Final Project and Group Identification Document

ANT-FR

Autonomous NERF Turret with Facial Recognition

A mounted non-expanding recreational foam turret that utilizes facial recognition software to detect and acquire designated targets within a field of vision.

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1 Executive Summary

There is a sense of nostalgia when using Non-Expanding Recreational Foam, which is best known as NERF. Throwing around a football or kicking a ball into a net was always a great pastime for children before the internet. In the early 2000's, Hasbro introduced their line of NERF Guns, which incorporated the idea behind super soakers with NERF. Boys and girls of all ages play with these toys daily, and let's be honest, even adults enjoy a friendly game as well. The fond childhood memories that our team has had with these toys is a leading factor as to why we are very passionate about working on this project.

Our project goal will be to design and build a functioning alpha prototype of an Autonomous NERF Turret that utilizes facial recognition software to lock onto targets. One of our intended outcomes for this project would be to bring back that nostalgia we experienced as a child, to other children and adults. To do this, this project needs to have scalability to be incorporated into businesses that have a "fun zone" theme such as: laser tag centers, arcades and makerspace areas. By keeping a strict budget that the average consumer can afford and making the design into modules or kits, we can scale the project to be easily purchased and utilized in businesses or even households, with ease of installation like that of IKEA furniture. Not only can we produce a fun and exciting product for consumers, this project can even be scaled for various training and simulations, which is the second highest grossing industry in the state of Florida. Autonomous turrets can be utilized in the military or police training to simulate real world firing and combat zones. The NERF component could be modified to use paintballs or airsoft pellets, which would add the extra benefit of realism to the training. Our project can have a vast amount of usages, depending on the industry that utilizes this project and the desired outcomes of the company using our design.

There are a few key functions that our project will need to perform to be a successful alpha prototype. By connecting to a database via a Wi-Fi or Bluetooth connection or physically having a large storage capacity, the autonomous turret will need to have the ability to access a database of images, which can be used as "potential targets" depending on the user. Using a mobile device or personal computer, the user will have the ability to upload and delete images from the database and be able to select an image as a target or deselect an image as a target. A target is an image of a person which the autonomous turret will fire NERF projectiles at, if the target comes into the field of vision of the input device used for the facial recognition. Using facial recognition software, the autonomous turret will need to reduce the number of false positives for acquiring a target that walks into the field of vision and be able to successfully hit the target at their center of mass when firing. While a target is within the field of vision and within the autonomous turret's degree of motion, the autonomous turret will have the ability to track a target and follow them until they leave the field of vision. If no targets are in the field of vision for the autonomous turret, the turret will continue to scan for targets without directly pointing at people walking through its field of vision.

The Autonomous NERF Turret with Facial Recognition project is intended to be a fun and exciting design challenge which will have real world applications in either small businesses or an entire industry for training and simulations. Our team will focus on customizing the technology by creating a user-friendly GUI and adding modularity to form kits for ease of installation. There are not too many products available on the consumer level for purchasing these types of systems, but our hope is that this project would be used in the future for professional and personal use and provide non-lethal applications for entertainment and training. If we can accomplish these tasks, this will show the feasibility of sentry like turrets being plausible for businesses and consumer uses.

2 Project Description

Chapter two covers the overall view of this project and the functionality. This includes the team motivation and goals, objects, requirement specification, and the use case diagram. The importance of this chapter is to show why our team selected this project and to explain our goals and the outcome of what ANT-FR is expected to do. This gives an overview to readers, so they can understand the coming chapters and to explain technical content to a consumer who may not have the technical know-how to understand specific details.

2.1 Project Motivation and Goals

The primary motivation for this project was to have fun shooting at other team members with a NERF gun, as our entire team has used NERF guns in the past when we were children and remember the fond memories of the “good ole days”. The initial pitch by Soar Technologies to sponsor a project was already appealing to the group, as we were interested in a computer vision component to our project, which is annotated in our design matrix. The funding played a primary role into the selection of a project because our chances of being funded had better odds if we went with a project that Soar Technologies was interested in, instead of pitching our own idea and competing with the other senior design teams. The appeal to a sentry turret with a NERF gun already made the team passionate about this project, but with the funding option combined, we didn’t have much of a choice when selecting which project that we were going to do.

The primary motivation for this project was that our team also wanted to step out of our comfort zones and work on a project that really tested our experience and knowledge. The Autonomous NERF Turret with Facial Recognition was the perfect project to do this. There are no explicit hardware design courses for undergraduate students that has you completing and building a complex robot. There are also no software courses for undergraduate student that teach facial recognition, as the computer vision courses dive into older topics and never expand greatly on the state of the art techniques used in computer vision today. This project fulfills our desires to learn new techniques, work on challenging and complex designs, and essentially steps us outside our comfort zones. The project serves as a milestone to us as this serves as a bridge to connect our academic careers with our future professional careers as engineers.

The primary goal for this project is to build a functioning alpha prototype of an Autonomous NERF Turret that utilizes facial recognition software to lock onto targets and fire at those targets. This project needs to be feasible, challenging, complex, and fit within a budget and time constraint. Using these as guidelines the four desired outcomes for this project were created. The first outcome is to have a database of faces being collected as potential targets which will enable us to collect pictures and store those pictures for selection as targets. The second outcome is to develop an application, mobile or web, that allows a user to view the images in the database and select a target of interest. This application can even be used to add, delete, or select/deselect a person of interest. The third outcome is to analyze objects within the field of vision of the turret. If an object is a human, and that human is a selected target, the nerf gun will track and fire at that target’s center of mass. Firing at the center of mass would increase the safety of the project as we do not want to cause harm to the target at this time. The fourth outcome is to try to minimize the number of false positives and to not aim the gun directly at objects initially. Our reasoning behind this is to not have a threatening device that is constantly tracking humans as they walk in front of the turret as this can reduce consumer confidence and cause a backlash of complaints from people being tracked.

Overall, the goals of this project are challenging and complex for our team but remains feasible. A sentry gun turret is not an original idea as many senior design projects have accomplished a project similar. Past projects focused primarily on object detection, facial detection, color detection, and other means of shooting at a target. The uniqueness from our senior design project and previous ones is that we will be using facial recognition to fire at selected targets which makes this project more complex and challenging.

2.2 Objectives

The goal of the project is to create a robotic system that analyzes live camera feed for when a person approaches within the frame, the image created when a face is detected is placed under scrutiny and evaluated on whether the person encountered is a valid target - selected by a human operator via a web application; if the target is verified, the turret will position itself and fire until the target is no longer in frame. The project will combine both software and hardware elements to accomplish its intended tasks, both of which will be broken down into common blocks in a diagram to demonstrate the interaction between individual components.

2.3 Requirements Specifications

The system will be powered using external, rechargeable batteries that can withstand prolonged use, are properly insulated, and will regulate a consistent voltage supply to all necessary components. For the safe operation and recharging of cells, the batteries must comply with international and US standards for safe operation and recharging of cells. As we do not have a chemical engineer on our team, we will not be manufacturing our own power cells, and we will have to rely on both retailer and producer to comply with the appropriate standards.

The chassis of the system must be able to support the weight of all hardware components, barring the stand that elevates the system off the floor, and accommodate the components to prevent self-damage during its intended use. For example, if the power system disconnects and components start falling off due to motion it will injure the operator. The turret chassis and components will be mounted onto a swivel that allows for movement around a vertical and horizontal axis, in which the position of the turret is controlled with servos that will provide variable speed for either rapid or precise adjustments in both axes.

The robotic system would ideally operate within a well-lit interior environment with level floors, where the brightness of light sources is like an incandescent light bulb, this may not always be the case due to environmental factors so special accommodations will be made.

The chassis and swivel will rest atop a stand with a minimum of three 3 legs to provide stabilization during operation and allow the system to be properly leveled at the center of gravity, to the average human, to facilitate fire vector calculations. The stand will support at the minimum 10 kg of mass, to account for a maximum of at least 17.5 kg of mass as an acceptable tolerance and stand at a height of approximately 145cm when assembled.

Table 2.1 below serves as a chart with quantifiable characteristics that will be invaluable for the House of Quality analysis. These quantities are for ideal operation of the sentry turret and are subject to change depending on the choice of individual components, to fulfill its function and each other component's functions.

Quantifiable Requirements		
Property	**Quantity**	**Quality Affected**
Assembly Time	15 - 25 Minutes	Ease of Assembly
Yaw Degree Tolerance	+/- 8 degrees from ideal	Accuracy
PCB Power	Continuous, avg. of 6 V.	Power Efficiency
Servo Power	Three (3) hours of operation until discharge	Power Efficiency
Yaw Servo	Ave. 60 RPM under load	Range of Motion
Pitch Servo	Min. 90-degree range	Range of Motion
5 V USB 2.0	480 Mb per second	Communications Speed

Table 2.1. Table of Quantifiable Requirements.

The robotic system will implement a modular design that serves to decrease the overall time required to assemble the sentry turret for those that may not be intimately familiar with the system. The overall assembly time should take no more than 15-25 minutes to assemble as to not sour the user and to reduce stress. For movement, the turret will achieve a minimum of 90 degrees of motion for pitch rotation to extend the range of the fired ballistics to reach those at the maximum distance allowed by the facial recognition software and camera. The servo in charge for the yaw rotation along the base will be positioned away from the center of project and will rotate a wheel that will turn the base along the axis. This servo must achieve an average of 60 rotations per minute, or a single rotation a second, to track moving targets effectively.

The power supply, whether it be by a single source for the entire system or separated to serve large blocks of components, must operate the system internal components and all peripherals. The power supply must be sufficient to operate each individual servo, yet it must be regulated as to not cause damage to the internal components, so it will be reduced, or 'stepped-down', from the total capacity to 6.0V. The use of a standard USB to power the embedded circuitry would serve to provide a constant power supply up to 2.5W, or 5V at a maximum of 500mA, and allow for the data transfer rate between the embedded system and any compatible hosts at a theoretical 480 megabits per second.

2.4 House of Quality Analysis

Below in figure 2.1 the house of quality diagram reflects the marketing and primary engineering requirements for the project. Relationship correlation between requirements are represented in the correlation box, above the house of quality. Identifying and managing these correlation tradeoffs is critical, not only for an accurate parts and equipment selection process, but an overall thorough design. Note that project cost and battery longevity act as the leading negative correlators, while response time and range of motion serve as leading positive correlators. Installation time appears to have very little impact on the other correlations.

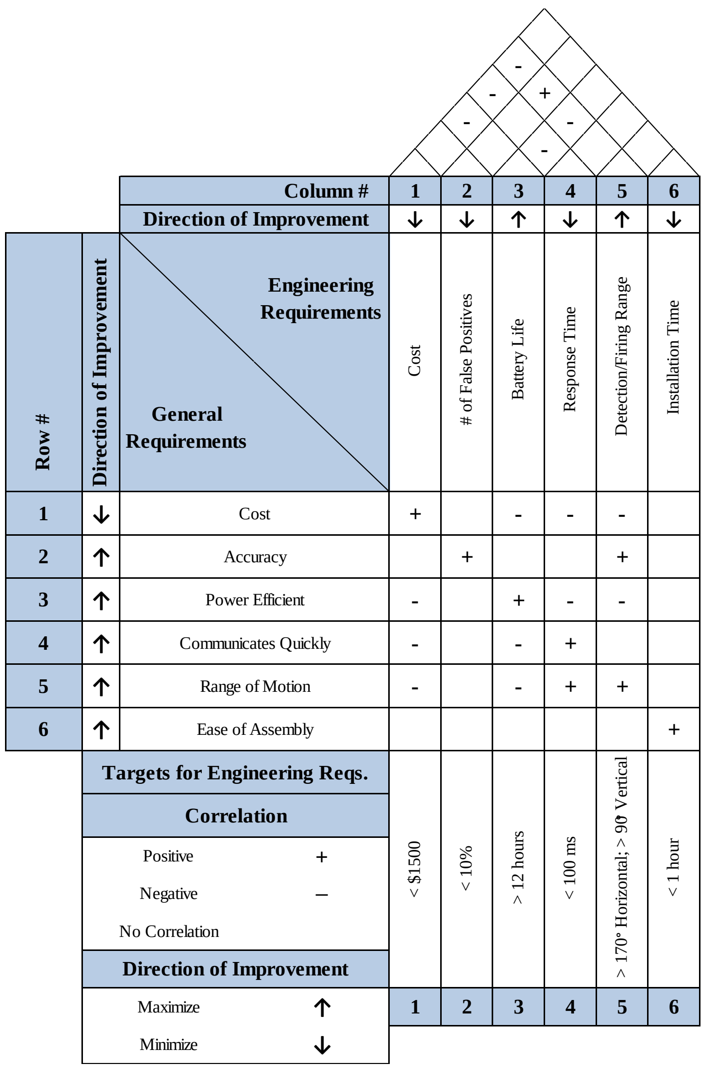

Figure 2.1. House of Quality.

During the final project showcase, several of these engineering/marketing requirements must be presented to display the usefulness of the turret. The first requirement that will be demonstrated is the range of motion. The turret should be able to detect, rotate, and fire in a field of vision no less than 170°. To achieve this requirement, the servo which will handle panning, will need to be capable of this range of motion. This can easily be shown by having human targets placed on either side of the turret and allowing the system to operate. The system should be able to rotate at least 85° to the left or right, scan/detect/recognize the target and make the decision whether to fire or not.

The second engineering/marketing requirement that will be demonstrated is its accuracy. The turret should have at least a 90% accuracy rating, meaning the number of false positives should be kept below 10%. This can be demonstrated by simply running the system through several trials during the final project showcase. Negative targets (people not selected to be fired upon), as well as positive targets (person's selected to be fired upon) should be placed in the field of vision of the turret. The turret should then be able to accurately distinguish between the two types of targets and fire the NERF gun when appropriate. A running tally should be kept each time a target is analyzed in the field of vision.

The third engineering/marketing requirement that will be demonstrated is ease of assembly. ANT-FR should be designed in such a way that the whole system can be built in a minimal time frame. This is desirable if the project is ever scaled up, manufactured, and sold as a kit. During the project showcase, the ANT-FR would be shown as operable/functioning, and then disassembled. The system would then be re-assembled and the time to accomplish this would be measured. To achieve this, major sub-systems would need to be designed in a modular style to create ease of assembly. For example, the major circuitry could be contained in a single box. Care should be taken so that assembly/disassembly of various sections of the turret does not cause harm to its functionality. In other words, the turret should be designed so it can withstand repeated assembly/disassembly.

2.5 Initial Design Architectures and Related Diagrams

A general overview for the base and framework of the turret will need to mount and house its hardware components, as well as making space for the laptop and provide an unobstructed view for the webcam. The main components of the base will be a turntable, which in turn is resting on a larger rectangular plane, to provide yaw rotation, with the rotation emerging from a small wheel connected to a continuous servo at the edge of the base. Parallel pillars will be affixed the turntable and will provide a mount where the dowel and encoded servo provides pitch rotation to the weapon. On the rear of the rectangular plane, the PCB will be set into place, serving as a hub for all wires to and from the servos, external laptop, and firing mechanisms. The rectangular plane will rest on top of a box that houses the laptop, webcam, and external battery packs that are not affixed to the frame or the weapon themselves.

2.5.1 Unified Modeling Language Use Case Diagram

Below in figure 2.2 is the Unified Modeling Language (UML) Use Case diagram which outlines an overall high-level view of how the system will operate which is divided into two components, the user interface and the NERF turret sequence. For the user interface, a user can view images in the database and select/deselect an image as a target, add new images of a person, and delete images in the database. For the NERF turret sequence, an object walks into the field of vision of the NERF turret, motion tracking/detection follows the object on camera, the camera searches for and detects a face if the object is a person, if the object is a person the facial recognition software runs to determine if face is in database, and turret fires at potential targets if they are selected as a target from the facial recognition software.

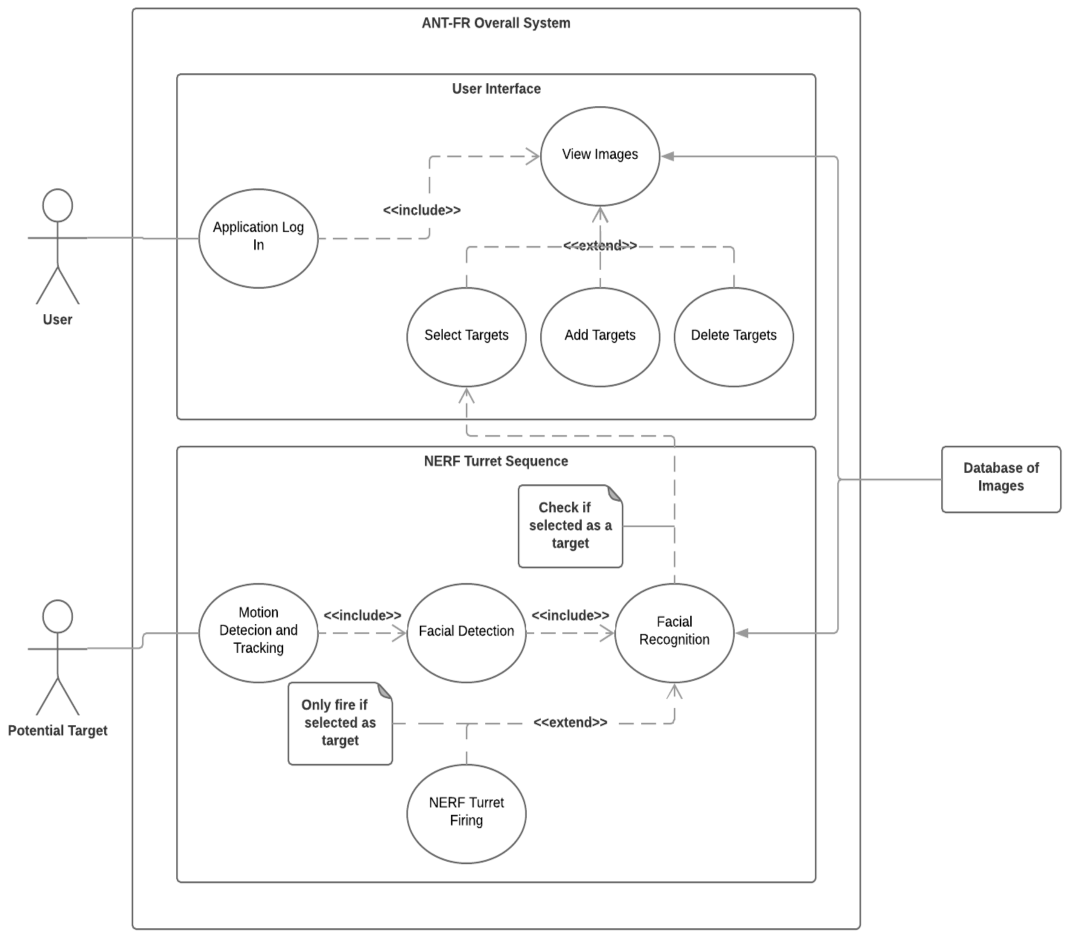

Figure 2.2. Unified Modeling Language Use Case Diagram.

2.5.2 Software Block Diagram

Figure 2.3 represents the Software Block Diagram which follows the software components and their relationships with each other for the proper execution of the system to engage the selected target. The subroutines of the software can be separated into four categories: Core System Processes, Embedded Programming, External Components, and Web App Functionality.

The core system processes oversee the integrity of the system, that all components are present, and that a valid connection is established at the beginning of operation. Operations such as defining idle processes, behaviors for when the turret has not encountered a potential target, and handling interrupts, variables and conditions that supersede any currently running subroutine needed to be established in the core system. The embedded programming monitors all peripheral equipment such as the motion detectors and the servos motors, it is also in charge of processing output information for firing on the system's target and the relative position of the turret. External component involves all calculations and algorithms that the onboard CPU cannot undertake, which includes facial detection and facial recognition, which attempts to match the detected face with the selected target's profile.

Once the information is processed, it is verified, and the firing vector is sent to the embedded system components. The web app functionality ensures that a target can be selected from an external database, increasing the user-friendliness while diminishing the need for onboard storage.

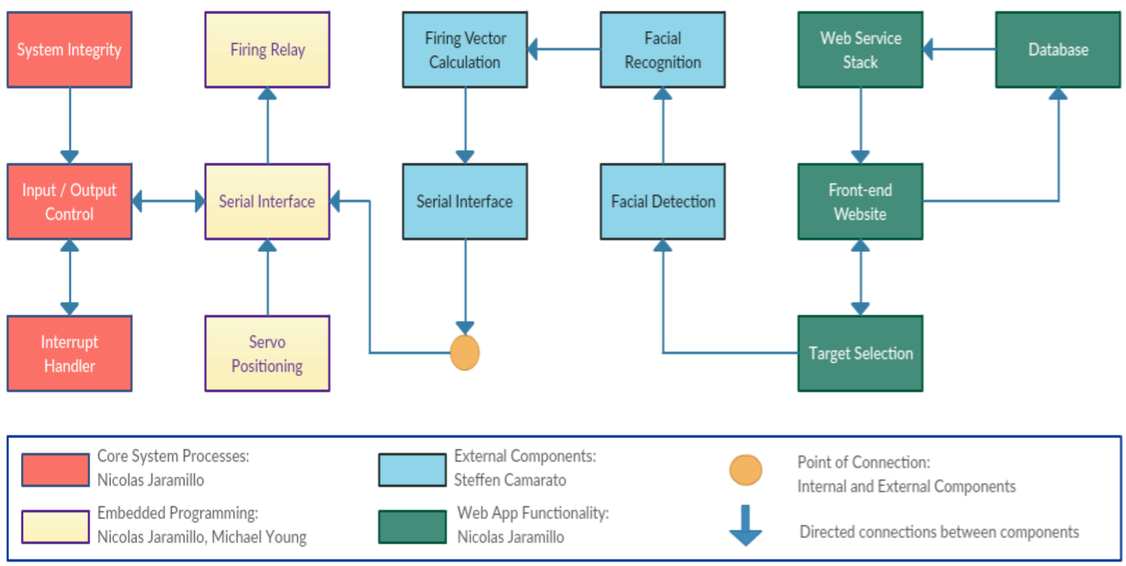

Figure 2.3. Software Block Diagram.

