achieve functionality in our design.

5 PROGRESS TOWARDS A SOLUTION

5.1 Design Decisions

Figure 2 illustrates our system design at a block level. Each bock is a carefully thought out design decision representing different subsystems of our project. This design implements considerations of a nonintrusive system, a simplistic user interface, and a crucial need for scalability. For the sensor subsystem, we chose to use inertial measurement units (IMUs) in place of attempting to wire cameras throughout the ALERRT Center's establishment. In doing so, we have not only saved cost on the implementation of a camera system but have created a system that can be scaled to other facilities outside a single building of the ALERRT Center. We made this design decision by accounting for both cost to the ALERRT Center and the need to be able to scale and reproduce our project in varying environments. By using IMUs we are not restricted to a single building to capture motion data, this greatly improves the reach of our product and extends the use to more than just the ALERRT Center. The user subsystem was chosen as a mobile device for the familiarity for the user, ease of use and abundance of devices, and most importantly to maintain a scalable product. The alternative to a mobile device would be to construct a small standalone piece of hardware to implement the required connect/start/stop functionality necessary for this project. However, the familiarity to the user would be nonexistent, the cost of constructing such a device with comparable functionality is much greater than that of a used mobile device, and system would be much more proprietary. Thus, the most desirable choice for this subsystem was to use a mobile device that localizes a system to the user and creates a tremendous amount of scalability for the project. The administrator subsystem was chosen as a personal computer (PC) because this is the most logical choice for data analysis and virtual recreation of a scenario. The administrator of the system will prepare the data for simulation using various software applications, none of which need be simplistic for user qualification purposes, as the administrator will be an on-site engineer.

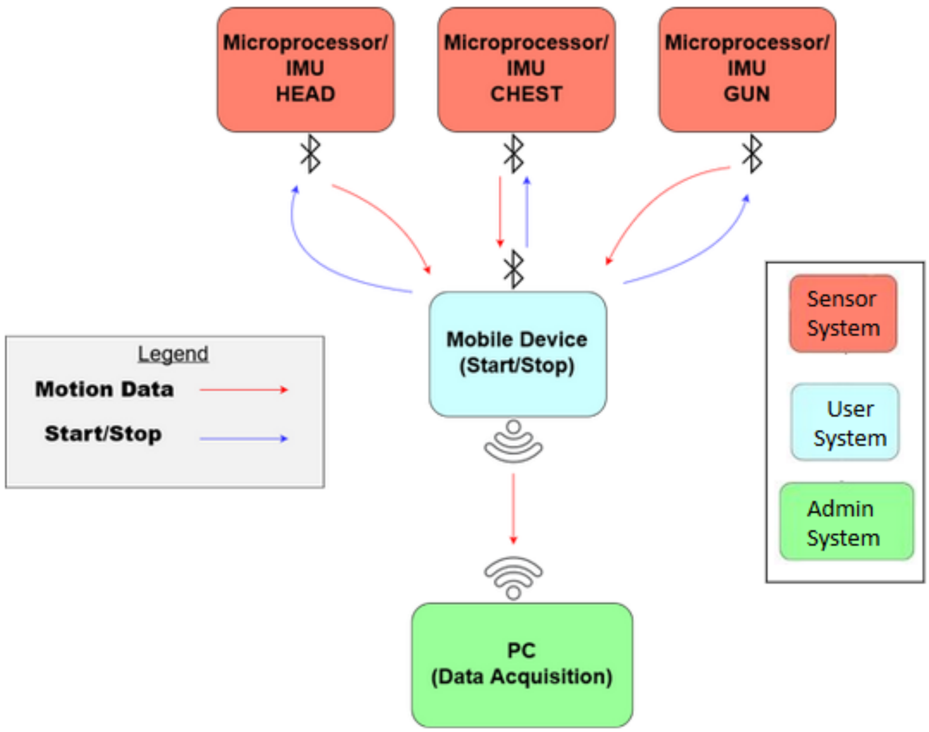

Figure 3 Functional Diagram – depicts each functional block of the design and relationship between them

5.2 Design Approach

A top-down approach was used to design our system. We first determined the overall functionality of the system, segmented that functionality into subsystems and created those subsystems through copious amounts of research and iterations of the subsystems. This project is one that has variations that have been attempted by many however, accurately executed by few. Finding the appropriate research was difficult, there are many ways to approach the problem of indoor motion tracking, whether it be RFID systems, near field communications, or marker-camera systems, all contribute their own advantages and weaknesses to the topic of motion capture. The portability and scalability of IMUs were what was most attractive to us and seemed to best fit the needs of the project. Figure 3 displays our software choices and how they related to the project in terms of use case. We used the Arduino IDE to outfit the opensource firmware to the project's functional needs. Xcode was used to create the mobile application to control the connect/start/stop functionality of the IMU. MATLAB was used to test displacement of sensors using captured data, and the Processing IDE was used heavily to visualize the orientation with respect to pitch, yaw, and roll of the sensors.

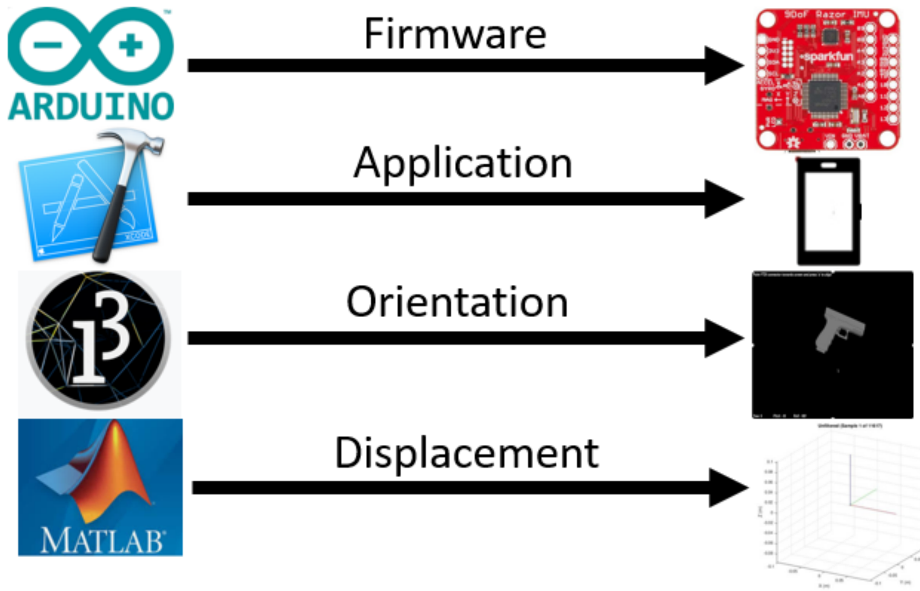

Figure 4 Software Applications – displays software used to design different aspects of the project

5.3 Project Approach

We decided to segment the project into separate discrete pieces, the hardware aspect that would include researching and choosing an appropriate IMU, wireless communication devices and how they would interface with one another. The second segment was the software aspect of the project which included the firmware for the IMU, a mobile device application to communicate and control the IMU, and data processing software to be able to visualize the recorded data. Each engineer focused on different aspects of either software or hardware and immediately began research on their topic. We checked in with one another each week to brainstorm ideas for new approaches to specific topics or discuss how to integrate our current pieces of the project together. For example, when the mobile device was realized to be the control unit for the IMU, we needed to ensure that the current Bluetooth module was compatible with the Bluetooth of a mobile phone, this resulting in us upgrading our Bluetooth module to a newer low energy version. Segmenting the project allowed us to continuously make progress on separate pieces of the project simultaneously and drive us to a working design.

5.4 Engineering Standards

Standard	Title	Application	Relevance
IEEE 802.15.1	Bluetooth - Wireless protocol (4.0)	The medium for data transfer between sensors and mobile application	Data Transfer
UART	UART - Universal Asynchronous Receiver-Transmitter	Communication between Bluetooth module and microprocessor	Data Transfer
SPI	Serial Peripheral Interface	Movement of bits on our microprocessor board	Data Transfer
NMEA 0183	GPS Protocol	The timestamp to synchronize our sensors used GPS	Universal Timestamp
NTP	UNIX Time Protocol	Format used to obtain our timestamp	Timestamp Format

Table 1 Engineering Standards – displays the engineering standards used in this project