2.5.3 Hardware Block Diagram

Figure 2.4 below is the hardware block diagram which shows the hardware components required to fire the NERF gun, starting at the power system. The sections of the hardware can be separated into four categories: Power System Components, Peripherals Components, External Components, and the System Output Components.

The Power System can be broken down into the battery itself, the rechargeable lithium ion cells, and the power regulator, which helps protect the hardware from power surges. After initializing, the voltage is taken to the input of the Printed Circuit Board (PCB), which contains the Wi-Fi connectors, the camera and motion detection components, and the servo motor outputs. The Wi-Fi connectors serve as the bridge between the system and the user, allowing commands from the user to be implemented and allowing updates to the database of images. The Camera provides data input that is to be interpreted by the facial recognition software; if recognition is above a certain probability, then the servos are given permission to run. The servo motors aim the turret towards the desired target and fires, if all targeting parameters are fulfilled as outlined in the software block diagram.

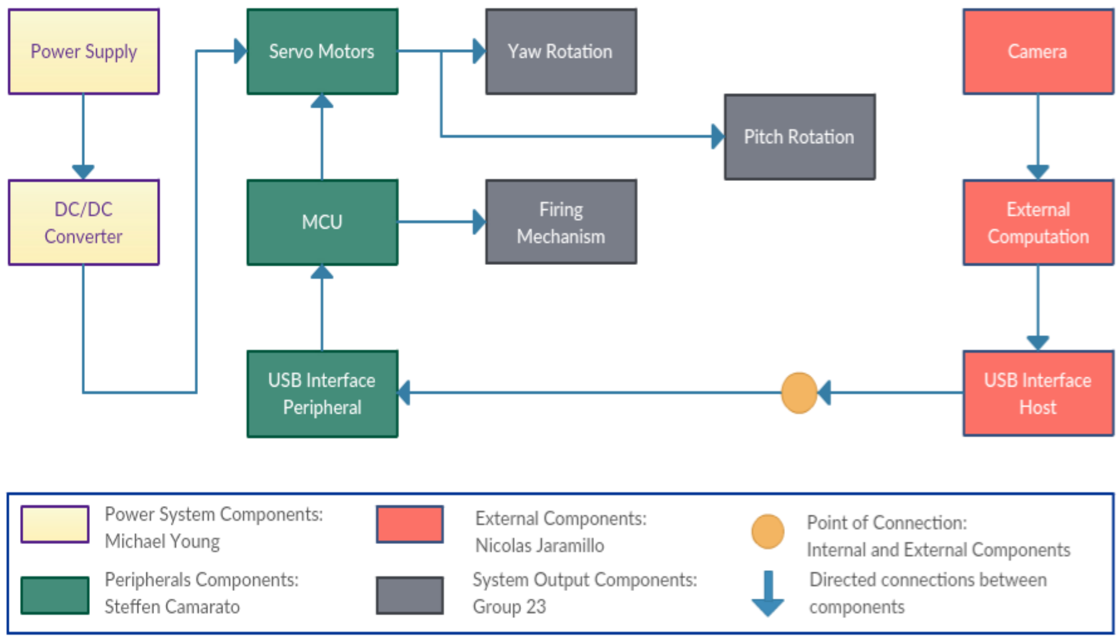

Figure 2.4. Hardware Block Diagram.

3 Research related to Project Definition

An important part of any major design project is research to realize the functions and features of the ANT-FR, specific research must be conducted to better understand similar existing projects and relevant technologies. Additionally, research must be done to determine parts that will likely be utilized for the system. This chapter details the research that was conducted for the ANT-FR.

3.1 Existing Similar Projects and Products

The idea of designing and building an autonomous NERF turret is not a novel idea as there are many tutorial videos of hobbyists building sentry guns, turrets, and other forms of battle bots. These designs incorporate a mounted gun to a base, which will lock on and shoot at a target as it analyzes the terrain in some form of mapping, detection, or randomly firing in various degrees of motion. Viewing previously created senior design projects from the College of Engineering and Computer Science, there are more than 30 projects that were created based off these designs. The ANT-FR project will be utilizing some of the design features mentioned, however, one distinguishable factor that stands out from previous projects is the utilization of facial recognition software to find targets. Currently, there are no projects that incorporate both together, as previous teams had some confusion between the difference between facial detection and facial recognition. The following examples are similar senior design research projects related to forms of turrets, and projects that used facial recognition as a core design requirement but may not be turret based.

3.1.1 Self-Targeting Autonomous Turret System (STATS)

STATS was created by Elso Caponi, Michael Lakus, Ali Marar, Jonathan Thomas, and was sponsored by Boeing. "The self-targeting autonomous turret system, or STATS, is a camera-based weapon system that uses software to locate and attack a moving target" [1]. STATS is a similar turret design to what ANT-FR will be utilizing but has some key differences between both designs. One major design component is the use of teleoperation to connect to the robot which will not be present in ANT-FR. The teleoperation is a unique design feature which gives the user the ability to control the robot and fire at targets. This feature allows for a human to take control and use their best judgement in situations which may be difficult for a robot to decide such as: bad weather, poor visibility, high level background noise, or if certain objects are not deemed appropriate to fire at. Combining teleoperations and autonomy gives this project a better utilization in real world applications and an extra feature of consumer satisfaction when using this robot.

STATS utilize an automatic airsoft gun, which differs from the NERF gun that ANT-FR will be using. The airsoft gun has a warning siren attached on top of the gun and flashes when potential threats are incoming while making loud noises as well. The gun is connected to servo motors that allows for motion in the X and Y axes to track targets and another servo is used for trigger pulling. A wooden base was used to attach the gun and hardware, which was designed to provide motion from -45 degrees to +45 degrees vertically and 0 degree to +180 degrees horizontally, which will be similar to how ANT-FR will function in movement. The robot will function autonomously using a programming language called Processing which is an open-source graphical library and integrated development environment. The other software component is the utilization of Open Computer Vision libraries to perform the motion tracking and detection, which is how some components of ANT-FR will be programmed with. For teleoperation, the robot was controlled via an XBee Wi-Fi module on the PCB and a windows tablet device which was a main design parameter for STATS.

The overall design of this project was successful, and the team met their deadlines and completed the requirements set forth by Boeing. One component of this project that may have been deemed more difficult was the wireless connectivity to the tablet and the robot, which required extensive troubleshooting and the entire team participation. The key component to the team's success was performing adequate research prior to building the robot, and an amount of enthusiasm from the team in the work they were performing.

3.1.2 Autonomous Turret

The Autonomous Turret was created by Hector Colon, Adam Houston, Kyle Steighner, and Nicholas Yielding without any sponsorships. The design of this project was "a turret-based weapons system capable of being operated on the system's own judgment of its surroundings and environment" [2]. The robot's gun mounting is capable of swapping between airsoft guns and paintball guns, but the overall system is small enough that the entire robot can be carried by one person. This project had some similar key features to that of the STATS design. One key feature is an audible alarm to alert the intruders that they are being targeted and the other key feature is the ability for teleoperations of the robot for manual control when desired.

The frame was constructed out of wood with a servo attached to a turn table to move the gun in a horizontal direction. No vertical motion was used to orient the gun, which would continuously fire bursts of pellets at a target in their leg region, which could be altered depending on the initial height of where the turret is placed off the ground. A unique difference from this project compared to ANT-FR is the utilization of C# and the AForge.Vision.Motion library packages available for breaking down the video stream and analyzing the frames. The team had a fluid method of utilizing C# to have a consistent language throughout the design by using the language for their embedded systems programming and motion/range finding detection libraries. The teleoperations control was done off a netbook via a USB. This allowed for users to manually control the robot and fire in rapid succession at the target.

This project required a few design modifications after feasibility of some of their designs were deemed too difficult. One design feature was a 360-degree horizontal motion, which proved to be too difficult in determining friend from foe, since this robot was not using facial recognition, there could be no way to determine what the robot would fire at. Next was the vertical motion of the robot being removed due to budgeting and design constraints, as airsoft and paintball guns use carbon dioxide (CO_2) pressure to fire. When the CO_2 tank was low enough, the weight would shift and aim the gun closer to the ground, but this is when the vertical motion would compensate for the weight and adjust the gun to stay parallel to the ground. Since the CO_2 tank did not lose pressure at a rapid rate, this design challenge was not needed and was cut from the project. Overall, this project was successful in their showcase.

3.1.3 Home Observable Monitoring Entry System (HOMES)

The HOMES project was created by Collen Caffey, Bruno Calabria, Ricardo Georges and was a sponsored project by Boeing. The design purpose of HOMES is "to provide homeowners with a cost friendly, reliable solution to home entry and monitoring" [3]. The project differs greatly from ANT-FR because this is not a turret, nor does it utilize a weapon to shoot at targets. The reason behind comparing this project to ANT-FR is that it relies heavily on facial recognition as a key component, which very few senior design projects have accomplished.

HOMES needed to perform facial detection to see if someone was looking at gaining access to the home, and then facial recognition would be performed to assure that they were an authorized user to gain access to the home from analyzing a database of images. Using a mobile application, a user will initialize their system by taking multiple pictures of their face with different angles and orientations and store these images in a database of authorized users. By using adaptive boosting (AdaBoost) and a technique called cascading, training can be performed on the user's face to ensure a high level of accuracy, so the user does not get locked out of their home. Using the Open Computer Vision Face Recognizer library, the team can use Eigenfaces, Fisherfaces, or Local Binary Patterns to compare the user's current face with the system's authorized faces. ANT-FR will perform a similar approach to training the system on a dataset of images to confirm facial detection and a similar dataset of images to confirm targets are properly selected.

The team performed two tests for facial recognition, the first test to determine the positive results and the second test to determine the false positive results. The first test is simply done by having someone stand in front of the camera and the system will power on an LED with a square box outlining the face of the person in the camera. The LED will remain on when an authorized user is within the camera. The false positive test is similar, but an error will pop up on the screen telling the user to "try again" and the system will exit facial recognition mode after 30 seconds if no faces are detected. A major difference is that ANT-FR will be analyzing a video stream which may or may not contain moving objects. Overall, this project was successful in their showcase demonstration.

3.1.4 Smart Mirror

Smart Mirror was created by Daniel Yoder, Austin Keller, Katlin Joachim, and Reid Neureuther. The design purpose of Smart Mirror is "to be a technological addition into the lives of a wide range of users by providing a unique experience while viewing their appearance" [4]. This project differs greatly from ANT-FR as this has no relation to a turret and does not use some form of a gun to lock on and shoot targets. The reason this project was selected is to have a second comparable design which relies heavily on facial recognition. A key difference between HOMES and Smart Mirror is that Smart Mirror uses neural networks, which ANT-FR will be using since neural networks is a state-of-the-art technique for facial recognition.

The team divided up their facial recognition component into three categories: Verification, Watchlist, and Identification. Verification was done to ensure that the user was an authorized established person within a database of authorized users. Watchlist is to enable an alert from detected users defined on the list. Identification was the main component which would compare the user's face to the database of images and finding the correct matches. Using Adaptive Boosting, training is done on the database of images to create a team of experts who can correctly identify the user in front the camera. The bulk of the projects facial recognition was performed using Open Computer Vision and the python programming language.

A key difference from Smart Mirror and ANT-FR is that Smart Mirror will be running off a Raspberry Pi for the computation and analysis, while ANT-FR will be done off a laptop. The team noted an issue with the amount of computation needed and the Raspberry Pi not performing fast enough so they went with a series of still images instead of a video stream. A technique the team utilized was a User Identified using Custom Feature Based Face Recognition Algorithm to reduce the computation time from 20 – 30 seconds for facial recognition to an astonishing 5 second recognition time in most cases. Overall, this project was highly successful in their showcase demonstration.

3.1.5 Existing Products

Similar products are near impossible to find on a consumer level because these products are not on the market nor are being sold to your everyday citizen. Autonomous turrets, or Sentry Guns, are being used worldwide but are based mostly in the military and defense industry. Countries like South Korea and Israel are using sentry guns in a lethal capacity, where anyone who cannot authenticate themselves are on the receiving end of a deadly weapon. Many of these sentry guns are motion detection based and not primarily facial recognition. "A good example would be the SGR-A1 which is currently being used in the Korean Demilitarized Zone which has a system for tracking, firing, and voice recognition" [5]. A goal for this high-tech sentry gun is to possibly reduce the mandatory two years of military service that all Korean men need to serve as they may no longer need the soldiers to work these borders.

Comparing ANT-FR to these systems is too far of a leap as we do not have the budget or experience to master such a sophisticated technology currently, and due to the number of patents and trade secrets, finding information about how these sentry guns are designed and operated is difficult.

3.2 Relevant Technologies

To better understand what will be needed to create the ANT-FR, relevant technologies must be considered. Hardware and software techniques will be explored in this section that could be implemented to realize the desired functions of the turret. While many of these technologies will be utilized, not all of them will be necessary, however this will become more apparent as the overall design progresses.

3.2.1 Facial Recognition

Computer vision is a top field in research right now and developing new techniques and methods to increase the efficiency and accuracy of detection is very lucrative. Many companies and consumers want more from their technology and that includes the future where robots are doing more work for humans which means that they must be able to see properly. An issue with current education is that it's difficult to teach state of the art techniques to undergraduate students because they first need to learn the basics. The issue with learning the basics is that most of the techniques learned are no longer in practice. Luckily, due to the sheer volume of people interested in the computer vision field, there are many resources that are free and open for someone to learn and explore. The advancements in motion detection, motion tracking, and face detection have paved the way for facial recognition to thrive. ANT-FR has a major component with facial recognition and the system can be divided into several processes.

The first process of facial recognition is to obtain an image of a face. This process pairs with the facial detection algorithms being used to find a face that is in the field of vision of the camera. Analyzing the video stream or taking a snippet from the video stream can be sent based on the frames per second. Once an image is ready for processing, a selection of an algorithm is needed to perform facial detection. There are generally four different types of facial detection which are feature-base, appearance-base, knowledge-based, and template matching. "The feature-based method is to locate faces by extracting structural features of the face" [6]. Training a classifier to find distinctive regions that a normal human cannot notice boasts a success rate of approximately 94%. "The appearance-based method depends on a set of delegate training face images to find out face models" [6]. This method uses statistically analysis and machine learning to find characteristics in face images which can be better than other algorithms on performance. There are many sub-methods used in this appearance-based facial detection, but neural networks will be a common sub-method utilized for ANT-FR. "The knowledge-based method depends on the set of rules, and it is based on human knowledge to detect the faces" [6]. Defining rules that a face has a nose, eye, and mouth pose too big of problems and this method is insufficiently produces many false positives. "Template Matching method uses pre-defined or parameterized face templates to locate or detect the faces by the correlation between the templates and input images" [6]. While this method is easy to create and get a project off the ground, it is rather inadequate for facial detection problems in real time systems. Performing adaptive boosting techniques, such as Viola-Jones Cascading which was used in the HOMES project, can significantly decrease the time needed to compare faces to a database. One main issue with this method is that most faces need to be facing the camera, which is an unlikely option for ANT-FR as a face may be in many variations.

The second process involves facial landmark detection. A common problem is that once you have a box drawn around a detected face, we need to find the location of different facial features such as: eyes, mouth, nose, ears, and the corners. Using facial landmark detection, faces can be aligned to a mean face shape which makes the alignment on different features relatively in the same areas. Algorithms being trained with aligned faces tend to perform much better because less computation and processing is used when the machine knows what areas to generally find these features. Scaling the image may be necessary to properly extract the facial landmarks because these landmarks are specific and unique to every human face just like a finger print.

The third process is storing these landmarks using neural networks. Extracting landmarks is resource-intensive and which will require the use of neural networks as well and a strong computer to run the algorithms needed. Varying the number of landmarks needed, the neural network performs training on the images depending on how many times the user wants the network to loop. With each iteration, the network becomes more intelligent and more successful which reduces the number of false positives in real world applications.

The fourth process is selecting the proper face using the neural networks. Once a network has been fully trained, the face sent from the ANT-FR system will be pushed through the neural network and compared to whether this person is in our database and if that person is selected is a target. Successful operation would be having a false positive rate of less than 10%.

3.2.2 Open Source Computer Vision Library (OpenCV)

"OpenCV (Open Source Computer Vision Library) is an open source computer vision and machine learning software library" [7]. OpenCV is a go-to library when working in computer vision and has a plethora of methods, libraries, and resource to accomplish problems that may be encountered building the facial recognition such as neural networks, face detection, and motion tracking. Using open source libraries such as this is a necessity because creating algorithms for facial recognition can take many years and would be well out of the scope of our experience for this project. OpenCV was designed in C++ but has moved to every programming language with Python being one of the most useful as it has many resources and libraries for computer vision.

3.2.3 OpenFace

"OpenFace is a Python and Torch implementation of face recognition with deep neural networks" [8]. As mentioned in section 3.2.2, creating algorithms for using facial recognition could take years and using readily available open source projects should be used. OpenFace is one approach to solving the neural networks issue and has been used on many projects and has been used for video streaming, which is ideal for the ANT-FR project. OpenFace has a high accuracy but other projects do have a higher accuracy in some situations.

3.2.4 VGG Face Descriptor

"The VGG-Face CNN descriptors are computed using our CNN implementation based on the VGG-Very-Deep-16 CNN architecture…" [9]. This project is licensed for non-commercial research purposes which has a .9727% accuracy rate. One downside to this project is that their softmax model doesn't embed features which can make classification and clustering difficult.

3.2.5 Labeled Faces in the Wild (LFW)

LFW is "a database of face photographs designed for studying the problem of unconstrained face recognition" [10]. This database contains over 13,000 images of faces which has been named and labeled of the person in the picture. LFW offers different sets of aligned images, funneled images, and deep funneled images. Using the LFW for training purposes will help give our project a good testing structure to verify the system is working properly.

3.2.6 YouTube Faces DB

YouTube Faces DB is "a database of face videos designed for studying the problem of unconstrained face recognition in videos" [11]. The database contains over 3,400 videos of approximately 2,000 different people. ANT-FR will be using video streaming and a premade database of videos to work with, which will provide valuable training for the system and will give us a good foundation to test our project with.

3.2.7 Eagle Schematic & PCB Layout Software

To effectively and efficiently design a complete working schematic and PCB layout, the use of advanced modeling software will be used. The software chosen for this critical task is Eagle CAD. This software is developed by Autodesk, the same company that produces AutoCAD, in which we are familiar with. Eagle is an ideal schematic and PCB layout modeling software because of its wide use in the microelectronics industry. Additionally, there are a host of tutorial videos, guides, and forums which will make it easier to learn and utilize. Eagle CAD also has an extensive library of circuit components from all the major manufacturers. Further libraries can also be downloaded and added into the program. This will be especially useful for parts that are not part of main stream libraries. Eagle is available for free to all current college students, making it easy to obtain.

It will be important to create schematics in Eagle of each sub-system before the complete schematic is modeled. This will allow for ease of trouble shooting/design. After individual sub-systems are verified to be accurate and functional from a design point of view, the complete system will be connected in Eagle. Since a third-party contractor will likely be used for manufacturing the PCB and potentially component integration, the layout and bill of materials will need to be generated in the correct format. PCB manufacturers utilize the GERBER file format for fabricating any given PCB. Eagle CAD can generate this file type, which will provide all the necessary printing vectors and materials for the manufacturer.

3.2.8 Programming Technologies

Integrated development environment provides additional tools for software development and the creation of programs such as debugging and memory management, they may also provide a specialized environment tailored towards a specific language or technology. Some of the preferred IDEs when developing this project are: Visual Studio Code, a multiplatform editor and debugging tool with an understanding and context for many languages with customizable features to increase ease-of-use. PyCharm, a Python language editor and package manager that notifies users of package conflicts and that allows for the installation of python libraries such as NumPy, Matplotlib, and PIP. Arduino IDE intended for CPUs based on an ATmega328P architecture, in which the compiler accepts C/C++ code with specialized libraries for better control of the embedded system.

3.2.9 Web Development Stacks

Web development stacks bundle software components and languages to enable web services, which consists of a computer with a capable Operating System, a web server, a CGI scripting language, and a database. A LAMP stack uses a GNU/Linux derived OS in tandem with an Apache HTTP server, the MySQL database management system, and the PHP programming language. Some web development stacks can be implemented with alternative technologies due to constraints or preferences.

The web development stack serves to facilitate development for web application, providing the SQL based framework for interaction between HTTP requests and the data stored database. The CGI scripting language will provide the necessary methods or functions to modify and retrieve information.