5.5 Progress Towards Goals

Once the details of the design were agreed upon by all, the process of achieving our deliverables was explicit. We began work on hardware selection right away as this was a major controlling factor in determining the appropriate software. We made steady progress for nearly six weeks until we were finally able to meet with the head of research at the ALERRT Center. He had a distinctly different idea of what our project was to achieve then we did. His thoughts on our project were that we were to create a two-dimensional real-time tracking system for first responders in training. After meeting him, we immediately set an appointment with our faculty advisor to discuss options for moving forward. This was the pivotal point in our project when we decided to put our stake in the sand and head that direction in terms of the scope of our project. This changed our deliverables from three-dimensional motion and orientation tracking to only orientation at several key locations of the responder. We came to the realization that accurate positional motion tracking from sensors alone, was an entire project, and required a technology and expertise that is yet to be invented. Once we settled on the specific scope of our project, we continued to work diligently at making progress on each functional deliverable until all were working and only needed a bit on fine tuning.

5.6 Verification

To verify our product, we performed several tests to ensure we met the technical requirements specified early on in our project and to gain an understanding of the quantitative performance one can expect when using our product. The main aspect’s that were tested had to do with the wearable sensor system as well as the interaction of the wearable system with the mobile device.

Within the wearable sensor system, we designed tests for the battery life, storage capacity, sampling frequency, sensor accuracy, and transfer rate. These tests were important in verifying our wearable system for a number of reasons:

1. Ensure our system has recording capacity for an entire training day (2 hours).
2. Ensure the data from our sensors is accurate and usable.
3. Data transfer speeds must be high enough as to not limit the usefulness of the system.

The interaction between the sensor subsystem and our mobile application subsystem are of crucial importance in order to propagate start/stop, error, and transfer signals. We designed tests to verify errors in the system such as:

1. Starting a recording session with no devices connected
2. Not receiving a return signal from the sensors after pushing Start or Stop
3. Receiving a battery signal of less than 20%
4. A device is disconnected mid recording
5. A data sample cannot be written to the SD card

In the unlikely chance one of the above errors occur, our designed tests allow us to know and tweak how the system will handle each error it receives. Also, within the testing of the two subsystems, we verified our subsystem's interaction speeds by designing a software test which calculates the roundtrip propagation delay.

5.7 Characterization Results

	TEST CASE	SPECIFICATIONS		RESULT /COMPLIANCE
		Input	Expected Output	
1	Accelerometer Calibration	Slow rotation around each axis of the sensor (angular velocity)	Accelerometer operation range for each axis	Pass {255, 255, 255}
2	Gyroscope Calibration	Sensor laying at rest	Gyroscope noise at each axis	Pass {0, 0, 0}
3	Magnetometer Calibration	Sensor rotation to plot 10,000 samples around the X, Y, Z coordinate system	A set of transformed coordinates that the magnetometer origin will be offset	Pass {443.807, -286.6533, -76.155667}
4	Sensor Displacement Accuracy	A 90˚ rotation around a measured path.	An observed sensor reading within 25% of the expected reading	Pass 6.6% Error
5	Sample Rate	A 90˚ rotation around a measured path at sampling frequencies of 20, 25, 33, 40, 50 Hz	A sample rate with the best accuracy	Pass 40 Hz
6	Transmission Range	A specified distance and ground-truth text file	Fully operational, uninterrupted data transmission for a distance of at least 5 meters.	Pass Unobstructed Path: 30.16 m Obstructed Path: 15.05 m
7	Battery Life	Sensor running at 40 Hz and writing to SD card using a 1 kB buffer.	2-Hour operation time	Pass 13.03 Hour Life
8	Storage Capacity	2 hours worth of writing data to SD card	A file size of less than 25 MB	Pass 6.07 MB
9	Transfer Rate	The file size of a one-minute recording at 40 Hz (67 KB)	File is received in less than 30 seconds	Pass 23 seconds
10	Battery Error	A battery capacity of less than 20%	Low Battery Alert on application	Pass
11	Storage Error	Full SD Card	Full SD Card Alert on application	Pass
12	No Devices Connected Error	Pushing Start without having connection to the sensors	Connect Devices First Alert on application	Pass
13	Sensor Unresponsive Error	Comment out sensor return signal code	Sensor not responding Alert on application	Pass
14	System Latency	Record UNIX timestamp when start is pushed and record UNIX timestamp when return signal is received.	A difference of 1 second or less	Pass 48 ms

Table 2 Test Cases – Outlines the test cases for this project

5.8 Deficiencies

Deficiency	Effect	Solution	Time need to solve
Errors are unknown until post simulation	Should an error with the hardware or software be encountered during a simulation there is no way to correct the problem during simulation, thus the issue would need to be addressed after the simulation has ended and may result in loss of viable data.	The easiest solution would be to set some sort of alarm off when an issue is encountered so that the user knows that something has gone wrong and could seek help for corrective action of the issue.	Two to three weeks would be needed to implement some sort of alarm whether it be a notification on the mobile app or a simple noise coming from the sensors.
User-controlled System	Allowing the user to operate the start and stop functions of the recording session has the potential to introduce a great deal of error. However, the system was designed with scalability in mind and this happened to be one of the byproducts of that specification.	Designing an administrator controlled synchronous start and stop of the recording functionality so that all the wearer has to do is be present and outfitted in the equipment.	It would take a great deal of time to figure out a solution to this problem. You could have the admin phone control all the start and stop functionality of the sensors, however, this would yield a crippling limit to the number of Bluetooth connections, and thus the number of participants in the simulation.
Rate of data transfer off the sensors is slow ~3Kb/s	This creates a longer time frame for the data that was just recorded to be transferred to the mobile device. Thus, a longer time frame to collect data and recreate the simulation using a software visualization.	The quickest fix for this issue would be to upgrade the Bluetooth modules to BLE 5.0 modules, that version of Bluetooth has an adjustable packet size, thus we could increase the amount of data sent per packet and reduce the time to transfer the data form the sensors to the mobile device.	This would only take as long as it would to receive new modules and rename them. A generous estimate would be two weeks.

Table 3 Deficiencies – Outlines the short comings or deficiencies of the project

5.9 Iterations and Redefinitions

Our initial project definition from our Statement of Work is as follows:

> “This product is designed to function as a set of wearable devices. The devices will be integrated into the existing training equipment provided by ALERRT and will record the wearer’s movement, orientation, and location in a 3-dimensional space across time. The data obtained from these devices will be processed by software with the goal of mapping the wearer in a virtual environment across the time in which they were wearing the devices.
>
> This will be accomplished by using motion capture sensors to convert analog sensor data to digital data. The digitized data will produce precise measurements in accordance to the body part in which it is worn. We estimate there will be three total devices worn. One on each of the following: the head, the chest, and one device integrated into the gun or weapon of the responder. By placing a device on each of the above body parts the data from each sensor can be integrated together as one to produce an accurate representation of the wearer moving through space. Initially, we will aim to produce one sensor providing usable data to demonstrate the ability to map movement.
>
> Additional features of the product will include a rechargeable battery and memory storage capacity built into the system. With the understanding that each response training session lasts 10-15 minutes, we plan to provide storage capacity of at a minimum of 4 times the average training session. To streamline data transfer, including the loading and formatting of digital sensor data, a user interface will be created.”

One of the major changes to this project from the time of writing the Statement of Work until this point, is the ability to track the user’s location. Upon completing research and implementing our design, we came to the realization that accurate indoor motion tracking based on sensors alone, is not feasible at this point in time, not by undergraduates nor by any major engineering company. The ability to accurately track motion from sensor data only, is just not achievable with current technology available on the market. Had we done slightly more research; we would have been a little wearier of promising such an attribute. The result of this was the removal of the displacement aspect of motion from the project and a shifted focus towards achieving an accurate recreation of the orientation captured by the sensor data. The lesson learned from this, is don’t make promises you can’t keep, and only speak to what you know. In other words, do more research before you sign up for something.

Another minor change is the length of battery life required for the system. Initially we estimated a training scenario to last at most 15 minutes. This was a close estimation, however a better fit for ensuring a long enough battery life was 20 minutes for a maximum scenario duration. We realized this change once we had the chance to visit the ALERRT Center and be part of an active shooter training session. The result was just to extend the operational battery life long enough to cover six scenarios at a comfortable 20 minutes a piece. We did achieve this aspect of our project, holding true to the claim of "4 times the average training session." We learned from this, that the more communication with your sponsor, the better. Things go smoothly when everyone is on the same page.