3.2.10 Mobile App Development

When developing an application, it must be created for a specific operating system in a smartphone, tablet, or other type of mobile devices. Android OS is one of the easiest to develop for, costs less to license, and has one of the largest market shares in mobile operating systems to date, but this wide reach across the market is cause for concern. Despite the benefits, mobile app development for Android OS limits the scope of the application as it neglects Windows, OSX, and many Linux users. For this end, a web application focusing on mobile devices would be preferable as it would be viewable across a wide variety of systems without less to platform

The development of mobile app will make use of three main technologies to properly display entities and objects, technologies such as HTML5, JavaScript, and CSS to provide intuitive user interface. The front-end development will be supplemented by premade, open-source frameworks such as Bootstrap, Ajax, and jQuery. Web development will further reduce development time and costs. There is no need to license software from Apple and there is no need to use Android Studio that needs to compile and emulate before testing.

3.2.11 Pulse Width Modulation (PWM)

As briefly mentioned in the voltage regulation section, a key component for operating voltage regulators, LED indicators, and the servos is pulse width modulation. While pulse width modulation would be automatically achieved in a prefabricated switching voltage regulator, it must be supplied through a signal wire to LEDs and servos. This requires careful consideration while designing the power system and PCB of the turret. To supply the required pulse width modulation to each servo, the microcontrollers considered have several output pins for providing this type of signal. It will be necessary to utilize these PWM pins to operate the servos. The microcontroller can then be programmed to vary the period for each PWM pin to select the desired position of each servo. This is called changing the duty cycle of the signal.

Many servos have a neutral position which is used for reference. This neutral position can be in the center of the angle of rotation, meaning there is an equal amount of rotation available in both the clockwise and counter-clockwise directions. Alternatively, the neutral position can be located completely to one side of rotation, meaning the available angle of rotation is in one direction. Ideally, the ANT-FR will be designed in such a way that it will track the current target and avoid the need to occasionally return to neutral position to reset. Pulse width modulation will also be necessary to control any power and/or charging indicator LEDs. RGB LEDs require PWM to control the specific color and brightness displayed. All in all, PWM is an imperative signal transmission technology that will be utilized in several ways.

3.3 Strategic Components and Part Selections

This section will cover the research accomplished in selecting the major parts of the ANT-FR. Tables and figures are shown, comparing relevant metrics of similar components. This information was then used to make a final selection of the part to be utilized.

3.3.1 Single-board Computer and Laptop

Our team decided to split the system into two major parts. The first would be the printed circuit board design which would handle the embedded systems programming for the servo motors, power components, and sensors. The second would be a laptop or single-board computer which would handle the computation and processing of the facial recognition component and the video display from the camera. We wanted to maintain a high level of efficiency and fast response times in terms of recognizing a face but doing this on the printed circuit board would have required a much larger budget because a graphic processing unit would have been essential, but extremely costly. Not only this, but the complex design challenges to implement a GPU would hinder the progression of the project which may not be completed on time.

3.3.1.1 BeagleBoard

The BeagleBoard is a single-board computer which is produced by Texas Instruments with a design of open source in mind. A more specific version of BeagleBoard is the BeagleBone

Black and it boots Linux in under 10 seconds. This version is great towards embedded systems and robotic applications as the two rows of the general-purpose input/output pins allow the BeagleBone “to communicate with a wide range of sensors, servos, outputs and other hardware, letting it act as the brain of a large, complex project” [12]. The BeagleBone has two 48-socket headers, compared to the Raspberry Pi’s 26-pin header, which allows for countless I/O including many analog I/O which allows connections to a variety of sensors, which a Raspberry Pi cannot do. Another advantage of the BeagleBone Black is the “right out of the box” setup as there is not much required to use this board but does lack extensive community support.

3.3.1.2 Raspberry Pi 3 Model B

“The Raspberry Pi is a low cost, credit-card sized computer that plugs into a computer monitor or TV and uses a standard keyboard and mouse” [13]. The BeagleBone Black was designed to be superior to the Raspberry Pi, but with future renditions and modularity to the Raspberry Pi, the Raspberry Pi can perform just as well if not better than a BeagleBone. Using a Raspberry Pi to an Arduino Shields Connection Bridge grants new dimensions and scopes to the Raspberry Pi for some major hardware interfacing. One benefit to using a Raspberry Pi over a BeagleBone is connection to a wireless network. Raspberry Pi 3 Model B comes with 4 USB ports, an on-board 802.11 Wireless LAN, Bluetooth 4.1, and Bluetooth Low Energy while the BeagleBone only contains a single port and an on-board ethernet port. Community support for the Raspberry Pi models is much more prevalent but setting up is more difficult than the BeagleBone.

3.3.1.3 Laptop Computer

A laptop computer can perform all the functions of a single-board computer but on a much higher level. Using a laptop would greatly maximize the modularity of the project and reduce the cost as most consumers or companies already own laptop devices that can run any software needed. Using a laptop would fix most issues that can occur when using a single-board computer and the laptop already has all the peripherals needed while a single-board computer requires more purchases to accomplish the same task.

3.3.1.4 Selection of Single-board Computer and Laptop

From researching past senior design projects that utilizes facial recognition and researching the differences between facial detection and facial recognition, many design challenges came forth and the issues on how we were going to overcome those design challenges. A common design challenge encountered by most senior design teams was that their single-board computers or their printed circuit board designs could not efficiently handle the load from the facial recognition software. Many teams were required to alter their designs to become less novel by settling with compromises between their original design and the new design. The main reason behind this was that using any form of neural networks requires a tremendous amount of processing power, which most standalone single-board computers cannot accomplish in an efficient manner. There would be long delays between facial detection to facial recognition to actual authorization into the application.

For these reasons, our team has chosen to utilize a laptop computer which will solely be used for the facial recognition software and camera. This allows our design to function as efficiently as possible and reduces the cost of hardware needed to purchase as our team already has a laptop available.

3.3.2 Single-board Microcontroller

Working with a single-board computer or single-board microcontroller is necessary for testing while other hardware components are being purchased and tested. Both components function rather similarly, but a single-board computer will outperform the single-board microcontroller in long term applications. Since our project requires a specific control task to operate the turret, either one is suitable to our needs if we have the peripherals needed for the single-board microcontroller.

3.3.2.1 Texas Instrument MSP430G2553

The Texas Instrument MSP430G2553 is an excellent single-board microcontroller and is most notable for the power consumption options that can be used for various projects. The MSP430 spends most of its time in sleep mode and features 5 low power modes with different settings such as disabling the CPU and Master Clock. These power modes allow for some of the best power management in single-board microcontrollers and is one of the main reasons why engineers use them for long term projects. The MSP430 offers more detailed memory management by allowing the user to adjust the stack and heap memory sizes, and an amazing debug tool to view the memory spaces in real time on your personal computer. Software like Putty can be used for the debugging since the MSP430 does not come with a serial monitor. The open source community is not as active for this product compared to other microcontrollers, but the documentation for their API is readily available when needed.

3.3.2.2 Arduino Uno Rev3

The Arduino Uno Rev3 is a simple and easy to use single-board microcontroller which is ideal for simple prototyping and electronics. Out of the package, the Arduino is simple and does not support the technology that a single-board computer has, but the Arduino has extensive modularity components for more storage, network capabilities, and other dongles for the desired project. The Arduino is easily interfaced with a Raspberry Pi so both boards can perform various functions. The Arduino allows a user to easily connect LEDs, sensors, and servo motors directly into the board without any extra components which is ideal for projects not requiring much computation or graphics. The Arduino community is very active and there are many libraries to assist with programming the board. Adding multiple dongles to the Arduino can increase the difficulty of the programming and make the project more time consuming. Those issues coupled with the low processing power and memory, may not be ideal for complex projects.

3.3.2.3 Selection of Single-board Microcontroller

Below is a list of components of the single-board microcontrollers compared side by side in table 3.1.

Single-board Microcontroller Comparison

	TI MSP430G2553	**Arduino Uno Rev3**
Processor	16-Bit RISC	ATmega328P
Memory	16KB Non-volatile	32KB Flash Memory
Storage	0.5 KB RAM	2KB SRAM
GPIO Pins	24	20
USB Ports	Mini USB-B	1 x USB 2.0 Type B
Power	Active mode: 230 µA @ 2.2 V	20mA–50mA @ 7V
Software	Code Composer Studio, Energia	Arduino, Genuino, Atmel Studio
Price	**$23.80**	**$19.00**

Table 3.1. Single-board Microcontroller Comparisons.

The TI MSP430G2553 is the clear winner for a long-term solution as you can get very detailed memory control, decide the stack and heap memory sizes, and the low power consumption. However, for this specific project, the intention is to run the facial recognition software off a laptop due to the heavy processing requirements from deep neural networks. This means that the PCB design will mainly be handling the sensors and power components, which does not require memory management nor does handling power consumption matter, as the limits of the power are dependent on the rechargeable battery pack duration for the gun. With all the parameters and requirements for this project, a single-board microcontroller that is less complex to use would be the best fit, which an Arduino Uno Rev3 satisfies this need, which will be the selected component due to the open source community and price range.

3.3.3 Power Supply

The power requirements for the turret prove to be unique and challenging. All the components, such as the microprocessor, printed circuit board, camera, NERF gun, and servos, to name a few, will operate at varying voltages and power requirements. This necessitates the use of a power source which will provide ample voltage to supply even the most demanding component. The maximum supplied voltage from the power sources will also need to be stepped down to provide the nominal operating voltage for smaller components. This will be accomplished through voltage regulation. Despite the turret being a stationary device, we have elected to power all the components using battery packs, rather than a “wall plug” setup. Since an external laptop will be utilized for computational assistance, it will obviously be powered through its own built-in rechargeable battery pack. The laptop will provide power to the printed circuit board since it will be connected via USB. The camera will likewise be powered via USB connection to the external laptop. This will provide simplicity in designing the power system. Additionally, the NERF gun will be powered using a compatible rechargeable battery pack designed for it. This section will explore the major options considered for providing power to the rest of the components.

This section will examine the battery technology considered for reliably supplying power to the servos and NERF gun. The NERF gun will be powered by its own separate rechargeable battery, while the servos are powered with another rechargeable battery pack.

3.3.3.1 NiMH (Nickel Metal Hydride)

NiMH batteries are commonly used in electronic devices such as mobile phones and laptop computers. They have a moderate cycle life but require maintenance due to their memory effect. To avoid issues associated with the memory effect, occasional deep cycle discharges are necessary. The charge time of NiMH batteries are comparable to lithium ion batteries. NiMH batteries are particularly effective at providing a high current when required. An important factor considered with this battery technology is its tendency to heat up if recharged too quickly. A high current, commonly found in “quick chargers” causes the battery pack to heat up, which if left unresolved could potentially cause damage to the surrounding circuitry and components. On the other hand, a low current charging cycle results in memory effect. As a result, a moderate current trickle charge would be necessary for recharging.

This battery technology is still feasible due to its high energy density output, relatively short recharge time, and low cost. NiMH battery packs generally cost less than lithium ion but are more expensive than nickel cadmium battery packs. The primary driving factor for considering NiMH battery technology is the low cost, hence its relevance in today’s modern technological applications of common devices. Below in table 3.2, a comparison of different NiMH batteries is shown.

Nickel Metal Hydride Battery Comparison			
Vendors	**AA Portable Power Corp**	**Digi-Key**	**Amazon**
Weight	518 grams	419.57 grams	453.6 grams
Dimensions	97mm X 47mm X 50mm	127.4mm X 18.2mm X 67mm	55.9mm X 248.9mm X 221mm
Capacity	4.5Ah	4.2Ah	1.5Ah
Voltage	8.4V	8.4V	7.2V
Price	**$45.80**	**$59.09**	**$25.85**

Table 3.2. Comparison of Nickel Metal Hydride Battery Products.

The voltages for the selected battery packs are expected to accommodate the varying voltage levels of all the loads which three voltage options are given. In addition to the battery pack that will provide power to the servos, a secondary battery pack will provide power to the NERF gun. Many NERF guns are compatible with rechargeable battery packs. This simplifies the number of loads that the primary battery source will supply and makes our design more modular. The NiMH battery pack is a viable option for powering the NERF gun. This battery pack is designed and manufactured for use in NERF brand foam dart guns. As a result, it will be a simple “plug and play” style power source.

The capacity of the battery will depend largely on the frequency of firing from the NERF gun. If a positive target comes into the field of vision often, the NERF gun will naturally be firing more frequently, and thus drain the battery quicker. On the other hand, if a positive target rarely comes into the field of vision of the turret, the NERF gun will rarely be utilized, and thus the battery will last much longer. This is not a major concern, since a positive target would need to be in the field of vision and fired upon for an extensive amount of time, albeit several hours, before the NERF gun NiMH battery depleted its charge. For these reasons, the amazon NiMH battery pack is the selected one.

3.3.3.2 Lithium Polymer (LiPo)

The next rechargeable battery technology considered for powering the turret is Lithium Polymer or LiPo for short. Compared to NiMH, LiPo batteries have a higher energy density. LiPo batteries also have a lower self-discharge rate, meaning they do not “leak” as much energy when in storage. This is particularly helpful in real life application if the turret was inactive for long periods of time. Additionally, the nominal voltage per cell is higher than NiMH, making higher voltage values attainable with fewer cells. Another major advantage to LiPo battery technology, is the lack of maintenance required. Since LiPo batteries do not carry a memory effect, maintenance is not needed. This advantage eliminates the necessity of occasionally deep cycling the battery for exercise.

LiPo batteries with all their advantages do carry a few disadvantages. Due to their complex manufacturing process, the price is typically higher than older technology's like NiMH. Furthermore, due to its chemical properties, conductivity is poor unless the battery is heated to an unreasonably high temperature. As a result, special electrolytes are needed to overcome the high internal resistance. This contributes to the higher cost of the battery in general. LiPo batteries are still popular because of their extremely small size, which is required in mobile applications. Should the ANT-FR be scaled in the future, a LiPo battery pack may be more viable for reducing the overall weight and size. The small footprint and decreased weight would be advantageous to using smaller and lower torque servos since they are sized based on total weight. However, since the size is not a critical factor for the turret, the added cost of this feature may be hard to justify and would restrict funds that could be spent on more useful features elsewhere. Table 3.3 below shows the comparisons between different LiPo batteries.

Lithium Polymer Battery Comparison			
Vendors	**All-Battery**	**Battery Junction**	**Amazon**
Weight	150 grams	379.88 grams	421 grams
Dimensions	110mm X 59mm X 22mm	170mm X 53mm X 22mm	154.9mm X 48mm X 26.9mm
Capacity	6Ah	6Ah	6Ah
Voltage	7.4V	11.1V	11.1V
Price	**$47.99**	**$94.95**	**$48.99**

Table 3.3. Comparison of Lithium Polymer Battery Products.

3.3.3.3 Lithium-Ion (Li-Ion)

The final battery technology considered for powering the turret is Lithium-Ion or Li-Ion for short. This technology has the greatest number of advantages among the batteries considered. Li-Ion has a high energy density, providing 3.6V per cell. This high voltage per cell can accommodate a higher load compared to NiMH and LiPo batteries, which will be useful considering the high demand from the servos. Li-Ion batteries, similar to LiPo, have a high cell cycle count, providing for a long-lasting battery. One advantage Li-Ion has over LiPo, is a lower internal resistance, which provides for better conductivity. Since there is a higher conductivity, there is less cost associated with manufacturing the battery, and therefore a lower purchase cost compared to LiPo. This higher rate of conductivity would prove to be useful considering the heavy current draw in which the servos will require. The charge times between Li-Ion and LiPo are comparable, as well as the self-discharge rate.

There are a few disadvantages to Li-Ion battery technology. Storing the battery at full charge in a high temperature environment, reduces the effectiveness of the cell. Additionally, charging the battery at temperatures below freezing (32°F) becomes less effective. The primary concern with any Li-Ion battery is the intolerance to improper charging. Should the battery be over charged, it could rupture, thus creating a serious safety hazard. Likewise, if the charge of the battery is depleted too low, the longevity would be negatively affected. Therefore, Li-Ion batteries require a protection circuit to prevent improper discharging/charging. This negatively impacts the cost of the batter pack. Despite the few minor drawbacks, Li-Ion battery technology has the advantages of LiPo, without its drawbacks, making it an ideal choice for providing the power required. Table 3.4 below shows the comparisons between different Lithium-Ion batteries.

Lithium-Ion Battery Comparison			
Vendors	**All-Battery**	**Battery Junction**	**Mega Batteries**
Weight	425 grams	190 grams	199 grams
Dimensions	166.5mm X 73mm X 19mm	72mm X 70mm X 20mm	76.2mm X 18mm X 69mm
Capacity	6.6Ah	5.2Ah	5.2Ah
Voltage	11.1V	7.4V	7.4V
Price	**$74.99**	**$47.95**	**$59.99**

Table 3.4. Comparison of Lithium Ion Battery Products.

3.3.3.4 Selection of Battery Pack Technology

While all battery technologies had an affordable option, it was important to consider the pros and cons of each. The NiMH batteries provided modest voltage for a reasonable price, however the ampere-hours were lower. This translates to lower longevity, which negatively impacts one of our engineering/marketing requirements. As a result, NiMH was eliminated for supplying power to the servos. However, NiMH will still be utilized to power the NERF gun due to the low cost and ease of compatibility.

The remaining battery technologies were LiPo and Li-Ion. Since both technologies are based on a lithium chemistry, they have similar advantages. However, LiPo batteries have poor interior conductivity, which could present problems for delivering a sufficiently high current to the servos. Additionally, since they are manufactured in very compact sizes, the high cost of the technology is not justified since we are not concerned with size. Li-Ion batteries do not have this drawback and carry the same advantages. Its cost is more directly associated with the advantages we are looking for, thus justifying the purchase price. Due to these considerations, a Li-Ion battery pack will be utilized to provide power to the servos.

As such, it will be advantageous to purchase a Li-Ion battery pack that contains an integrated protection circuit. This protection circuit safeguards the batteries from depleting its charge too low, or from being overcharged. If the battery charge can be depleted to a low value, it can permanently damage the battery by reducing its effective lifespan. Alternatively, if the battery is overcharged, it can overheat and potentially rupture, thus destroying it. By choosing a Li-Ion battery pack with an integrated protection circuit, we further simplify the design of the power system despite the slight cost increase of having this feature.

The Tenergy 18650 11.1V 6600mAh rechargeable Li-Ion battery pack will provide ample voltage, current, and longevity to the servos. This battery pack contains the desired integrated protection circuit. Careful consideration was taken to ensure that the minimum discharge voltage was greater than or equal to the nominal operating voltage of the servos, thereby a boosting circuit would not be necessary. The maximum continuous discharge current of 5.4A will be more than sufficient to accommodate the current draw from the high torque servos.

3.3.4 Voltage Regulation

This section will examine the methods for effectively stepping down and regulating the voltage that comes from the power supply so that each load receives its proper operating voltage. As 5V will power the printed circuit board via USB connection, no voltage regulation will be necessary for this voltage. However, the PCB may additionally offer 3.3V for other minor tasks, thus voltage regulation to step down from 5V should be considered. Furthermore, since the primary battery pack will operate at a nominal voltage of 11.1V, this voltage will need to be stepped down to the operational voltage of the servos. While two different methods of voltage regulation will be presented, both may be necessary for this project for the reasons explained hereafter.

3.3.4.1 Linear Voltage Regulation

One method of stepping down and maintaining a constant voltage from the power supply is using a linear voltage regulator. A linear voltage regulator is typically very inexpensive, making them ideal for budget conscious projects. Linear regulators can often be 3-4 times less expensive than a switching regulator. They are also useful in low power applications, such as connecting the power supply to a PCB. This is because many linear voltage regulators operate with low dropout voltages. This type of voltage regulator would be helpful for stepping 5V down to 3.3V for smaller loads such as LED indicators or camera(s). Several popular development boards utilize a small linear voltage regulator to step the 5V input down to 3.3V for auxiliary power. Another advantage of linear voltage regulators is the relative simplicity of implementing them. In many applications, a linear regulator requires only a couple additional components, whereas a switching regulator requires several additional components for operation. Linear regulators are also known for their low noise because of being fully analog devices, compared to switching regulators which carry a more moderate to high level of noise. Keeping noise within and across each sub-circuit to a minimum is important for realizing accurate outputs.

While linear regulators are useful for stepping between small differences in voltage, they are not as efficient for making large step downs. Due to their design, linear voltage regulators waste an increasingly large amount of power as the required step-down size increases. This power waste is often in the form of heat. Many linear voltage regulators do not come with substantial cooling capability; thus, they require additional parts for this. The substantial heat created from a large voltage step down could be destructive to the regulator and even the PCB if left unchecked. Linear voltage regulators are also less effective when higher output currents are needed. As a result, this technology would only be utilized for making small voltage step downs.

Despite the drawbacks, linear voltage regulators remain a viable method for small scale voltage regulation. When comparing linear regulators to switching regulators in a small voltage step down scenario, efficiency becomes a non-issue, especially if the load current is low. The low noise, simplicity, and low cost of the linear regulators make them the ideal choice in a low power, small step-down situation. As we are utilizing the architecture of a development board as a backbone to our PCB design, it would be ideal to mimic its linear voltage regulator that steps 5V down to 3.3V. One example of a linear voltage regulator used on a development board is the LP2985 low dropout linear regulator. This specific regulator takes advantage of low noise, 150mA max current, and a nominal voltage output of 3.3V. It would be ideal to utilize this regulator (or an equivalent), however due to its extremely small size, it may be difficult to mount to the PCB without the use of highly sophisticated equipment or a third-party company. Therefore, a component with similar specifications but a larger footprint would be beneficial. Additionally, the 3.3V rail would benefit from a larger maximum current rating. Below in table 3.5 are several options considered for a linear voltage regulator.

Linear Voltage Regulators Comparison

Part	**LD1117**	**MCP1700**	**LM3940**
I_{OUT} Max	800mA	250mA	1A
V_{IN} Max	15V	6V	5.5V
V_{IN} Min	-	2.3V	4.5V
V_{OUT} Max	3.36V	5V	3.3V
V_{OUT} Min	3.26V	1.2V	3.3V
Mounting Type	Through-Hole	Through-Hole	Surface
Price	**$1.25**	**$0.38**	**$1.45**

Table 3.5. Comparison of Linear Voltage Regulators.

3.3.4.2 Selection of Linear Voltage Regulator

Choosing the appropriate linear voltage regulator was a difficult task due to the many design constraints and decisions to consider. Several key factors considered were physical size, mounting type, and maximum continuous current to name a few. Since all three options were less than $1.50 each, price was not a heavy consideration. It was easy to eliminate the MCP1700 voltage regulator for several reasons. Although it was the cheapest option, and it provided the necessary input and output voltage constraints, namely 5V input and 3.3V output, it had the lowest available continuous current at 250mA. While 250mA is enough for the purposes of the 3.3V rail, having more capacity from the other two regulators was attractive in the sense that it provides greater flexibility for auxiliary components operating at this voltage.

Having eliminated one of the three voltage regulators, we were left with the final two, namely the LD1117, and the LM3940. The LD1117 provides input voltage flexibility, up to 15V to be exact, and while the USB interface will provide an input voltage very close to 5V, having more room to work with is beneficial. Its maximum continuous output current being 800mA gives ample space for a variety of loads. The LM3940 provides even more maximum continuous output current at 1A. Additionally, it has a very stable output voltage of 3.3V, requiring only one additional external component to operate. Although the LM3940 has a narrow input voltage range, it is designed specifically for a stable 3.3V output. Despite the LD1117, as well as the MCP1700 being excellent options for linear voltage regulators, the LM3940 was selected for the 3.3V regulator. The only challenge with utilizing this low dropout voltage regulator will be its small size compared to the other options. Careful and precise surface mounting soldering techniques will need to be used to mount it to the PCB.

The use of a linear voltage regulator, while controversial due to the competitive features of a switching regulator, is still valid. As seen in tables 3.6 and 3.7, switching regulators are 3-4 times more expensive than linear regulators. For supplying a low load 3.3V power rail on the PCB, the significantly lower cost of the linear voltage regulator is justified. Additionally, the selected linear regulator is a low dropout (LDO) regulator designed for very low noise contribution. This will prove to be helpful in assuring that the loads receive an accurate output voltage and current. Furthermore, implementing the specified linear regulator requires less external components compared to a switching regulator, thus reducing the complexity of design on the PCB. Finally, with a voltage step-down size of only 1.7V (5V to 3.3V), the efficiency ratings of both types of regulators would prove to be similar, and thus negligible.

3.3.4.3 Switching Voltage Regulation

The other method of stepping down the power supply voltage is using a switching voltage regulator. A switching regulator will be utilized for obtaining the correct voltage required by the servos. This method of regulation is increasingly more popular due to its ability to step voltage down, up, or both. For example, if we chose a battery with a nominal voltage which matched the highest required load voltage, a switching voltage regulator would be necessary to occasionally step up the voltage as the battery depleted to a lower level.

Switching voltage regulators can also handle a higher dropout voltage compared to linear voltage regulators. This makes it possible to have a higher voltage battery source and still be able to step the voltage down for low power devices. Additionally, switching regulators are highly efficient compared to linear regulators since they dissipate very little to no power. The result being a lack of heat related issues in the circuit to account for. A switching regulator is also more effective in passing high current compared to a linear voltage regulator. One important drawback of switching regulators is the moderate to high level of noise they produce. This is undesirable especially for supplying precise output voltages. Due to this, it would be ideal for stepping the battery pack voltage down and passing on the necessary voltage and current to the servos.

A major component of switching voltage regulation is pulse width modulation. Through changing the on-time of the switches in the regulator, the output voltage is modified. The two types of switching regulators that are common for stepping down the power supply voltage are the *Buck* and *Buck-Boost*. The *Buck* switching voltage regulator simply steps down the input voltage. This type of regulator will be most useful since the battery pack has a higher voltage of 11.1V, and all the servos will have a required voltage of less than or equal to 7.4V. The *Buck-Boost* switching voltage regulator can both step down and step up the input voltage. This would be the ideal regulator if a moderate voltage battery pack was chosen, such as 7.4V. With any battery, as the power level depletes, the supplied voltage decreases as well. As a result, a battery with a nominal voltage of 7.4V, could supply a voltage as low as 5-6V when at a low charge state, thus the *Buck-Boost* voltage regulator would then be able to boost the input voltage higher if required by the load. *Buck-Boost* switching regulators are typically more complex, and as a result were not chosen for the ANT-FR power systems. It was simpler to select a higher voltage battery and utilize a *Buck* regulator. Below in table 3.6 are several options considered for *Buck* switching voltage regulators.

3.3.4.4 Selection of Switching Voltage Regulator

Choosing a switching voltage regulator proved to be even more challenging than the linear regulator. As shown in table 3.7, there are many *Buck* regulators that have similar characteristics. The LM2596 and LM2576 have nearly identical features. The differences came down to the slightly different frequency range, as well as the price difference. The LM2576 is significantly cheaper than the LM2596, which would save on cost, especially considering that several switching regulators are needed. Due to this and the fact that the two are nearly identical in all other aspects, the LM2596 was eliminated.

Switching Voltage Regulators Comparison			
Part	**LM2596**	**LM2576**	**LMR14050**
I_{OUT} Max	3A	3A	5A
I_Q	5mA	5mA	0.04mA
V_{IN} Max	40V	40V	40V
V_{IN} Min	4.5V	4V	4V
V_{OUT} Max	37V	37V	36V
V_{OUT} Min	3.3V	3.3V	1V
Mounting Type	Surface	Surface	Surface
Frequency	Approx. Fixed	Approx. Fixed	Variable
Price	**$4.73**	**$3.03**	**$3.37**

Table 3.6. Comparison of Switching Voltage Regulators.

Only two switching regulators remained, namely the LM2576 and the LMR14050. The LMR14050 carried a higher maximum continuous output current at 5A, which is close to the battery pack maximum current. In contrast, the LM2576 carried a respectable 3A. Both switching regulators draw very little quiescent current when in idle, with the LM14050 having a fraction of a milliamp. This low quiescent current translates to higher battery longevity, which is an engineering/marketing requirement for the turret. The LM14050 however, has a slightly higher cost, and utilizes adjustable frequency oscillation. Having to select/adjust the frequency for the integrated circuit would create more complexity surrounding the voltage regulation systems. As a result, the LM14050 was eliminated. The LM2576 was chosen as the switching voltage regulator. Careful consideration and testing will need to be done in connection with the servos, to ensure that they provide the necessary current demanded by the servos. Switching voltage regulators were chosen for stepping the battery pack voltage down to the required servo voltage because of the large voltage step down required, as well as the high load current. Both requirements are strengths of the switching voltage regulator.

3.3.5 Universal Serial Bus 2.0 Type B (USB)

The use of universal serial bus (USB) will be critical for the ANT-FR. Since the onboard microcontroller of the printed circuit board will need assistance processing the facial recognition systems, a USB interface onboard the PCB will link the PCB to an external laptop. This USB interface will convey information regarding image processing between the microcontroller and the laptop. Another consideration of this onboard USB interface is whether it will receive power from the laptop.

It is common in most laptops for USB ports to supply power in addition to data transfer. As such, providing power to the PCB via USB connection from the laptop would be an efficient method of simplifying the power systems and adding modularity to the design. Since the PCB will require roughly 5V for nominal operation, the USB will be more than capable of providing this voltage and low power load. The USB interface however, will not provide power to the servos. These will still need to be powered by the battery pack. Stream-lining the power delivery, as well as communication to and from the PCB through USB will aid in accomplishing several of our engineering/marketing requirements. By receiving power from the USB, the PCB will effectively be running off the laptop battery source which is designed to last several hours at a time without recharging. The external battery pack powering the servos will then be able to provide power longer since there will be a smaller total load.

Related to USB technology is the connection of the camera to the turret system. As a requirement of the facial recognition system, a camera will be utilized as the vision of the ANT-FR. This camera will be connected and powered via USB from the external laptop. By connecting it in this way rather than through the PCB, data transmission to and from the camera will be sped up, resulting in a faster reaction time. This is because the facial recognition system will be run between the microcontroller of the PCB and the external laptop. Utilizing USB in the above methods, will greatly enhance the speed, as well as practicality of the ANT-FR.

The USB interface required will be closely modeled after the reference design of the USB 2.0 Type B interface contained on the single-board microcontroller. These systems have already been proven effective and come with a wealth of knowledge as open source platforms. As such the onboard USB system is designed as a USB bridge. Essentially, the information transmitted in through the USB port must be converted to a UART or serial format in which the microcontroller can interpret. To accomplish this, an advanced integrated circuit (IC) chip is utilized to configure the logic. This advanced IC chip requires software drivers to communicate with the external computer.

Due to the complexity of designing a USB interface on the PCB, many reference designs were considered. By utilizing a USB interface, the need for a secondary microcontroller IC, incorporated onto the PCB is necessary for data translation.

3.3.6 Light Emitting Diode (LED) Indicators

From a functional standpoint, it is desirable for the PCB to have a light that will indicate whether the system is on or off. This will come in the form of a red green blue (RGB) light emitting diode (LED). The RGB LED will utilize pulse width modulation to display different colors and/or patterns to convey the status of the system. PWM will be obtained from one of the corresponding pins of the microcontroller. The microcontroller can then be programmed to control the configuration and status of the RGB LEDs. While being a simple component to the total system, this is important for maintaining a user-friendly system which provides basic I/O information. Due to the simplicity of an LED, a parts comparison table has not been included for this component.

3.3.7 Master Power Push-Button

Since the ANT-FR is a projectile launching system, it is important to have a safety mechanism for shutting it down in case of an emergency. Equally important is the ability to turn off the system in a safe manner. As a result, we have considered designing a master power push-button for disabling power to the servos. Because the servos mechanically aim and fire the NERF turret, providing a push-button to interrupt their power source (battery pack) will be an efficient method for shutting it down. This push-button would act as a switch between the battery pack and voltage regulating components which logically come before the servos themselves. When the push-button has been pressed in the OFF position, the circuit is either directly opened in the case of a mechanical switch, or a MOSFET controls the connection between the input and output pins of the push-button circuit. On the other hand, when the push-button has been pressed in the ON position the circuit is closed, allowing current to flow, and consequently the servos to operate. While switches come in many different combinations of poles and throws, a single-pole, single throw (SPST) switch should suffice for the purposes of switching the system on/off.

An important constraint to note for selecting a push-button switch is the maximum load current and voltage. Since the switch will bear the full current of the load, it must be matched to the right current and voltage. Any given SPST switch has a maximum rated current and voltage that it can safely pass and interrupt. If this rated current or voltage is exceeded, the switch will likely overheat and be destroyed. To accurately select a SPST switch, the nominal load current and voltage should be known. In this case, the battery pack and servos act as the input and output. The push-button should be able to withstand the higher voltage of the battery on the input side, as well as tolerate the current being drawn through it by the load side. Since the servos will have moderate-to-high torque, they will carry a higher nominal current.

3.3.8 Rangefinder

Another relevant technology for the ANT-FR is range finding. While an onboard camera will be utilized for the vision of the turret, this camera will not be able to accurately detect the range or distance of objects/targets within its field of vision. This presents a unique problem. How will the turret recognize if a target is within its range for detection, recognition, and possible engagement? The system has a maximum detection distance in which it will engage if a target enters. It is important to note that for product demonstration, the turret will be demoed in a relatively small room, and as such range will not be an issue. However, the concept of range finding it still relevant for product scaling.

Common range finding technologies include lasers, sonar, radar, ultrasonic, and lidar. All these technologies are utilized in military applications. The most easily implemented of these technologies would be a laser or an ultrasonic sensor. A laser would provide the facial recognition system with a clear visual of its target since it commonly projects a visible beam. Laser rangefinders cast a beam of light towards the object, and a clock measures the time it takes for the beam of light to return to the sensor. Ultrasonic sensors emit sound waves with one sensor and measure the time for the same wave to return to a second sensor, thus giving us an estimate of the distance from the source to the object in question.

Laser rangefinders tend to be commonly used in hunting and military operations where firing upon a target is desired. This technology of range finding is utilized in this application because of its accuracy. Ultrasonic rangefinders tend to be less accurate over larger distances and uneven terrain. Inaccuracy occurs because of the tendency for sound waves to either be absorbed by objects, or to reflect in a direction away from the ultrasonic sensor, thus skewing the actual distance. Ultrasonic rangefinder technology, however would still be useful for the ANT-FR along with laser rangefinders because the showcase environment will be a smaller room with even surfaces. Below in table 3.7 are several options considered for supplying the turret with range finding capabilities.

Rangefinder Comparison

Part	**Ultrasonic Range Finder – XL – Maxsonar EZ4**	**Ping Ultrasonic Distance Sensor Board 28015**	**HC-SR04 Ultrasonic Range Finder**
I_{OUT} Max	100mA	35mA	-
V_{IN} Max	5V	5V	5V
V_{IN} Min	3.3V	5V	5V
Pulse Reading Time	100ms	115μs	-
Price	**$49.95**	**$27.00**	**$2.50**

Table 3.7. Comparison of Rangefinders.

3.3.8.1 Selection of Rangefinder

When searching for viable range finding sensors, it was common to find them in pre-fabricated boards because of the complex nature of their design. Major design criteria that were compared are maximum range, maximum output current, and the price. The Maxsonar EZ4 carried a hefty price tag at $49.95, as well as the highest maximum output current of 100mA. While this output current is still within the design constraints of the PCB, it is an unnecessarily high drag on the power systems. For the above-mentioned reasons, the Maxsonar EZ4 was eliminated.

The remaining two range finders being the Ping Ultrasonic Distance Sensor Board 28015, and the HC-SR04 Ultrasonic Range Finder were easy to compare. While having similar voltage characteristics and minimum range finding distances, the maximum range finding distances differed. The 28015 can only detect objects up to 300cm or 3m away, while the HC-SR04 can detect objects up to 500cm or 5m away. Finally, the HC-SR04 is substantially less expensive at only $2.50 compared to the $27 price tag of the 28015. For these reasons, the HC-SR04 was chosen as the turret's range finder should we decide to implement this additional feature as a stretch goal.

3.3.9 Servos

Servos will be used to engage the trigger mechanism of the Nerf Gun and to position the robotic system with a horizontal rotation and a vertical tilt. The system will be responsible of taking the position of the target in a three-dimensional space, necessitating depth perception, and translate that into a quantifiable angular position for both servos. An early design draft for controlling the vertical tilt had been to implement a pneumatic piston as it would allow for quick immediate changes and it would have a higher load weight tolerance than most servos. The idea was rejected early on due to the slow reaction time and lack of precision; the pneumatics would also require an onboard air compressor which would increase expenditures for little benefit.

The degree of motion available to the servo will affect the efficiency and accuracy of the turret to be positioned to aim the Nerf Gun at the target's center of mass. The conventions for rotation in servos are encoded to either 180 or 360 degrees, or unencoded continuous rotation. It is preferable that the rotation of the servos be encoded, as to give allow the onboard CPU to decode the position of the validated target from the laptop computer into angle values. A weaker, unencoded continuous servo would be ideal to control the firing mechanism into short, nonuniform bursts as it does not require any degree of precision.

Between the two types of encoded servos, 180-degree motion and 360-degree motion, the choice would depend on its position away from the center of mass of the system, the total weight of the system, and the resistance to rotation and tilt the system has when acted on. Servos with 180-degree motion would be required to be placed closer to the system, increasing the torque and initial voltage needed which would necessitate a higher voltage range to operate, but would require less time to reposition which increases responsiveness. Servos with 360-degree motion would need to be placed further away from the center of mass which decreases the needed torque and initial voltage, effectively lowering the operational voltage when in motion, but it would require that the servo rotate for longer and decreases responsiveness.

3.3.9.1 HSR-2645CRH

Servo model HSR-2645CRH is a low powered, continuously rotating servo belonging to the Hitec line of specialty servos. The Hitec line of servos can be tuned using a Hitec Servo Programmer, which configures parameters such as sensitivity and expected resistance to tailor the user's experience. This servo comes included with a 24-tooth spline output shaft but is does not provide position feedback as it lacks encoder; this continuous motion relies on voltage pulse and continuous power supply, removing any degree of accuracy.

3.3.9.2 HSR-2648CR

Servo model HSR-2648CRH is a low powered, continuously rotating servo belonging to the same fabrication type as the HSR-2645CRH and is user configurable. Unlike the HSR-2645CRH, this model implements a 25-tooth spline output shaft. Like the HSR-2645CRH, it does not provide position feedback as it lacks encoder; this continuous motion relies on voltage pulse and continuous power supply, removing any degree of accuracy.

3.3.9.3 HS-5645MG

Servo model HS-5645MG is a low powered, encoded servo from the Hitec servo line that can rotate at a maximum of 199 degrees. Like the HSR-2645CRH, the HS-5645MG comes with a 24-tooth spline and is configurable using a Hitec Servo Programming.

3.3.9.4 HSB-9380TH

The HSB-9380TH is a high-performance servo from the Hitec line that is encoded to ensure accuracy for fine-tuned rotation. It boasts several programmable features such as dead band width, direction of rotation, speed of rotation configuration, endpoints, neutral points, fail safe switch, fail safe points, resolution, and overload protection. This model also contains one of the highest stall torques at 6 V for Hitec standard size servomotors.

3.3.9.5 Selection of Servo Motors

Table 3.8 provides a comparison between various performance markers and prices of three servos of similar size and voltage requirements. The figures listed are under no loading weight, or "stall" conditions, and may not be entirely representative of overall performance.

Comparison of Servo Motors

Model	**HSR-2645CRH**	**HS-5645MG**	**HSB-9380TH**
Dimensions	40.6 x 19.8 x 37.8 mm	40.6 x 19.8 x 37.8mm	40.6 x 19.8 x 37.8 mm
No-load Speed @ 6.0V	0.15sec/60deg	0.18sec/60deg	0.17sec/60deg
Stall Torque @ 6.0V	138.87 oz/in	168.0 oz/in	472 oz/in
Max Travel (out of box)	Continuous	119.0deg	120deg
Pulse Amplitude	3-5V	3-5V	3-5V
Price Range	**$31.99**	**$64.00**	**$179.99**

Table 3.8. Comparison of Servo Motors.

There is a noticeable increase in performance between the HSR-2645CRH and the HS-5645MG, from stall torque to speed at zero load, despite having the same price range, with the latter also using less power for both low and high voltage operations which would increase estimated runtime at full charge. The HS-5645MG is encoded to allow precision whereas HSR-2645CRH is not. Due to its great performance per cost and its accuracy, servo model HS-5645MG is the preferred option. There is nearly a three-fold increment of the stall torque performance between the HS-5645MG and the HSB-9380TH but the increase in price may justify the additional expense. The servos operating on the horizontal rotation and the vertical tilt are not required to be identical, with the vertical tilt requiring the servo to maintain its position firmly against the weight of gravity. The team agrees that the performance increase does justify the higher cost, thus the servo to be used for pitch rotation will be HSB-9380TH.

The design for the frame necessitates a continuously rotating servo to achieve full degree of rotation for the turret. The servo will be attached to a wheel with a high degree of traction that will be located on the end of the disc base of the sentry turret, which in turn is assisted by bearings while maintaining the center of the disc affixed. Servo model HSR-2645CRH, while lacking the degree of precision needed for controlling pitch rotation, is continuous and capable of rotating at 46 RPM at the minimum, which translates well when considering the resistance offered by the turret.

3.3.10 Communication Devices

After detecting the valid target, the external computational device must send a verification signal to the robotic system to commence firing. The criteria for the method of the turret to maintain an external connection are that it must prove to be reliable under expected runtime conditions, common place to ensure component availability, and realistic to implement on both the PCB and the computer at real time.

3.3.10.1 Wi-Fi

Wi-Fi connection is not ideal as it would inhibit the laptop computer’s ability to connect to the online database of targets. One could resolve this by having the profiles of the potential targets stored onto the laptop computer and have the operator control the system from there, but that would defeat the purpose of implementing a web application or a mobile application to select the next valid target.

3.3.10.2 Bluetooth 4.2

Bluetooth allows for devices to connect to another Bluetooth enabled device using short-ranged radio waves. A variation of Bluetooth, Low Energy Bluetooth, is especially useful for embedded system designs, reducing the operational voltage by nearly half.

While Bluetooth is a popular standard in mobile devices, there is no guarantee that the transmitter and receiver set would be present in devices such as laptops or desktop computers. Implementing this method would require additional peripheral devices to maintain connection which will consume more resources, both financial and power.

3.3.10.3 UART Microcontroller

USB peripherals will be provided with their operational voltage by the host to sends a 5V power supply to the PCB, lifting the burden away from external battery packs which can mainly focus on the servos and other peripherals. The main subtypes of USB for a given version are Type-A and Type-B, where the differences may seem to be superficial but increases the stability between a host and its peripheral.

As the onboard ATmega328p is not well equipped to interpret and process signals from a standard USB 2.0 connection, the use of another processor to convert a USB connection into a 5V serial TX and RX sequence that can be read by the main processor will be needed. The three methods for the USB to serial conversion under consideration are an Atmel model ATmega16U2 microcontroller, an FTDI model FT232HQ-REEL dedicated USB to Serial UART chip, and Silicon Labs CP2102-GMR. Below in table 3.9 are the UART microcontroller comparisons.