6 CONSTRAINTS

6.1 Budgetary

The standard for motion capture and positioning systems in the current market is a mixed video camera and sensor system, often referred to as a marker system, because the video camera and sensor combination overlay data to mark an object's movement and orientation in space. While these systems produce precise measurements, the cost can exceed $75,000 [2], often limiting motion capture to movie sets, video game studios and other high budget arenas. Other constraints that come with these systems include the environment and equipment that must be used. Marker systems require confined areas where cameras can be set around a perimeter as well as wearing equipment which can be intrusive and even limit movement.

With a budget of $500, both budgetary and environmental constraints were put on our project. These constraints played a major role in our design, forcing us to use a purely sensor-based approach known as markerless.

6.2 Design Feasibility

The most hindering design constraint was the nonintrusive aspect of the design set forth by our sponsor. By nonintrusive, we were not able to manipulate the environment, mainly because this system had to be able to work in multiple environments – outside and indoors. This was a huge limitation; we could not use cameras to triangulate our sensors for accurately tracking displacement. We had to integrate our sensors into the existing ALERRT Center equipment, which meant nothing big and bulky, the idea is that the equipment be as transparent as possible to the user as to not impede their training in session. Thus, we needed small sensors that are easily concealable, and a protective housing should one of them be shot by a paintball during a training exercise. This also effected data transmission, we needed a system that could send data efficiently without having a bunch of extra wires hanging out everywhere.

6.3 Manufacturability

Our system is the first step in the direction toward creating a virtual/augmented reality simulation. We were the ground breakers on this project and have paved the way for future Senior Design teams to build onto our design. With that consideration, we have kept in mind the necessity for scalability, ease of maintenance, and simplistic use for both the user and administrator of the system. Our sensor firmware is modified open source code that is well supported, well commented, and well documented ensuring simplicity for future development. Our user interface is simplistic and contains limited interaction and knowledge of the inner workings of the system in efforts to reduce user error and provide quality data. Maintenance has been made easy to provide, by selecting widely popular hardware that can be interchanged with minimal effort and technical ability, we made considerations into the fact that other students will most likely be the ones to inherit and further develop our system. Making use of easily available materials, we have minimized the constraints such as cost and system proprietary components in efforts to ease manufacturability.

6.4 Maintainability

The software and firmware of our system are designed with modularity in mind. Keeping in mind that we are the first to work on this project, we know that other future teams may need to modify or update functionality of our software. For this reason, our entire software database is upload to GitHub for version control and sustainability. Our software partially open source (firmware for the sensors) and other parts are designed from scratch, such as the mobile application written to control the start and stop of the sensors. In both cases, we have made efforts to write or modify clean, concise code so that it may be easily maintained.

6.5 Environmental

In the sense of being “Green” our project does not produce any pollution, waste, or consume anything crucial to the environment. The only consideration to take would be to properly dispose of the batteries should they need replacement.

6.6 Health and Safety

Health and safety considerations for this project amount to possible sharp edges of the enclosure you may scrape yourself on, or small components that could be choking hazards for children. Considering the application of our system, the users are being shot by 9mm paint balls and will not be in the vicinity of small children during use, thus some scrapes from the case are the worst-case scenario. The voltage of the battery isn’t even large enough to produce a harmful shock.

6.7 Social

Our system is designed to be used by highly skilled law enforcement tacticians. These men and women may or may not have technical breadth, which is where the simple user interface comes into play. The user only needs to press a couple buttons on a mobile device application to be able to control the system and is not required to understand any technical background information on the system in order to operate it.

7 BUDGETS

We were able to utilize existing resources to come in well under budget for this project. To design the prototype we even had excess spending due to burning out Bluetooth modules and sensors. Thus, we had to order more supplies over the course than is actually required to make a single unit from here on out. It should be noted that this is the cost of making a single prototype unit.