Comparison of UART MCUs

Component	**ATmega16U2-MU**	**FT232HQ-REEL**	**CP2102-GMR**
Description	AVR microcontroller	Single Channel USB to Serial	Single-Chip USB-to-UART Bridge
Number of Pins	32	48	28
Interface	SPI, USB, UART, USART	UART/FIFO IC	USB, UART
Memory Size	16 kB Flash	None Specified	1024 B programmable ROM
Min. Supply Voltage	2.7 V	2.97 V	3.0 V
Max. Supply Voltage	5.5 V	3.63 V	3.6 V
Watchdog Timer	Yes	No	Yes
Cost per Unit	**$2.52**	**$4.25**	**$3.17**

Table 3.9. Comparison of UART MCUs.

The Silicon Labs CP2102-GMR is an integrated circuit that specialized to serve as a USB to UART bridge and is marketed as to quickly add USB capabilities to reduce development time and is fully compatible with USB 2.0 standards which is a great benefit.

Unfortunately, this component comes programmed from the manufacturer which reduces flexibility and it is being phased out by the manufacturer, being flagged as "not for new designs". While this integrated circuit may be beneficial for its simplicity and it is at a comparable price, the team prefers the flexibility allotted by the ATmega16U2 microcontroller and as such the CP2102-GMR will not be used.

The ATmega16U2 is programmed as a USB-to-serial converter, the technical descriptions specify a throughput approaching 1 million instructions per second. Using the Atmel microprocessor may prove beneficial as it uses a supply voltage range that the team wishes to use, removing the need to implement yet another voltage regulator output. While the FTDI chip is specialized to serve as a USB to serial converter, the lower supply voltage range would require another voltage regulator for its power supply - increasing costs and design complexity. For these reasons, the ATmega16U2 is the preferred option if USB 2.0 is selected for communication.

3.3.10.4 Selection of LAN Technologies

Table 3.10 takes three components that implement a method of local-area data transfer, quantifies various qualities and compares them based on similar categories.

Comparison of Communication Devices			
Type	**LE Bluetooth 4.2**	**Wi-Fi**	**USB 2.0**
Transfer Medium	Radio - 2.4 GHz	Radio - 2.4, 5 GHz	Physical
Reference Model	RN4871	E103-W01	MAX3421E
Dimensions	9 x 11.5 x 2.1 mm	3 x 16 x 24 mm	7.8 x 12.2 x 16 mm
Power Consumption	1.9 to 3.6 V	3.0 to 3.6 V	1.4 to 3.6 V
Interface	UART - ASCII	UART - ASCII	USB to Serial
Range	100 m	100m	Cable Length
Price	**$ 7.90**	**$2.50**	**$4.12**

Table 3.10. Comparison of Communication Devices.

Bluetooth transmits data over radio frequency at common channels which other sources of radio frequency, such as Wi-Fi or other Bluetooth devices, could create interference. In addition, Bluetooth is not a secured connection and may be easily interfered with or hijacked by someone with malicious intent. A Wi-Fi signal must be maintained between the host and the peripheral, which would restrict access to the internet if only one adaptor is present on the host. This may be resolved with the ability of Operating Systems to share data to devices connected to the same network, but this is implemented and controlled with the computer's Operating System and would not be feasible or realistic for the team to implement on the turret's embedded systems.

USB types contain the same number of connector pins and have identical data transfer rates for their respective version, allowing for an ease of conversion should the need arise. USB is also backwards compatible, allowing peripherals with an older standard to connect to a host that implements the newer. The difference between Type-A and Type-B is that the later makes a clear distinction on which of the two connected components is the host and which is the peripheral as to prevent a short circuit. Type-A USB ports are generally located on host computers while Type-B ports, and other subtypes like mini-USB and micro-USB, are located on the peripheral.

3.3.11 Camera

The camera selection is a major component as the facial recognition is solely dependent on the input being provided by the camera. A bad resolution or low frames per second will distort the video streaming and images being received as input to the facial recognition software, which will produce higher false positives or false misses, and make the recognition unusable if a human cannot be detected.

3.3.11.1 Logitech C930e

The Logitech C930e series is designed as a business webcam and features a high field of view and high definition zoom. The most notable features for this camera is the 90-degree field of view, which most standard cameras display a 78-degree field of view. The C930e offers a Full HD 1080p at 30 frames per second but doesn't offer 60 frames per second. The camera comes with auto-light correction and an autofocus feature which will be highly desirable for this project. A common issue with this camera series is that it can display some inaccurate colors, which can be an issue when attempting to use color detection algorithms.

3.3.11.2 Logitech Pro/Brio Webcam

The Logitech Pro/Brio series is the newest and best high-tech camera from Logitech for a consumer level webcam designed for Ultra High Definition video conferencing. The most notable feature about the Brio is the 4K Ultra HD 2160p at 30 frames per second. An optional 60 frames per second at 1080p is available but doesn't offer full high definition. Adjustable fields of view for 65, 78, and 90 degrees are available with a 5x high definition zoom. The camera comes with auto focusing and auto-light correction which can be very useful in outdoor environments. Overall, this camera offers the best in resolution. The 4k resolution is a great feature, but not many services utilize 4k resolution, as technology hasn't caught up yet, and this feature can go unused.

3.3.11.3 Razer Kiyo

The Razer Kiyo is widely popular as a streaming webcam and is most notable for its multi-step light that surrounds the camera. This light is adjustable to various brightness levels and provides extra illumination and elimination of harsh shadows in the background. While using this feature in the daylight may not be as noticeable, this feature during night time would be noticed. The Kiyo offers an 81.6-degree field of view with a high definition of

1080p at 30 frames per second. An option for 720p at 60 frames per second is available as well. This webcam also offers an autofocus feature and a still image feature of 2688x1520, which can be very useful for taking snippets from video streaming for facial analysis. One notable issue with this camera is that even small movements can trigger the camera to auto-focus, which may be unreliable during high movement activities.

3.3.11.4 Selection of Cameras

Table 3.11 below shows the comparisons between all three camera options and the final selection of the camera being used.

Comparison of Camera Devices			
Type	**Logitech Pro/Brio**	**Logitech C930e**	**Razer Kiyo**
Resolution	4K UHD 2160p	Full HD 1080p	HD 1080p
Field of View	90	90	81.6
Frames Per Second	30	60	60
Digital Zoom	5x	4x	None
Autofocus	Yes	Yes	Yes
Auto-light Correction	Yes	Yes	Yes
Lens	Glass	Glass	Glass
Weight	4.7oz	5.7oz	10.6oz
Dimension	2.5in x 1.4in x .73in	1.14in x 3.7in x .95in	3.66in x 5.08in x 1.06in
Price	**$159.99**	**$129.99**	**$99.99**

Table 3.11. Comparison of Camera Devices.

All three cameras have their pros and cons and offer different purposes for the desire of the project. The Razer Kiyo is the most affordable option but the auto focusing issue can come into play when the turret will be operating in a high traffic area and many objects will be passing through the camera's field of vision. The choices would come down to both Logitech cameras, which heavily differs in features and pricing. The Logitech Brio is by far the superior camera as the 60 frames per second on the C930e is only available in 720p. As the camera is a major component for this project and this project is dependent on a reliable camera source. For these reasons, the selection will be the Logitech Pro/Brio series.

3.3.12 Microcontroller

The microcontroller is the heart of the printed circuit board and will function as the control unit for the entire project. A microcontroller is a small computer on an integrated circuit, but very primitive in nature compared to a system on a chip. Because of the reduced sizes and costs, a microcontroller is ideal for an economical design and for digital control in devices or processes. Microcontrollers are highly popular in devices for data collection, sensing, and actuating.

3.3.12.1 ATmega Series

The Atmel ATmega series features advanced high-speed AVR core, a large flash memory and an integrated analog to digital and digital to analog converters. The flash memory ranges from 4kb to 256kb, and the pin size ranges from 28 to 53 I/O pins. These pins include dedicated pulse width modulation pins from 3 to 6 pins., depending on the model. This series is UART enabled which is needed for the USB interface to communicate between the MCU and the USB, while most microcontrollers support a UART interface.

3.3.12.2 ATXMega Series

The Atmel ATXMega series features an advanced High-performance AVR core, a large flash memory and an integrated analog to digital and digital to analog converters. This series is identical to the ATmega series but offers a much lower voltage of 3.3V compared to the ATmega 5V. The ATXMega generally tends to have more advanced peripherals which has an added level of complexity and better utilization for more complex projects. The programming behind the ATXMega is significantly different as well, which may cause issues when testing on an ATmega MCU and converting to an ATXMega MCU.

3.3.12.3 AT89 Series

The AT89 (8051) series is a highly popular and old series that has been around for a long time and still widely in use around the world. The flash memory ranges from 1kb to 32 kb and offers a range of 20 to 44 Pins. The architecture is easy to understand and the documentation for this series is readily available because of how long this series has been around. The 8051 is easy to assemble on a breadboard and the 40 Pin DIP package is useful for testing purposes. A major downside to this series is the lack of on-chip peripherals, which interfacing new peripherals will greatly increase the cost and complexity.

3.3.12.4 Selection of Microcontroller

Table 3.12 below shows the comparisons between all three camera options and the final selection of the camera being used.

The AT89 series is a great pick, but due to the lack of peripherals and with newer architecture, such as AVR, the AT89 series will not be selected. The ATmega and ATXMega series are both excellent choices and both microcontrollers fulfill the requirements needed for this project. The deciding factor would be the comparisons between the cost of each microcontroller, where the ATmega328p is approximately 3 times cheaper than the ATXMega128D3. For this reason, the selected microcontroller will be the ATmega328p.

Comparison of Microcontrollers			
Type	**ATmega328p**	**ATXMega128D3**	**AT89C51RC**
Architecture	28-pin AVR	64-pin AVR	40-pin 8051
I/O Pins	23	50	32
Timers	2-8bit, 1-16bit	5-16bit	3-16bit
Memory	32kB	128kB	32kB
Internal RAM	2k SRAM bytes	8k SRAM bytes	512bytes
Oscillator	20MHz	32MHz	24MHz
A/D Converter	10-bit 6 channel	12-bit 16 channel	None
Price	**$2.20**	**$6.90**	**$2.50**

Table 3.12. Comparison of Microcontrollers.

3.3.13 Non-Expanding Recreational Foam (NERF) Gun

Foam ammunition is preferred for this project due to the low risk of damage to the sentry's internal components and of injury to either the operator or the target when utilized correctly. The foam ammunition type and the weapon of choice would affect the design of the frame and other hardware components, as such, the following sections will present the benefits and disadvantages of the three main ammunition types and compatible weapons.

3.3.13.1 Foam Dart

Foam darts are the most ubiquitous ammunition type for foam weapons, which have since diversified with accessories such as glow-in-the-dark seams or suction-cup ends. However, most weapons using foam darts as their default ammunition mainly implement spring magazines or ammunition belts which have proven difficult to quickly reload.

One weapon taken into consideration that makes use of foam darts is the Nerf N-Strike Elite Rhino-Fire Blaster. The main benefits of the Elite Rhino are that it is mounted on tripod with stabilized swivel, can be repurposed to fit the dowel of the hardware mount to be controlled by the servo, and that it is fully motorized, which increases the range to a range of 90 ft on average. The ammunition is loaded by either side, loaded by a spring-loaded drum for a faster reload. The single detriment, other than the limitations placed by the gun's ammunition type, is the high price point, $137.68 without any accessories, additional darts, replacement drums, or battery packs.

A comparable blaster, while not boasting the same capabilities of the Elite Rhino, is the Adventure Force Enforcer Belt Blaster which is also fully motorized, achieving a range of 80 ft when fired, for a lower price of $41.99. The greatest fault in the design is that it features belt-fed ammunition that can only hold 40 darts at a time and requires hand reloading.

3.3.13.2 NERF XLR Discs

Foam discs are touted as reaching further distances than foam darts, yet they are more susceptible to curvature due to rotation and wind resistance - reducing their overall range and accuracy. The foam disc ammunition is a key feature of the Nerf Vortex series of blasters, yet they have made an appearance in the latter Zombie Strike series. The physical design of the foam discs makes it difficult to load seamlessly into the chamber of most weapons, which is why most nerf vortex series guns are not motorized and require the use of pump-action to load its ammunition.

Weapons under consideration that makes use of foam disc ammunition are the Nerf Vortex Nitron and the Nerf Vortex Revonix 360. The Nitron is the only weapon from the Nerf Vortex series that makes use of a motorized flywheel, which increases its range and accuracy, and its loaded with a round spring magazine that holds 20 discs. The Nitron is a very limited presence in the marketplace due to its discontinuation which raises the price from original $39.99 in the United State by entire orders of magnitude. The other blaster under consideration is the Nerf Vortex Revonix 360 as it has the largest range at 60 ft and implements rotation spring barrel that fits 30 discs. The Revonix is, as opposed to the Nitron, pump-action and would require further mechanical components to automate.

3.3.13.3 High-Impact Rounds

Foam ball ammunition have been widely adopted in Nerf's Rival series and are a relatively late addition to the ammunition type supported by foam weaponry providers. Foam balls are marketed as "High-Impact Rounds" due to the high kinetic energy potential. One weapon under consideration that makes use of foam ball ammunition is the Nerf Rival Nemesis MXVII-10K that uses a motorized flywheel, which increases range and kinetic impact for automatic fire, and a hopper fed ammunition system that holds 100 rounds. The average retail price of the Nemesis comes at $99.99 in the United States, which is quite attractive for its relative performance.

Another weapon that boasts similar capabilities is the Nerf Rival Khaos MXVI-4000 which also implements a motorized flywheel to increase its range and automate its firing mechanism, yet the ammunition of the Khaos is fed through a bottom loaded spring magazine that holds 40 rounds. The average retail price of the Khaos comes at $69.99 in the United States.

3.3.13.4 NERF Weapon Selection

The main qualifiers when it comes to the foam weapon that will be mounted on the sentry turret base is the ease of reloading, ammunition capacity, and simplicity of the firing mechanism. The specific weapon chosen will affect the design for the hardware of the base, the embedded circuitry, and may increase the number of peripheral components that would increase cost and complexity. Below in table 3.13 shows the comparisons between the different models.

Comparison of NERF Guns			
Model	Rhino-Fire	Nitron	Nemesis MXVII-10K
Series	N-Strike Elite	Vortex	Rival
Product Number	34276	32218	B8240US20
Capacity	50 rounds (25 drum)	20 rounds	100 rounds
Ammunition Type	Nerf Darts	Nerf XLR Discs	High-Impact Rounds
Ammunition Intake	2 x Drum	1 x Magazine	1 x Hopper
Mode of Fire	Automatic	Automatic	Automatic
Batteries Required	6 "D" Batteries, Battery Pack	6 "C" Batteries	6 "D" batteries, Battery Pack
Shelf Status	Available	Resellers	Available
Price	**$99.99**	**$39.99**	**$99.99**

Table 3.13. Comparison of NERF Guns.

The two weapons that implement foam disc ammunition, the Nitron and the Revonix, have a serious detriment as the Vortex series of Nerf blasters have been discontinued in late 2013 to make room for the Zombie Strike and Mega series of blasters, which decreases availability and increases the price of the remaining weapons through third party vendors. Furthermore, the Revonix requires pump-action to load its ammunition into the chamber, which would require additional components such as a hydraulic cylinder or a pneumatic piston to create enough force and to automate the reloading process. Due to the limited availability and the hurdles to automate the reloading of the weapons, neither the Nitron nor the Revonix will be implemented

Out of the two weapons that implement foam darts, the Nerf N-Strike Elite Rhino-Fire Blaster and the Adventure Force Enforcer Belt Blaster, the Rhino appears to be an ideal candidate while the Enforcer is seriously lacking in capabilities. The sentry mount affixed to the bottom of the Rhino at center mass would provide an ideal location to drive the dowel that facilitates pitch rotation; in addition, the drum magazines inserted into either side are quite beneficial when it comes to speed of reloading. The Enforcer, while it does provide a stable mount to which it can be controlled with servos, implements a small ammunition belt that is susceptible to jamming and would require human interaction to hand-load. Out of the two foam dart blasters, the Rhino is a serious contender and will be considered as a backup choice. The two guns in the Nerf Rival series, the Nemesis MXVII-10K and the Khaos MXVI-4000 are both comparable weapons as they are fully automatic and motorized, while holding a decent number of rounds. However, the lack of a hopper on the Khaos and decrease in range due to the lower price point is not an acceptable exchange for the team. The Nemesis is the candidate for the weapons systems over the other options, including the Rhino, due to its hopper system, range, and availability.

Overall, the Nerf Rival Nemesis MXVII-10K is the best fit for this project as the hopper can be customized via 3D printing to make a bigger ammunition storage which can store more rounds and increases up time of the turret firing.

3.3.14 Firing Mechanism

To fire the NERF gun, an electrical connection is required to connect the onboard NiMH rechargeable battery and the firing motors. The NERF gun contains two flywheel motors and a hopper agitator motor which propel the foam ammunition out of the barrel. The positive lead wires of all three of these motors will be disconnected from the onboard safety switches and spliced together as one wire. Additionally, the positive lead wire for the NiMH rechargeable battery contact will be disconnected from the safety switches. To fire the NERF gun, the motor wire and battery wire need to be connected. Since ANT-FR is autonomous, this electrical connection needs to be controlled by the primary microcontroller. To accomplish this, a relay module will be implemented. The relay utilized, has common, normally open, and normally closed terminals. The positive lead of the battery will be connected to the common terminal, while the motor wire should be connected to the normally open terminal. In this configuration, the wires are not connected unless the relay receives a signal to close the contact between the common and normally open terminals. To control the contact within the terminal 5V, ground, and digital signal connections should be made with the primary PCB. The 5V and ground connections act as a reference voltage to assist in toggling the contact, while the digital signal line allows the external microcontroller to toggle the relay. A Vellman 5V single relay module was chosen to accomplish this task.

3.4 Parts Selection Summary

This section outlines the summary of all the selected parts in section 3 that our team will be using to design and construct our project. Below in table 3.14 is a summary of the part selections.

Part Selection Summary Part 1			
Part Type	**Product Model**	**Part Type**	**Product Model**
Single-Board Microcontroller	Arduino Uno Rev 3	Li-Ion Battery	Tenergy 18650 11.1V 6600mAh
Voltage Regulation	LM3940 LM2576	Rangefinder	HC-SR04

Table 3.14. Part Selection Summary Part 1.

Part Selection Summary Part 2			
Part Type	**Product Model**	**Part Type**	**Product Model**
Servo	HSB-9380TH HSR-2645CRH	Primary Microcontroller	ATmega328P-PU
USB Microcontroller	ATmega16U2-MU	Camera	Logitech Brio Webcam
NERF Gun	NERF Rival Nemesis MXVII-10K	NiMH Battery	NERF Gun 7.2V Rechargeable Battery Pack
Relay	VMA406		

Table 3.15. Part Selection Summary Part 2.

3.5 Facilities and Equipment

The University of Central Florida's facilities and equipment are available for our team to use to build our senior design project. The Texas Instrument Innovation Lab located on the first floor of the Engineering II building can be used as a maker space, where 3D printing, laser cutting, work benches, and tools are available for students. The fourth floor of Engineering I has a lab room to perform testing and maintenance on hardware components and computers to work with to perform analysis of our parts. There are many areas on at the university to work in, but these two locations will be the primary facilities used while on campus.

Our sponsorship from the Valencia College's Division of Engineering and Built Environments does not come in a monetary value but they are allowing us to use their facility resources to build our project. Valencia college offers separate facilities for various components of our project design. The first will be the Open Computer Lab which has workbenches, computers, and equipment for testing and maintenance. The equipment and software in this lab are: oscilloscopes, function generators, breadboard testing, soldering devices, voltage meters, AutoCAD, EagleCS, SolidWorks, Multisim, and drafting software. The lab also bolsters a healthy supply of small parts such as resistors, capacitors, inductors, and wiring. The second is a 3D Printing Lab which has over a dozen different 3D printers from different manufacturers and different types of materials consisting of Acrylonitrile Butadiene Styrene (ABS) plastic, Polylactic Acid (PLA) plastic, and Photoreactive Resin. Each material has a variation of colors and properties which will be used based off the need of the project. The 3D Printing Lab also comes with many drafting and design software and common tools with workbenches to perform cleaning and maintenance on the 3D prints. The third is the Mechatronics and Electrical Engineering Lab which offers many of the same resources as the Open Computer Lab. The fourth is the Photonics and Optics Laser Lab, which offers various sizes and intensities of lasers combined with the software and testing components need for them. While Valencia

College’s facilities will be able to properly assist our team with most resources needed, the Division of Engineering and Built Environments also has a storage facility where most bigger and heavier equipment is stored such as: milter saws, table saws, circular saws, torque wrenches, impact wrenches, nail guns, air compressors, drill sets, and various power tools and small hardware such as nails, bolts, or screws.

The bulk of the project will be built and/or stored at Valencia College’s Division of Engineering and Built Environments. The reason our team has decided to do the base of our work from here is for two reasons. The first reason is the location of each team member’s home, which are much closer to Valencia College than the University of Central Florida. This allows for a shorter driving distance and more time to meet up and work on the project. The second reason is based off the utilization of the University of Central Florida’s facilities. The spaces are too small to accommodate all the students who are currently in senior design and forces students to arrive to the labs first or schedule an appointment to get work done. This will be a great burden to any team and reduce performance which will no longer be a major issue when working out of Valencia College.

4 Related Standards and Realistic Design Constraints

A standard specifies characteristics and technical details that must be met while a design constraint refers to a limitation on the requirements and operation of the design. Both are essential for any design as they create a set goal path on how to implement a design in the real world. This chapter covers the overall view of the standards and design constraints that are team will be focusing on while researching and designing our project.

4.1 Standards

Standards are essential in the world of engineering because standards provide the fundamental foundations for every engineer to work together and complete goals. Without standards, engineers can develop technology which may work on some applications but not on others because that engineer wanted a task to be novel. This creates an unnecessary difficulty that slows progress and hinders teamwork. Standards fix these issues and gives a set guideline on how a system should operate so that every application can use that system.

4.1.1 Web Development Standards

Hypertext Markup Language (HTML) and Cascading Style Sheets (CSS) are cornerstone technologies in the display of information from an online database to the user for both web applications and mobile applications; both HTML and CSS are maintained by the World Wide Web Consortium (W3C). It may prove advantageous to use the HTML standard due to HTML5's increased support of multimedia elements such as images, audio, and video. The website and database are at the mercy of the established Internet Protocol Suite and standards developed by the Internet Engineering Task Force such as the HTTP application protocol, TCP transfer protocol, and the IP (IPv4, IPv6) network layer.

There are no true web development stack standards, but there are many established ones that have become commonplace in the industry implementing software components that have been standardized. For this project, the team will develop the server database with a LAMP stack, consisting of Linux, Apache, MySQL, and Python. The language MySQL is a preferred derivation of SQL, a domain-specific language used for managing data which is a recognized standard by both the ANSI and the ISO. Python, while not a recognized standard by de jure, is taken as a de facto standard programming language; it will be used for CGI scripting in in the LAMP stack as an alternative to Perl or PHP due to the team members familiarity with it. By using a website to interface the end user to the robotic system, the team must either purchase bandwidth and storage from an internet hosting company to maintain the database or host it on their own.

4.1.2 LAN Standards

After detecting the valid target, the external computational device must send a verification signal to the robotic system to commence firing. The criteria for the method of the turret to maintain an external connection are that it must prove to be reliable under expected runtime conditions, common place to ensure component availability, and realistic to implement on both the PCB and the computer at real time.

4.1.2.1 IEEE 802.15.1

IEEE 802.15.1 allows for interaction between two pared computer devices that share compatible versions, which are intended to be backwards compatible, and are set to be discoverable. A low energy application is implemented on the standard which is ideal for embedded systems and in lower-end smartphones. For general purpose, the standard is designed as full duplex, but individual components, especially in the case of low energy or simplified UART instructional set, would reduce the connection to a half-duplex.

4.1.2.2 IEEE 802.11

IEEE 802.11, which includes various derivations, is a standard for WLAN connections to enable computer communications via local radio frequency. This standard implements a half-duplex system that would only allow for communications along a single channel but only in one direction at a time. The standard may also provide flexibility as it commonly uses the 2.4GHz UHF and 5.8GHz SHF ISM radio bands, of which are subdivided into multiple channels.

4.1.2.3 Universal Serial Bus 2.0 (USB)

The USB is an industry standard that creates a specification for connection, communication, and power supply between computers and their peripheral device. USB standard is currently maintained by the USB Implementers Forum (USB IF). The specific type under consideration is USB 2.0 which supports a data rate of 60MBps. As a USB can transfer a consistent 5V power supply with a current of up to 500mA, the USB acts as a convenient power source for low powered machines that the team can take advantage of and power the embedded components of the PCB with the USB connection directly. Doing so allows for relocating external power resources to other subsystems such as the servos and firing mechanism.

4.1.3 Portable Battery Pack Standards

4.1.3.1 General

Standard IEC 60086-2, BS gives a general overview on standards, including secondary cells. The ANSI C18 series of standards goes more into detail about specific types of portable cells and batteries, while still encompassing most battery technologies. The ANSI C18 series of standards that will be considered are the ANSI C18.1M Portable Primary Cells and Batteries with Aqueous Electrolyte - General and Specifications, ANSI C18.2M Portable Rechargeable Cells and Batteries - General and Specifications, and ANSI C18.3M Portable Lithium Primary Cells and Batteries - General and Specifications.

4.1.3.2 Nickel-Metal Hydride (NiMH)

Standards BS EN 61951-2:2001, IEC 61951-2:2001, and BS EN 61951-2:2003 specify secondary NiMH cells and batteries containing alkaline or other non-acid electrolytes, which are portable sealed rechargeable single cells. BS EN 61951-2:2003 serves as an update to accommodate modern designs and technologies.

4.1.3.3 Lithium-Ion

There is a misnomer that needs to be addressed. Lithium Batteries use Lithium in its pure metallic form and are not designed to be rechargeable, while Lithium-Ion cells implement lithium compounds that are designed to be recharged hundreds of times. Henceforth, lithium cells that are mentioned as being rechargeable are Lithium-Ion cells. Standards BS EN 61960-1:2001 and IEC 61960-1:2000 specify secondary lithium cells and batteries for portable applications, while standards BS EN 60086-4:1996 and IEC 60086-4:1996 denote primary batteries and safety standard for lithium batteries.

4.1.4 Lasers and Laser Rangefinder Standards

4.1.4.1 Classification and Availability

Standard IEC 60825-1 specifies the main characteristics and requirements for the classification system due to safety concerns. The revised classification system limits commercial availability and legality of use, it is divided into seven classes: Classes 1, 1M, 2, 2M, 3R, 3B, and 4. Of the seven, only classes 1, 1M, 2, and 2M are commercially available without the need for a license or government approval.

4.1.4.2 Laser Safety

The ANSI Z136 series of standards specifies standards for safety and is divided into several subpoints that are dedicated to the use of lasers for specific uses and applications. The standard under consideration is ANSI Z136.8 – Safe Use of Lasers in Research, Development, or Testing – provides guidance for the safe use of lasers and laser systems found in research, development, or testing environments, where safety controls, common for commercial lasers may either be missing or disabled.

4.1.5 Printed Circuit Board Standards

Standard IEC 61188-5-1 PCB Assemblies – Design and Use provides information on land pattern geometries used for the surface attachment of electronic components. Standard IEC 61191-1 Printed Board Assemblies Part 1 General Specifications Requirements specified the requirements for soldered electrical and electronic assemblies using surface mount and related assembly technologies.

Standard BSR/IPC 2615-200x Printed Board Dimensions and Tolerances covers the dimensions and tolerances of electronic packaging as it relates to printed boards and the assembly of printed boards. The concepts defined in this standard are derived from

American National Standard for the dimensions and tolerances, ANSI/ASME Y14.5-1994 (R1999).

4.1.6 Coding Convention Standards

While coding and programming languages are not usually standardized themselves, there are many guidelines for common practices and conventions exist for specific applications of programming languages.

The Apache Software Foundation have released a style guide for the C programming language in respect to the Apache HTTP Server and related services. The conventions outlined in the style guide are meant to increase functionality and promote proper documentation. General guidelines under Apache include the naming and declaration of functions under ANSI-style arguments and the use of a single expression per line except for when unary operations or negations are employed. The Apache may also recommend layouts for levels of indentation and for flow control, but it is flexible and allows for the guidelines to be broken if needed.

Further coding conventions exist for the implementation of the SQL domain management language. The conventions for the SQL language are meant to increase database security and data integrity such as the formatting reserved words, naming functions descriptively, and parsing or limiting user input. This last guideline is especially important as it prevents an attack on the server using SQL Injections, in which a malicious SQL statement is inserted (or "injected") into a data field to be executed.

4.1.7 Universal Asynchronous Receiver/Transmitter Communication

Universal Asynchronous Receiver/Transmitter, or UART, is a serial communications interface in the form of a physical circuit commonly found within microcontrollers or as a stand-alone integrated circuit. Two UART-capable devices communicate by converting parallel information from a controller into a sequence to the receiver, the receiver then converts the data back into a parallel form. All of this requires a physical connection from the transmitter pin of one device to the receiver pin of the other, and vice versa. Figure 4.1 below shows a simplistic model of the RS-232 Protocol used by UART communications to transmit digital information as a sequence.

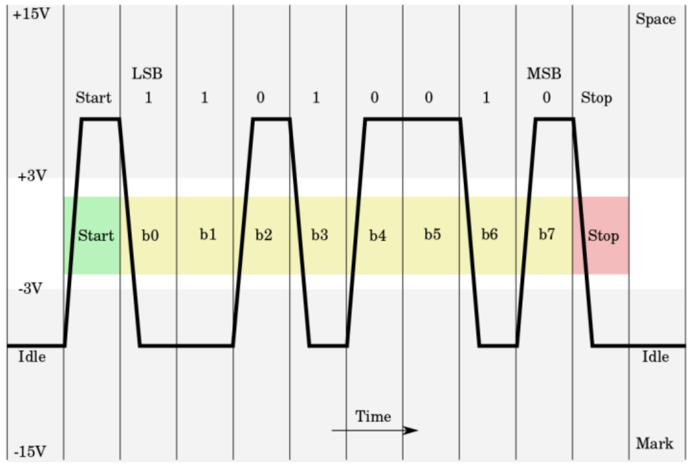

Figure 4.1. Diagram of RS-232 Oscilloscope Trace.
(Reprinted with permission from Wikimedia Commons).

The model shows how the protocol initiates transmission by sending specified start-signal, it then alternates between a voltage over a ±3V threshold within a specified frame, and it concludes after a stop signal is reached. UART communications is a subsection of the larger Universal Synchronous/Asynchronous Receiver/Transmitter (USART) microchip that facilitates communication through a computer's serial port using the RS-232C protocol. While UART communications requires a larger sequence of bits per second (or baud), it offers fewer options for its base format and is limited to the RS-232 protocol, it is still preferable over USART. The benefit from greater functionality is negated by the increase in complexity. The use of the external clock with USART would allow for continuous communications at a higher data rate than with UART, up to 4Mbps, but this comes at the cost of increased power demands. While USART can be used as a simple UART by disregarding the synchronous clock generation, it defeats the purpose of using USART and would present itself as an unnecessary price increase for little in return.

4.1.8 IEC 62680-1-2:2018 Standard

A standard that encompasses all versions and types of USB is the IEC standard 62680-1-2:2018, a revision of the previous 62680-1-2:2016 and 62680-1-2:2017 which have been withdrawn and revised. The 2018 revision of the standard defines power delivery system interface covering all elements of a USB including hosts, devices, hubs, chargers, and cable assemblies.

4.1.9 IEEE 1118.1-1990 Standard

IEEE 1118.1-1990 Standard for Microcontroller System Serial Control Bus describes the serial control bus for the interconnection of microcontrollers and other devices with limited re-programmability that are independently manufactured and may be distributed. The documentation of the standard contains the definition of the bus network and provides a reference model for protocol as well as confirming that 1118.1-1990 conforms with its parent standard 1118-1990.

4.1.10 IEEE 1044-2009 Standard

IEEE 1044-2009 Classification for Software Anomalies is a standard that provides a uniform approach to the classifications of software anomalies, unconcerned with the anomaly's origins or the time encountered within the project lifecycle. This standard defines practices that increase the probability that defects are detected within a system at early stages of development, which may prove crucial for certain software development models. One such model is the Waterfall Model, where errors that are detected early are inexpensive to correct while errors encountered late into development are quite costly.

4.1.11 IEEE 208-1995 Standard

IEEE 208-1995 Standard on Video Techniques defines methods for measuring the resolution of camera systems are described and image quality. The primary application of the methods defined in the standard is to quantify the limit where fine detail in a captured image or frame can no longer be reproduced by the camera. This standard helps define when the details of a subject are lost to the point that the face detection and facial recognition algorithms can no longer identify features and will fail.

4.1.12 IEEE 200-1975 Standard

IEEE 200-1975 Reference Designations for Electrical and Electronics Parts and Equipment defines methods and practices to uniquely identify and locate discrete items on diagrams and in a set, as well as for correlating items in a set, graphic symbols on diagrams, and items in parts lists, circuit descriptions, and instructions. The standard sets out to standardize the use of iconographic representation for the benefit of the international community.

4.1.13 EIA / TIA Serial Communication Standards

Serial data transmission standards maintained by EIA/TIA including RS-422, RS-449, and the S485 20mA current loop are used for many data links, providing effective connectivity for the day but not nearly as widely used today. Standards developed and maintained by EIA/TIA are effectively defunct since 2011 when the EIA ceased operations, yet these standards influenced the industry. Some standards associations maintain legacy support or have developed standards based on those previously held by EIA/TIA and their partners.

4.1.14 DS/IEC 748-1 Standard

DS/IEC 748-1 Semiconductor Devices. Integrated circuits. Part 1: General specifies integrated circuits as being a circuit where all or most of the internal circuitry and components are closely associated. The widespread adoption of integrated circuits being considered indivisible, acting as a single component, serves to simplify construction and commerce. This standard defines multiple subsections of integrated chips such as single-chip integrated circuit, multichip integrated circuit, and thin-film integrated circuit

4.1.15 IEEE 1481-2009 Standard

IEEE 1481-2009 - IEEE Standard for Integrated Circuit (IC) Open Library Architecture (OLA) delineates methods for integrated circuit designers to "analyze chip timing and power consistently across a broad set of electric design automation" [49]. These methods allow for integrated chips to express timing and further increase performance and capacity in a uniform way. This standard has replaced the defunct IEEE 1481-1999 - IEEE Standard for Integrated Circuit (IC) Delay and Power Calculation System when it was approved by the board in December 9, 2009,

4.1.16 Encompass Light Emitting Diode Standards

CIE 13.3-1995 Method of Measuring and Specifying Color Rendering Properties of Light Sources is a standard that recommends that consumers and manufacturers not use white light LEDs with fluorescent and HID lamps. The Commission on Illumination published this regulation to further increase safety for the established methods of verifying the color-rendering index, how less a light source renders objects, materials, and skin tones. This standard was introduced at the end of the commission's technical committee in its CIE Technical Report 177:2007 "Color Rendering of White LED Light Sources".

4.1.17 LM-79-08 Standard

LM-79-08 by the Illuminating Engineering Society of North America is a series of approved methods for the Electrical and Photometric Measurements of Solid-State Lighting to measure an LED luminaire, better known as an integral lamp, as a whole system according to a standard process using specified equipment for luminous flux. The methods will be able to determine the testing report issued according to a standard format that will provide total luminous flux, luminous intensity distribution, electrical power characteristics, luminous efficacy, and color characteristics.

4.1.18 LM-80-08 Standard

IESNA LM-80-08 is an approved standard for measuring the lumen maintenance of an LED source which is meant to apply to LEDs as either a package, array, or a single module, but only at a component level. This is only at component level and should not be undertaken with the complete system, and the guide does not provide methods of extrapolation. The methods within LM-80-08 will provide the luminous flux of a current over 6000 hours with measurements taken at regular intervals.

4.1.19 ISTMT Standard

The Situ Temperature Measurement Test (ISTMT) defines a procedure to measure the LED source case temperature of an LED system, or the temperature of an LED within the luminaire. Once ISTMT is known, we check if the temperature within the luminaire is within the range of operation as indicated by a specific LEDs source report. It is then the basis for lifetime interpolation either based on TM-21-11 or another method.

4.1.20 ANSI C82.16-2015 Standard

ANSI C82.16-2015 American National Standard for Light-Emitting Diode Drivers - Methods of Measurement, this standard describes common procedures and a set of precautions for measuring the performance of LED drivers. The scope of the report by ANSI includes the following with much more unstated: general lighting applications, input supply voltage at 50 or 60Hz, output open-circuit voltage of 600V or less, constant-current or constant-voltage DC output, and configuration in either fixed, variable (dimmable), pulse width modulation, or programmable (tunable) output power. The standard is meant to complement existing standards and specifications that set performance limits and provides guidance for testing methods.

4.1.21 IEEE 1726-2013 Standard

1726-2013 IEEE Guide for the Functional Specification of Fixed-Series Capacitor Banks for Transmission System Applications which is a series of general guidelines to prepare the specifications of a transmission fixed-series capacitor (FSC) banks with a protection against overvoltage. Three technologies mentioned by the standard is metal oxide varistors, metal oxide varistors with forced-triggered bypass gaps, and thyristor protected series capacitors. The standards were reviewed by the IEEE Power and Energy Society and supersedes the previous 18-2002 IEEE Standard for Shunt Power Capacitors.

4.1.22 IEEE 295-1969 Standard

295-1969 IEEE Standard for Electronics Power Transformers, reaffirmed in 2000 and 2007, is a guide for design, application, and test procedures for power transformers and inductors that are supplied by power lines or generators. The power supplied must essentially be a sine wave or a polyphase voltage. The standard further specifies components and definitions relating to transformers and transformer applications such as the rectifier supply transformer, filament and cathode heater transformers, and transformers for alternating current resonant changing circuits.

4.1.23 IEEE 9945-2009 Standard

IEEE 9945-2009 - International Standard - Information Technology Portable Operating Systems Interface (POSIX®) Base Specifications, Issue 7 is a revised and adopted version of IEEE Standard 1003.1-2008 for the global community that defines a standard OS and environment, along with common utility programs, for both application developers and for system implementers.

4.1.24 IEEE 15205-2000 Standard

IEEE 15205-2000 - ISO/IEC 15205:2000 (IEEE Std 1496-1993) SBus -- Chip and Module Interconnect Bus details an input/output bust with either a 32 or 64-bit width. SBus is a module that is designed for systems with a small number of expansion ports, where SBus cards may connect directly on the system's motherboard parallel, such as a mezzanine card. These cards are designed to provide a strong connection for external devices through the back panel and is capable of a transferring data rate of 168MBps. While the standard had been withdrawn after its initial publication date, it has had an impact on the C/MSC Microprocessor Standards Committee with plans to be revised and reintroduced by the committee.

4.1.25 IEC 60062 International Standard

The IEC 60062 International Standard, also known as the RKM code, ensures that leaded axial resistors up to one watt are marked with the electronic color code, a marking system that uses colored bands along the body to indicate component value and tolerance, which can be seen in figure 4.2 below. An electronic code for various electronic components had been established as early as the 1920's but was not standardized until 1952 by the IEC. Color bands were and are still a popular method of labeling components, but they do come at a drawback for people who are color blind or those who suffer from another color vision deficiency.

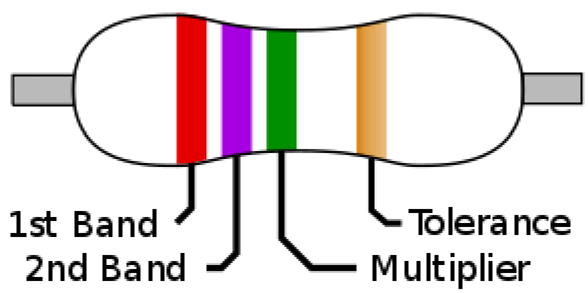

Figure 4.2: Electronic Color Code.
(Reprinted with permission from Wikimedia Commons).

In a common 4 band label for resistors, the first band indicates the first significant figure of the resistive value, the second band offers the second significant figure of the resistance, the third band is the decimal multiplier which states at what multiples of 10 are the values of the first two bands are multiplied by, and the final band indicates tolerance levels (resistors without a band are assumed to have a tolerance of 20%).

Apparent from resistors, the IEC standard does not define a color code for inductors, but various manufacturers default to those established by the resistor color code, encoding inductance in μH. This standard has been revised multiple times and is planned to be updated within the next four years by multiple international standards accreditors such as the ISO.

4.1.26 EIA-96 Standard

This standard is the Surface Mount Device (SMD) resistors are marked with an alphanumeric or numeric code to indicate value and tolerance as the SMD resistors are often too small for the resistor color code as indicated by International Standard IEC 60062.

There are many standards that exist for this type of marking for resistors for 3 and 4-digit codes, which are by far the most prevalent in the industry, being present on Welwyn chip resistors that are common in the industry.

The alphanumeric sequence for IEA-96 is separated into a code that takes a letter, S or Y, R or X, A, H or B, C, D, and E, and two decimal digits, from 00 to 99. The first two digits are taken as the two most significant figures of the resistance while the third indicates to at what power of 10 the resistivity is multiplied by.

4.2 Realistic Design Constraints

Engineers must consider what is feasible or what is realistic when designing a system. This may take the form of monetary constraints due to limited funding, legal constraints due to regulations, and international criminal law, and environmental constraints that are imposed by the location the system is operating in.

4.2.1 Economic and Time Constraints

Implementing a GPU to parallelize and effectively accelerate the calculations required for facial recognition would require that the team interface the card with the PCB and power it separately as appropriate for the model. Design conventions would require a PCI express bus to communicate with the central processor and the onboard memory. Furthermore, the system would necessitate a CPU architecture with a valid instructional set that the GPU can interpret. With an increase in monetary expenses, an upgrade to a dedicated GPU card, and a general-purpose CPU, would result in an increased demand for system memory, weight tolerance, design complexity, and power consumption while decreasing mobility.

Ceding the responsibility of the facial recognition to the PCB would make the embedded systems and PCB design obsolete and require the construction of a general-purpose computer which is not acceptable according to the team’s budget, and to the estimated time frame. As such an external computation device, a laptop computer, will perform the strenuous calculations and transmit simple signals to the turret to authorize weapon fire.