	Estimated Costs		
Cost Category	**Materials**	**Cost**	**Actual Dollars Spent**
Capital Expenses	**Fabricate Prototype:** • 3D Printer	$6,000	$0
Non-Capital Expenses	**Fabricate Prototype:** • Solder Kit • Cables • SparkFun M0 IMUs • LiPo Batteries • Header Pins • HM-10 Bluetooth Modules • Dummy Gun • 64 GB Micro SD Card	$326	$294.45
	Fabricate Prototype: • Arduino Nanos • Breadboards	$28	$0
	Total	$6,354	$294.45

Table 4. Budget Costs

8 WORK SCHEDULE

Major Tasks			
	Task	Team Member	Completion
1	Create iOS Application foundation	Bo	Complete
2	Configure Bluetooth Devices	Matt	Complete
3	Multiple Sensor Mobile App Connections	Bo	Complete
4	Update Sensor Firmware	Matt/Bo	Complete
5	SD Card File Transfer	Bo	Complete
5	Configure Cloud API	Bo	Complete
6	Prepare Test Protocols	Matt/Karina	Complete
7	CAD Model for Non-intrusive enclosure	Karina	Complete
8	Battery Management System	Matt	Complete
9	Script for Data Download	Bo	Complete
10	Data Visualization	Bo	Complete
11	3D Print CAD Design	Karina	Complete
12	Testing	All	Complete

Table 5 List of Major Tasks – Displays the tasks completed for the project

9 PERSONNEL INTERACTIONS

9.1 Teamwork

Teamwork	
Team Member	**Responsibility**
Bo Heyse	Software Integration • Sensor Firmware • Mobile Application • Visualization Software Testing Project Manager
Matthew Healea	Hardware Integration • Component Selection • Communication Protocols • Power Management System • Specific Firmware Functionality Testing
Karina Paz	Nonintrusive-Enclosure Design Testing

Table 6 Team Members and Responsibilities

9.2 Mentorship

We had regularly scheduled meetings with Dr. McClellan, our faculty advisor, on a biweekly basis which sometimes needed to be rescheduled due to conflicts in his or our schedules. These would serve as the main source of mentorship throughout the semester. These meetings were a source of guidance and often served as design reviews to fool check our design decisions. He would point out things to think about that might not have made sense in our design. For example, how we would handle our errors, the storage format of our data, or the flow of the user interacting with our system. Much of our success can be attributed to having an advisor that asks the hard questions and calls out design decisions he does not think are wise. As a team it forced us to really think about each decision and the potential flaws of that decision. We believe the pressure he put on us from these meetings had the biggest impact on the success of the team.

10 ETHICS

In the IEEE code of ethics, we as engineers recognize the importance of how technology affects the quality of life throughout the world. Ethic 5 states an agreeance to "improve the understanding of technology, its appropriate application, and potential consequences." By implementing technology in the ALERRT Center's training, we began a path towards the improvement of training accessibility for police municipalities. To understand technology, we can see how it is used to improve training accessibility and ensure the safety of human lives during an active shooter(s) scenario. The appropriate application of a sensor-based design allows for a system that improves training by using motion data which does not intake information that will infiltrate or impair the ALERRT Center and therefore holds no potential consequences.

11 SUMMARY & CONCLUSIONS

Our project's primary objective was to create a sensor-based motion capture system designed specifically for the Texas State ALERRT Center which extracts 3-Dimensional motion data at key points on a first responder's body. Doing this would allow their training to be virtualized, resulting in access to municipalities and responders that can't afford to attend the training the ALERRT Center provides.

The approach that was taken was based around inertial measurement units that digitizes analog motion in the form of an X-Y-Z coordinate system. To easily extract data and control the sensors a mobile application which utilizes Bluetooth communication protocols was developed. Data will be stored locally on the sensors during the recording and then afterwards, transmitted via Bluetooth protocols to the mobile application. The data is then readily available to power a projection of the object's the sensors are attached to, in our case, the head, gun, and chest of a user.

The biggest deficiency the system has in its current state is based around the Bluetooth communication protocol being used. At the moment, it utilizes BLE 4.0 which was the first generation of Bluetooth Low Energy devices. In the early generations, Bluetooth Low Energy was synonymous with low energy usage but also low transfer speeds. Therefore, the modules our system utilizes are capable of only around 3 KBps. As we later discovered, BLE 4.2 and BLE 5.0 vastly increased the data throughput of Bluetooth Low Energy protocols. The availability of these devices on the market allows us to overcome this deficiency at a low cost.

Overall, the deliverables we have made satisfy almost all of our original objectives. Our statement of work lists that we needed a total of three sensors per unit, the wearer's displacement and orientation at any given time, the ability to scale the design up or down, a battery life that can last 2 hours, storage capacity of at least 4 times the average training session, wireless data transfer, and a simple user interface will be created. All of these have been delivered from our design apart from the user's displacement, which can be extracted via software manipulation on the data. In light of this information, our deliverables satisfy the main project goals.

12 DISCUSSION

12.1 Academic Preparation

There were a number of classes in the Electrical Engineering curriculum that benefited our group by introducing us to the ideas, tools, and processes that were expanded on in this project. In particular, Microprocessors, Circuits, and Electronics concepts were directly involved in our project. Above all though, we believe our preliminary coursework provided us with the critical thinking and problem-solving skills used to design and develop this project. Electrical Engineering is a vast and all-encompassing subset of the engineering discipline. This can easily be seen by the variety of different projects being tackled during Senior Design 2 in this past semester. From power electronics, IoT, battery management, robotics, and software, it almost feels impossible to directly learn all the specialties and fields of Electrical Engineering, much less take a course over each. What we feel our preliminary coursework did was provide the puzzle pieces and senior design allowed us to put the pieces in their correct place and make sense of the different pieces in a bigger picture.

Unfortunately, not all of us in the team were Computer Engineering focused, in a software heavy design, so there was a lack in knowledge of some of the processes required for software development and understanding. But, understanding how to think critically, we were able break down large systems into smaller, more discrete, manageable pieces that could be split based on certain team members specialties. This aided us in designing and developing our product to be modular, scalable, manageable and ultimately deliver a great product.

12.2 Lessons Learned

As a team, we learned that the engineering process takes strong research, planning, and critical thinking skills. We learned about focusing on one task at a time and checking the tasks off one by one until the project is complete. We learned how to be resourceful, read code, spec sheets, and other people’s comments. In our team and advisor meetings we learned the importance of clearly organized thoughts in the design process. We learned how to manage stressful situations and deadlines. Most of all, we learned to give and take criticism with a light-heart.

12.3 Soft Skills

Senior Design gave us the opportunity to improve our problem-solving skills, presentation skills, teamwork skills, interpersonal communication skills, and technical writing skills. These skills were constantly honed by facing new challenges or technical problems outside the span of our current knowledge, presenting information to varying audiences, and learning to work as a team to make great accomplishments in short amounts of time.

12.4 Schedule Deviations

All of our team members had a rigorous work schedule outside of school. Therefore, it was very difficult to meet outside of regularly scheduled class times with all of the team members in attendance. On the other hand, what we were able to control is our productivity during the Senior design class times. We maximized our communication during class times and provided updates during each meeting. We always left our meetings with a task to accomplish and that allowed us to stay on track during this semester.

12.5 Staffing

This project was adequately staffed with three team members. We had two Micro and Nano Device concentrations and one Computer Engineering concentration. We each attempted to pull much of the weight with respect to our concentration of the project yet maintained helpful throughout the entire course of the project, even when some of the work was slightly beyond our technical ability. Towards the end of the project the work was mostly software driven, thus another Computer Engineering concentration would have been helpful, however, we stepped beyond our comfort zones to learn new technical abilities which resulted in a pretty amazing outcome with regards to what we accomplished for this project.

12.6 Final Observations

Hindsight is always 20/20 and there are many things that could have been done to make our lives easier. If we could have done this project over again, we would have tried to accomplish more work over the summer. We all took classes or had internships over the summer so it's not like we sat around and did nothing, but even spending an hour a week meeting and getting the foundation of the design together would have resulted in less stress during the second semester of design. Also, some features of our design were added on the fly in order to meet our requirements. Thinking a little bit harder about the features required in order to implement our requirements during design 1 would have gone a long way. These are just little things that could have been done to minimize stress, but overall we feel really good about how the project went.

13 ACKNOWLEDGMENTS

Our team would like to acknowledge Dr. Hunter Martaindale and Mr. Coby Briehn of the ALERRT Center for allowing us to work with them to improve this project. Also, we would like to thank Dr. Stan McClellan for all his technical support throughout this course and Mr. Mark Welker and Mr. Lee Hinkle for their support and feedback to constantly improve our design.

14 REFERENCES

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