The system will require electrical power to function, yet there is a trade-off that needs to be taken into consideration when the team is deciding between different methods to energize the components. Wall outlets would provide a consistent 120V AC supply which will require an AC to DC converter is also reduced to a safe voltage as to prevent damage to the internal components. A wall mounted power supply would conversely decrease mobility severely and increases the likelihood of a power surge. A rechargeable battery pack would provide reduced amount of voltage requiring a single DC to DC converter, lowering the PCB manufacturing costs, greatly increase mobility, and are immune to power surges in the local area. The detriment of using an external battery pack is that the charge is limited and would require a substantial pause to recharge and that damage to pack would require the purchase and shipping of another.

For practicality in respect to mobility, design simplicity, and cost, the team has found it beneficial to power the system using rechargeable battery packs as opposed to the wall outlets.

4.2.2 Environmental and Social Constraints

Changes in the environment, such as illumination and humidity, may compromise the accuracy of the facial recognition and would need to be considered during the training of the neural networks. Further challenges that may arise from common operation in an outdoors environment is the lack of a firm, leveled foundation on which to secure the mount. Due to these factors that are entirely out of control from the team, it has been determined that the turret will be under operation indoors with standard incandescent lighting to provide uniformity.

4.2.3 Ethical, Health, Political, and Safety Constraints

In accordance to Federal and State laws, as well as local ordinances from the city of Orlando and the University of Central Florida, the members of the team will be mindful of and take steps to prevent unlawful acts, nor shall they promote, instigate, or condone other groups to act unlawfully on their behalf.

4.2.3.1 Ethical

Due to the robotic system mounted foam-based weaponry that may be misconstrued as a genuine firearm, the team will act to clearly mark and label all non-lethal weapons. This will differentiate the component from an authentic firearm. The team will remain in contact with local law enforcement (e.g., UCF Police Department) for direct input to minimize incidents that would incite a panic.

The decision to use foam-based weaponry instead of other non-lethal or lethal weaponry is a deliberate choice to maximize safety, rather than one of convenience. Lethal weaponry had been discarded as an option as to eschew the legal ramifications of Lethal Autonomous Weapons (LAW) imposed by both the United States government and international law. To avoid classification as a LAW by local officials, the selection of a target must be done so by the end-user operator, and there will be no motion to allow the system to change targets without authorization. Other forms of non-lethal weapons and ammunitions had been in consideration during the initial stages of development due to them either resembling firearms too closely, capable of lasting harm and accidental death, or impracticality due to limited range or unavailability.

4.2.3.2 Health and Safety

The system is not intended to be lethal to human beings, as such the system design should consider potential vectors for unintentional injuries that may be sustained by both the operator and the target during regular operation. The target is meant to be shot at center mass, avoiding injuries to their face and head, thus the firing vector should adjust to a direction lower than intended towards the target’s abdomen and chest.

The chassis of the turret is to minimize the number of sharp corners as the corners coupled with the servos' horizontal rotation and vertical tilt would create a slashing motion that may injure people or damage objects within its vicinity. An emergency shutdown button is to be implemented and positioned were the operator can safely access it, of which it should be assumed that the machine may move at any second and any extremities can become caught in the internal workings of the system.

The working parameters and tolerances of the facial recognition software should prioritize accuracy and verification of targets rather than speed, fire-rate, or aggressively as to minimize false positives.

4.2.3.3 Political

There is a growing movement throughout UN member states that propose that a fully autonomous weapons system would threaten human rights and their principles, as well as international humanitarian law, as they are not bound any morality and obscure culpability. This movement is led by the Campaign to Stop Killer Robots (CSKR), calling for a ban on the development, production, and use of fully autonomous weapons systems.

The CSKR's mission is rooted in the desire to "better protect civilians during warfare and its aftermath" [26] as autonomous weapon systems could be used to target civilian populations indiscriminately. The campaign differentiates fully autonomous weapons systems with those that are merely semi-autonomous by the role that humans have during real time operation and if system exhibits independent "goal-oriented behavior" [26].

The campaign lauds the desire to implement autonomous weapons systems to mitigate the loss of human lives in respect to soldiers and other military field personnel. The campaign also condemns the increased risk that civilians are placed by potential lack of responsibility and increased apathy by the militaries and governments that implement these systems.

4.2.4 Manufacturability and Sustainability Constraints

Our team is not manufacturing their own components as the conceptual design, implementation, testing, and production of most new components would take months and are a project onto itself. All hardware components of the robotic system, both onboard the PCB and its peripherals, must be relatively modern, released from reliable manufacturers, and can be purchased routinely from either wholesale or retail vendors. Much of the software required for the facial recognition, neural networks, and the online database archives do not require to be up to date, because previous stable releases being archived or supported long after an update is made. The licenses for this software are generally permissive for academic and in some cases are open source, allowing for redistribution, alterations, and other liberties for use.

5 Project Hardware and Software Design Details

This section covers the bulk of the project outline and how each component will be constructed and designed. The hardware subsection covers the ANT-FR subsystems for the schematics of the PCB which includes the components for the regulators, power supply, framing, USB, and the microcontrollers. The software design subsection covers in detail how the facial recognition will be designed and dives into the user interface which covers the front-end and the back-end components of this project.

5.1 Hardware Design

This section will cover the hardware design, including the schematics of each subsystem of the ANT-FR system. The major subsystems will be discussed to prove their utility, while the schematic will clarify how the individual components will interconnect. Understanding how each subsystem works, as well as how it connects with the complete schematic, provides clarity for project prototyping, assembly, and software design. Prototyping will be based off these major subsystem designs, so it is important to create a functional schematic design.

Schematics were constructed in Eagle CAD, as this was the software of choice for circuit modeling. Utilizing the schematic, Eagle CAD contains a function that will make a rough draft of the PCB layout. This will prove to be extremely helpful when creating the PCB layout due to our lack of experience with designing efficient board schemes. Furthermore, Eagle CAD can create the appropriate bill of materials for the entire schematic, thus helping us to compile the needed components.

5.1.1 Turret Framing

The turret design will be separated into three main components for ease of modularity. The first component will be the vision which will be a connection for the laptop to connect to the turret and webcam. The design for this component is to have a USB connection cable in the center of the turrets frame which will allow for a user to grab the cable and connect the turret into the laptop. The webcam will have a separate USB cable that will run down the center as well, which can easily be plugged into the laptop.

The second component will be the actual frame for the turret and the placement of the printed circuit board. This will be the main component as most of the hardware and materials will be used in this component. An initial base will be used to elevate the turret off the ground and a turn table will be mounted to the base. A servo will be connected to the turn table which will give the turret the freedom to move in a horizontal motion by turning the turn table in the desired direction left and right. Two large pillars will be in the center of the turn table which will be used as the mounting for the third component. In between the two pillars will be a rod which is attached to a second servo motor. As discussed in section 3.2.11, pulse width modulation (PWM) will be an instrumental technology in the ANT-FR circuitry. The regulation of duty cycle of any given control signal will be run through the primary microcontroller. This regulation will allow for various outputs. The primary use for PWM in the ANT-FR system will be controlling the servos. The back of the turn table is where the printed circuit board will be mounted, the power supply, and most of the wiring, which can be seen in figure 5.1 below.

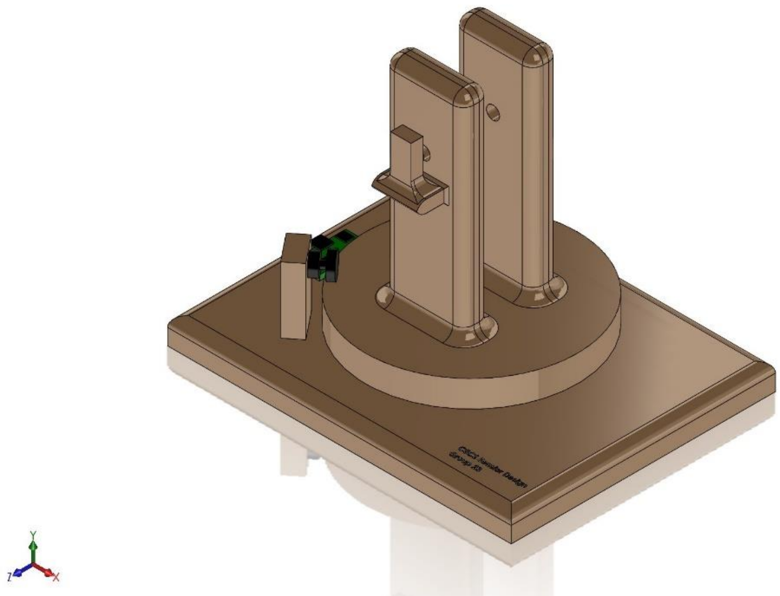

Figure 5.1. ANT-FR Second Component Framing.

The third component will be the NERF gun which will be installed in-between the two pillars of the second component. The NERF guns trigger assembly will be dismantled and repurposed by connecting the trigger assembly directly to the printed circuit board. This will allow the software to send a signal to fire the gun. Also, a kill switch will be installed into the gun to disconnect all power which will stop firing if needed. Overall, the design is to maintain a high modularity and consumer friendly product. A consumer can open the box and pull out the three components and install them directly with ease. The third component can be upgraded or swapped for a weaker or stronger gun, depending on the consumer's desires.

5.1.2 Universal Serial Bus 2.0 Type B (USB) Schematic

The universal serial bus 2.0 type B (USB) subsystem of the ANT-FR schematic and PCB is one of the more complex subsystems. This is due to several reasons; the use of a secondary microcontroller for data processing and translation, overcurrent protection, differential pair utilization, electrostatic discharge (ESD) protection, and electromagnetic interference (EMI) protection. These topics will be discussed below.

5.1.2.1 Overcurrent Protection

Overcurrent protection is vital in the USB subsystem, largely because the entire PCB could be overloaded, thus attempting to draw too much current. This would lead to a current surge traveling back to the connected computer causing damage. To protect against this unwanted scenario, a temperature dependent fuse will be utilized. Any USB 2.0 Type B connection port has four connection pins and a shield. Pin1 would connect to this positive temperature coefficient (PTC) resettable fuse before it moves on to the common 5V rail and pin31 of the ATmega16U2 microcontroller. When a large current passes through the fuse, it heats up and effectively opens the circuit. With the circuit open, the PCB and external computer are protected. The fuse will close the circuit allowing normal operation when it cools off. According to the reference design, a fuse which will operate/pass 500mA of current is ideal.

5.1.2.2 Differential Pair Utilization

Differential pair utilization is another major consideration for the USB subsystem. Pins 2 and 3 of the USB 2.0 Type B connection port are the data transmission lines. These data transmission lines ultimately need to connect with pins 29 and 30 of the ATmega16U2 so that information can be passed back and forth between the external computer and the primary microcontroller of the PCB (ATmega328P). However, care must be taken to ensure that these lines have near identical impedances for two reasons; the first being to ensure that the ATmega16U2 receives a smooth, error free signal, the second being to protect it from ESD. Both transmission lines should have equal trace lengths and be very close to each other when laid out on the PCB design, this will assist in matching the impedances. Additionally, the datasheet of the ATmega16U2 calls for approximately 22Ω (+/- 5%) of impedance which will be taken care of by resistors.

5.1.2.3 Electrostatic Discharge (ESD)

Connected before these resistors are varistors which are a variation of a resistor. The varistors protect against unwanted ESD transmitted through the metal shield and into the four lines. If a large change in voltage is detected in either pin 2 or pin 3, the varistor’s impedance decreases to a very low value, providing an alternate path for the current (rather than through the line resistors). The downstream ends of these varistors are connected to the same node which encounters another protective device. Because of the varistors, the entire PCB will be protected from ESD entering through the USB port.

5.1.2.4 Electromagnetic Interference (EMI)

The protective device encountered by the varistors, as well as the USB shield before entering the ground bus, is a ferrite bead component. This device serves the purpose of protecting the PCB, and especially the USB subsystem, from unwanted EMI which can disrupt the smooth transmission of data. Any interference/noise is absorbed by the ferrite bead and dissipated in the form of heat which allows the transmitted/received data to have minimal noise. Noise and interference is a common issue encountered in micro-electronics, thus this method of handling it is imperative. Below in figure 5.2 is the schematic of the components discussed above. It represents roughly half of the USB subsystem.

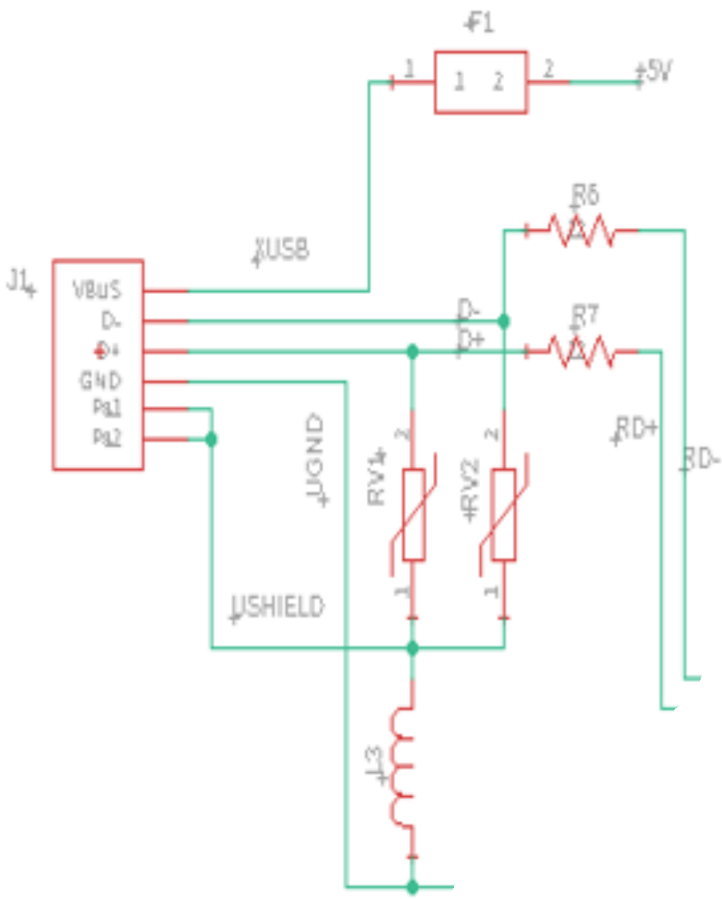

Figure 5.2. USB 2.0 Type B Schematic Part 1.

5.1.2.5 ATmega16U2 for USB

The primary component of the USB subsystem is the ATmega16U2 microcontroller. To properly convert back and forth from UART or serial communication format, the microcontroller requires firmware. It will be ideal for the ATmega16U2 to be purchased with this firmware pre-loaded, allowing us to bypass the use of additional programming headers. Beginning with pins 1 (XTAL1) and 2 (XTAL2(PCO)), a small sub-circuit exists for utilizing a high frequency crystal oscillator. The datasheet of the ATmega16U2 calls for a crystal with a frequency within 400kHz to 16MHz. For the full potential of the microcontroller to be achieved, a higher frequency crystal was chosen. The crystal and a resistor are connected in parallel across the two pins with a capacitor going from each pin to ground. These capacitors act as load capacitors for the crystal while the resistor in parallel assists in amplifying the oscillation.

Pin 3 (GND) directly connects with pin 33 (PAD) and ground. A capacitor connecting pin 4 (VCC) to ground is used. Tied into pin 4 is pin 32 (AVCC) which is also connected to the 5V power rail. Pin 27 (UCAP) is connected to a capacitor which then connects with pin 28 (UGND). It should be noted that pin 28 and pin 33 are connected to each other and act as ground. The fourth pin of the USB 2.0 Type B connection port is also connected to pin 28 for a reference to ground. Perhaps the most crucial connection of the ATmega16U2 is of its path to the ATmega328P. Pin 9 (PD3) passes through a resistor before connecting with pin 2 (PD0) of the ATmega328P. This effectively cross connects TX with RX. Likewise, pin 8 (PD2) passes through a resistor before connecting with pin 3 (PD1) of the primary microcontroller. This time RX is cross connected with TX. Knowing whether these RX and TX communications are occurring between the two microcontrollers seemed useful, and as a result, the 5V power rail was tapped with a resistor in series with an LED, which then connected to pin 10 (PD4). This same method was used for pin 11 (PD5). If TX communication is occurring, the LED on pin 11 will illuminate. Similarly, if an RX communication is in progress, the LED on pin 10 will illuminate. These will prove useful particularly during testing, but also during the project showcase to demonstrate effective communication between microcontrollers.

Concluding the design of the ATmega16U2 circuit is the connection of pin 13 (PD7). This pin connects to pin 1 (RESET) of the ATmega328P indirectly through several other components. A capacitor sits in the middle of the connection with a resistor connected to ground before it. Coming off pin 1 of the primary microcontroller is a resistor connected in parallel with a diode, both attached to the 5V power rail. A reset switch connected to pin 1 of the ATmega328P gives us the ability to manually reset both microcontrollers during the programming process. Below in figure 5.3 is the schematic of the components discussed above. It represents the remaining portion of the USB subsystem.

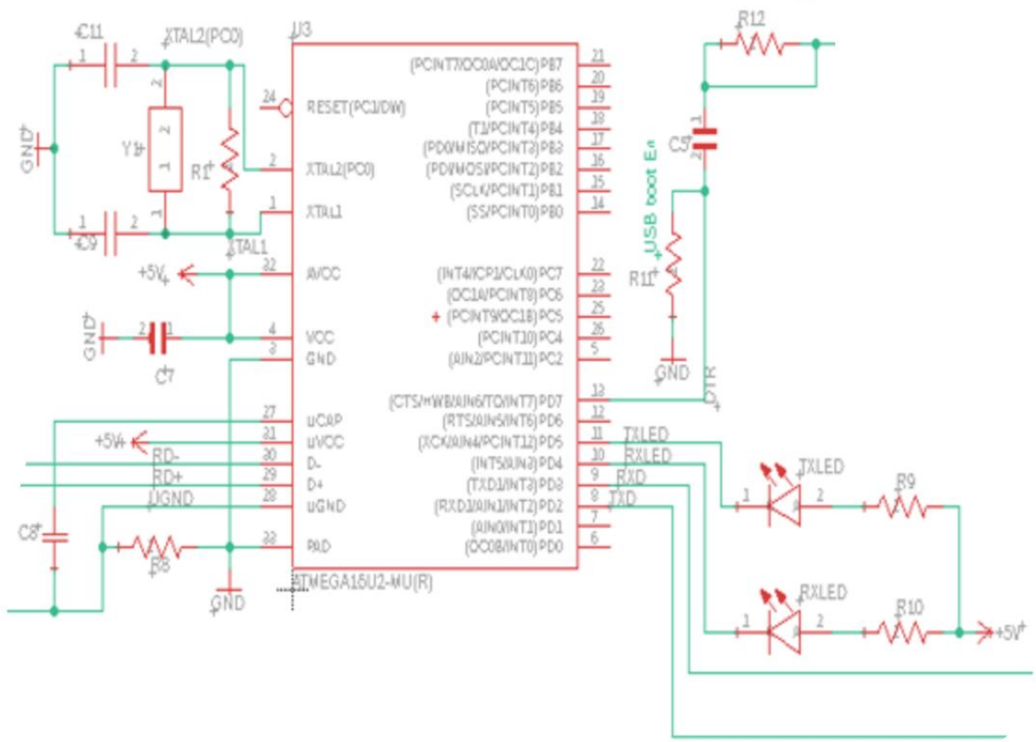

Figure 5.3. USB 2.0 Type B Schematic Part 2.

As discussed, the USB subsystem created a great deal of complexity for the PCB design. The use of a second microcontroller proved to add numerous additional components such as a crystal oscillator, varistors, a fuse, and a ferrite bead. All these unique components serve the various purposes discussed and will combine to provide a stable and reliable USB interface; an interface that is crucial for the ANT-FR. A complete schematic of the USB 2.0 Type B subsystem is shown below in figure 5.4.

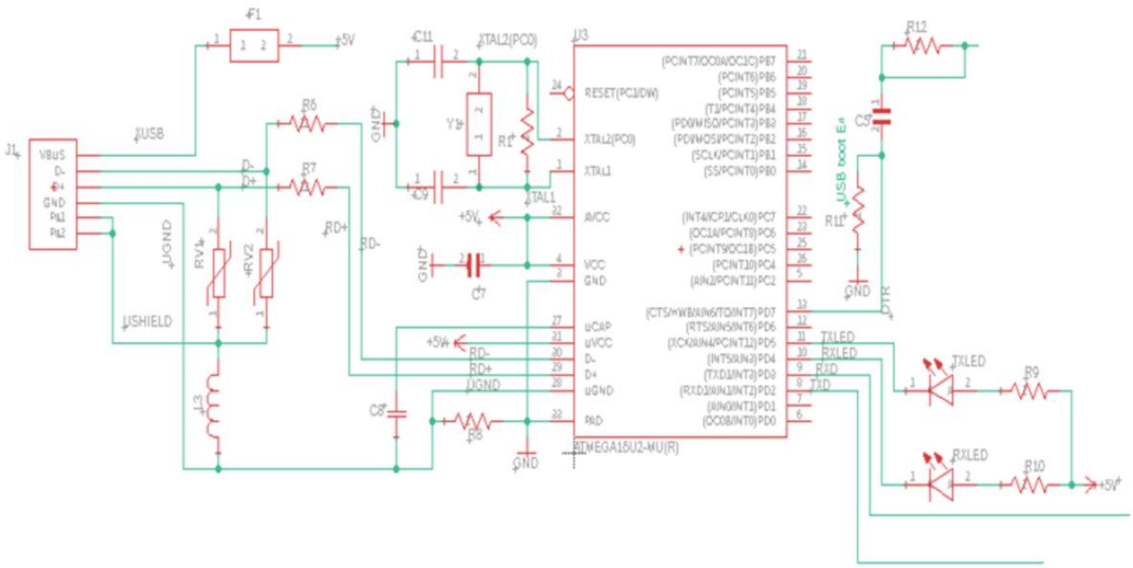

Figure 5.4. USB 2.0 Type B Complete Schematic.

5.1.3 ATmega328P-PU Schematic

The primary microcontroller subsystem of the ANT-FR schematic and PCB is another complex component. Like the USB subsystem, it is centered around a complex microcontroller. As such, this primary microcontroller will be the ATmega328P-PU. The process of prototyping and building the ANT-FR will again benefit from purchasing this microcontroller with a bootloader already installed. By doing so, we can eliminate the need for header pins used for flashing the bootloader onto the ATmega328P. Another design consideration for ease of access and implementation is the use of shield headers in connection with the pins of the ATmega328P. Routing the utilized pins of the primary microcontroller to headers will require additional work when creating the PCB layout, however it will provide an easy and effective method for accessing the PWM compatible pins. A reference design was utilized for a basis of creating this subsystem. The subsystem consists of a bypass section, frequency oscillation, reset function, TX/RX data reception, and output to shield headers.

The first set of components of the ATmega328P subsystem are the bypass circuits. Pin 21 (AREF) runs to ground through a bypass capacitor which helps to stabilize the analog outputs. Pin 20 (AVCC) connects with pin 7 (VCC) and the 5V power rail. This node then has another bypass capacitor running to ground, for stability. Pin 22 (AGND) and pin 8

(GND) are grounded. All these pins together, essentially receive power and provide stability for the ATmega328P.

Like the USB microcontroller, the ATmega328P requires an oscillation device circuit on pin 9 (XTAL1) and pin 10 (XTAL2). The ATmega328P does not require as precise of an oscillator as the USB subsystem, therefore a resonator can be utilized to reduce cost and simplify the design. A resonator typically comes with the load capacitors built-in, therefore the only other component needed is the resistor connected in parallel. The resonator is attached to ground on the load side. Below in figure 5.5 is the schematic of the section of the primary microcontroller subsystem discussed thus far.

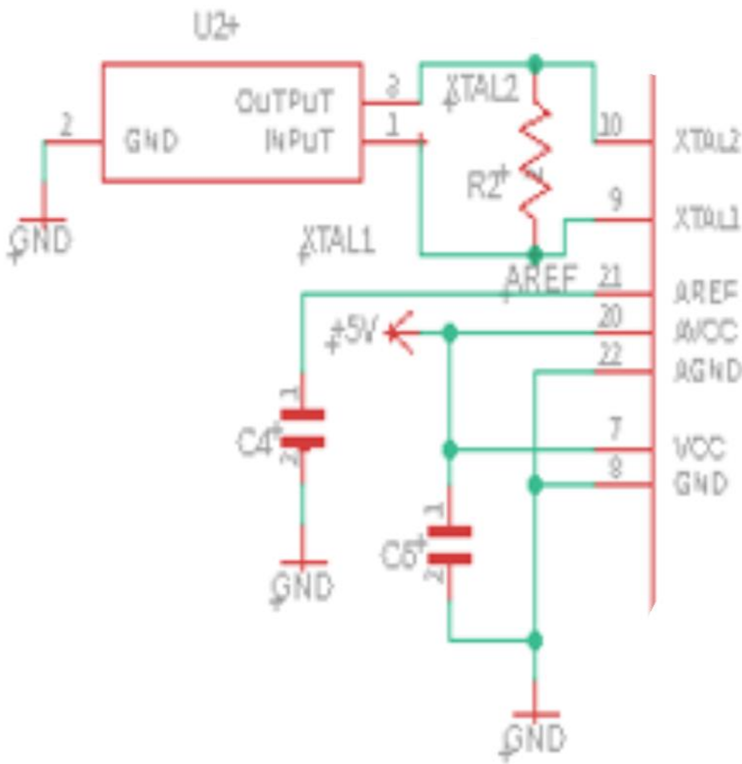

Figure 5.5. ATmega328P-PU Schematic Part 1.

Another major section of the ATmega328P subsystem is the reset function. As partially discussed in the USB subsystem, pin 1 (RESET) is connected indirectly to pin 13 of the ATmega16U2. A capacitor sits in between the two pins. Attached to pin 1 is a resistor and diode in parallel and connected to the 5V power rail. Additionally, a physical reset pushbutton switch is connected across pin 1 and ground which allows the user to reset the ATmega328P during programming. The 5V power rail connected to the resistor and diode allow for charging of the capacitor when it has discharged to ground. The capacitor discharges either through the reset switch or through a resistor connected to ground on the USB side when the data-terminal-ready (DTR) is toggled. Below in figure 5.6 is the schematic of the section of the primary microcontroller subsystem discussed.

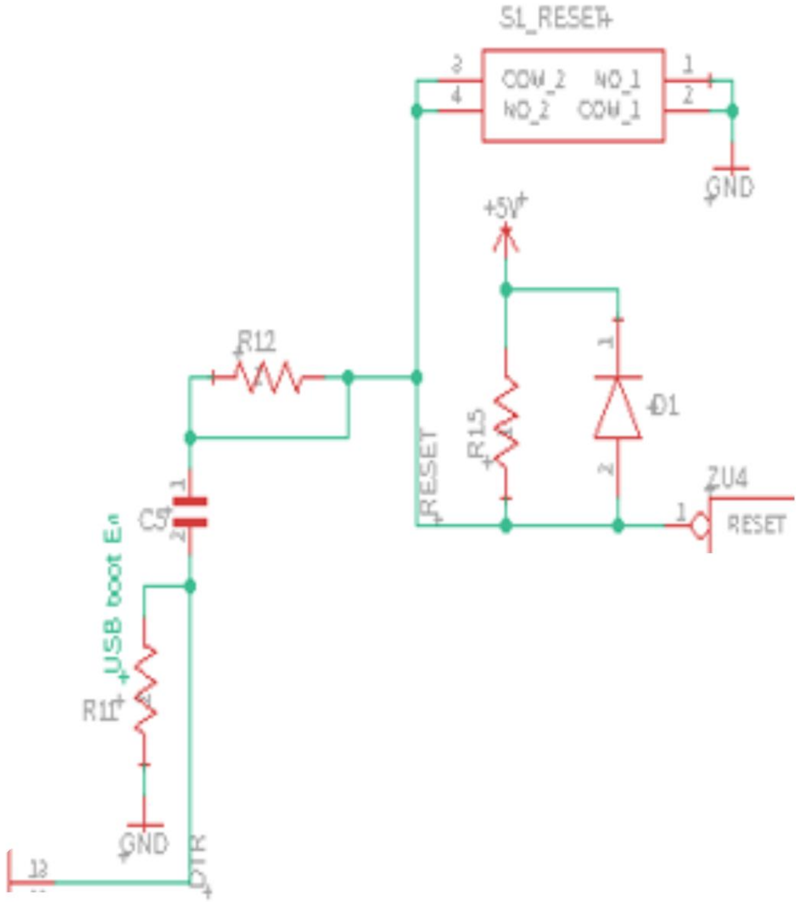

Figure 5.6. ATmega328P-PU Schematic Part 2.

The serial communication between the USB subsystem and the ATmega328P subsystem is crucial for receiving and transmitting data between the PCB and an external computer. As discussed in the USB section, port 2 (RXD) runs through a resistor before it connects with port 9 (TXD1) of the ATmega16U2. Likewise, port 3 (TXD) travels through a resistor before it connects with port 8 (RXD1) of the ATmega16U2. Because of the cross connection between serial ports, data transmitted from the external computer into the USB port is converted to serial format and sent to the primary microcontroller for reception. While simple, these two transmission lines provide the necessary communication between the two microcontrollers of the PCB. Because of the ATmega16U2 and the ATmega328P being in constant communication via the TX and RX serial ports, it is important that these ports not be utilized for anything else. The TX and RX serial ports are designed to be used by only one source at a time; simultaneous use by more than one source would cause disruption to the communication between the two microcontrollers.

Finally, the ATmega328P contains multiple output pins in the form of digital and analog signals. To take advantage of PWM, it is important to understand where this type of control signal can be drawn from in the circuit. Since the turret will utilize the ATmega328P-PU microcontroller, we know that the PWM signal pins are 5, 11, 12, 15, 16, and 17. Within our schematic and PCB design, each of the ATmega328P-PU pins will be tapped into headers which will make it easier to access them. As a result, the servos' control wire can be routed to these designated PWM pin inputs for quick access. Likewise, any LEDs incorporated into the schematic and PCB design will tap into these PWM inputs for proper duty cycle regulation. While there are many pins that are available for use, not all will be utilized. To reduce the complexity of the schematic and PCB layout, only the implemented output pins will be sent to a header. The unused pins have the option of being programmed in a couple of different configurations as needed. Below in figure 5.7 is the schematic of the section of the primary microcontroller subsystem discussed.

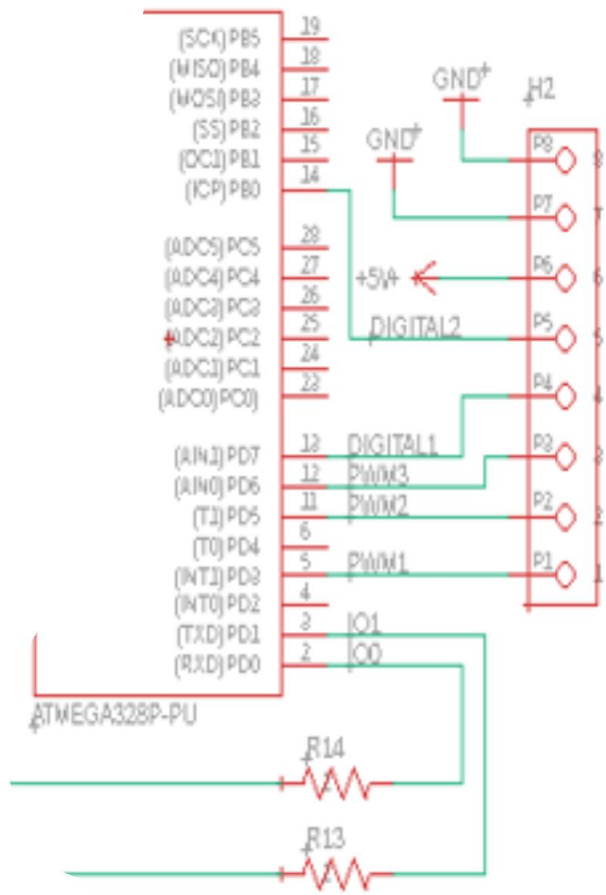

Figure 5.7. ATmega328P-PU Schematic Part 3.

The ATmega328P subsystem design utilized some of the same circuit elements as the USB subsystem, such as the use of an oscillator for frequency regulation. Additionally, bypass capacitors are needed for providing stability to the input power of the microcontroller. While many of the pins will go unused, the utilized outputs will be fed to a header and made easily accessible. All the discussed sections of the primary microcontroller will combine to provide a robust core for the PCB. This subsystem is crucial for the system to function. A complete schematic of the ATmega328P subsystem is shown below in figure 5.8.

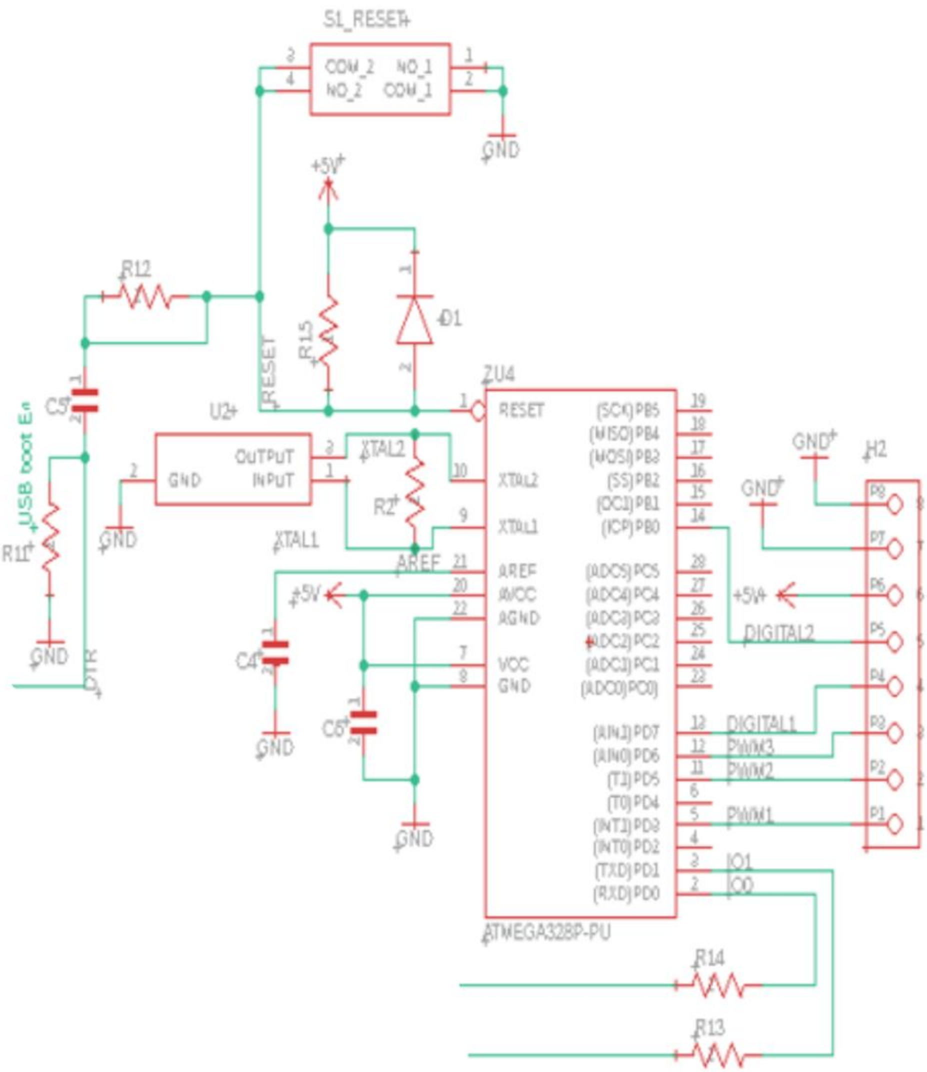

Figure 5.8. ATmega328P-PU Complete Schematic.

5.1.4 Power System: Voltage Rails

Before detailing the power supply subsystem, it will be useful to understand what loads will be placed on the system, as well as their respective voltages. Defining these voltages will allow us to better visualize the flow of the circuit. Below in table 5.1 is the list of loads, their nominal operating voltages, the source of power, and the assigned voltage rail.

As seen in table 5.1 below, there are a wide variety of loads, ranging from the microcontrollers, to the NERF gun itself. Upon inspection of the various operating voltages, the need for common voltage rails becomes apparent. The highest voltage of the

ANT-FR system comes from the lithium-ion battery pack at 11.1V. This voltage is only seen by the switching voltage regulator which will step it down to the nominal operating range of the servos (6V). The servos are the only loads that will encounter the 6V rail. Moving onto the NERF gun, a 7.2V rechargeable NiMH battery pack provides the necessary voltage to operate the NERF gun.

System Load Voltages

Component	Nominal Voltage	Power Source	Assigned Voltage Rail
Servos	4.8-6V	Li-Ion Battery Pack	6V
Switching Voltage Regulator	4-40V (Input)	Li-Ion Battery Pack	11.1V
Atmega328P-PU	1.8-5.5V	External Computer via USB	5V
Atmega16u2	2.7-5.5V	External Computer via USB	5V
Indicator LED	1.7-3.5V	External Computer via USB	3.3V
NERF Gun	-	Onboard NiMH Battery Pack	7.2V
Camera	-	External Computer	5V

Table 5.1. System Load Voltages.

Furthermore, the camera used for the "vision" of the ANT-FR will be directly connected to the external laptop, and as such, will receive 5V. The microcontrollers on the PCB have a flexible operating voltage range and will be connected to the 5V rail created by the USB connection. Finally, the indicator LEDs will be connected to both the 3.3V and 5V rails, dependent on their specific function.

5.1.5 Firing Mechanism

The acceleration trigger acts as a "power switch" for the blaster and is located directly above the firing trigger. Pulling the acceleration trigger causes power from the battery pack to be sent to the flywheel system, powering the flywheels and making them spin and increase the total kinetic energy of a round. The weapon's rate of fire is proportional to how long the main trigger is pulled - where holding it down completely achieves an automatic firing sequence. The team would need to isolate the acceleration trigger and be able to complete the circuit when the firing signal is sent to the PCB from the external computation device.

The firing trigger is located lower on the grip than the acceleration trigger and is purely a mechanical device. This is only inhibited by the series of safety switches which detail whether the gun is powered, if the hopper has been removed, or if the general safety is on. To automate the firing of the weapon, an external 5V relay will be used to make the connection between the internal motors and the NERF gun's battery pack.

The team will need to drive a dowel through the side of the gun close to the center of mass to mount the gun on the two pillars on top of the rotating disc. However, the team does not wish to damage the internal components of the weapon by drilling through the side, nor does the gun provide any area to do so as the weapon is dense with internal components. To counter this complication, a clamp would grip onto both of longest sides of the blaster and secure it while a premade fixture at the bottom allows for the dowel to be driven through. This hollow clamp application would also increase modularity as it would allow for both larger and smaller weapons to be mounted onto the base without damage to either the internal mechanics or the external body.

5.1.6 Power System Schematic

The ANT-FR power supply subsystem, while a smaller design, plays an imperative role in detailing the power rails for the PCB, as well as the battery-to-servos circuit. It is important to note that there will be four sources of power for the turret. The NERF gun will receive power from its own NiMH rechargeable battery pack. Additionally, the camera will be powered by the external laptop through the computer's USB port. Next, the two microcontrollers and corresponding circuitry will be powered off the USB 2.0 Type B connection port, while the servos will be powered by an external lithium ion battery pack. Accordingly, the power supply subsystem consists of the USB power reception, indicator LEDs, and voltage regulation.

Powering the microcontrollers and their corresponding components is the USB 2.0 Type B connection port. This port receives 5V from the external computer it connects with. As a result, pin 1 of the type B connection port brings in this 5V. It is immediately routed through a positive temperature coefficient (PTC) resettable fuse. This fuse protects the external computer from being damaged because of too much load current being drawn through the PCB. When a high current is travelling through the fuse, it heats up and opens the circuit, only closing again when it cools off. After traveling through this protective fuse, the 5V rail of the PCB is established in which the loads requiring this voltage can draw from. Important to note is the bypass capacitor connected from the 5V rail to ground which provides stability against any noise.

While considered an elementary portion of the total schematic, the indicator LEDs will help to make the ANT-FR a user-friendly system. LEDs will give the user an indication of whether the ATmega328P is receiving power and therefore functioning, as well as displaying whether the ATmega16U2 and ATmega328P are communicating with each other through the TX/RX transmission lines. The latter, giving confirmation that the reception and transmission of data is occurring through the USB connection port. A green

LED indicates if the ATmega328P is receiving power. To accomplish this, a resistor is connected to the 5V rail followed by the green LED whose cathode is connected to ground. When the USB connection port is receiving 5V, pin 7 (VCC) and pin 20 (AVCC) of the ATmega328P are connected to the 5V rail. Since the green LED is connected to the same voltage rail, we know the primary microcontroller must be receiving power. Below in figure 5.9 is a schematic of the components as discussed of the power subsystem.

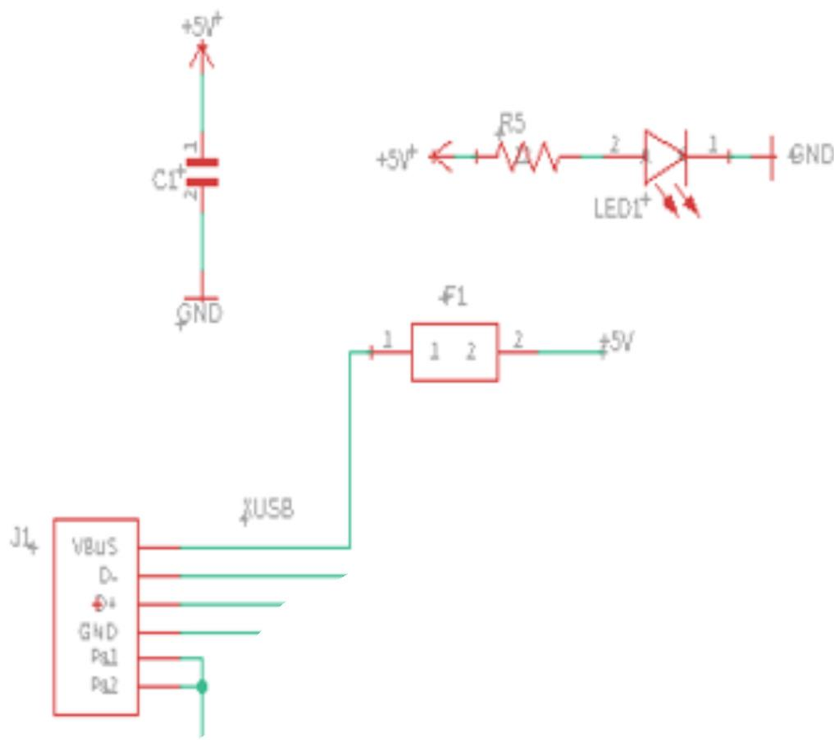

Figure 5.9. Power Subsystem Schematic Part 1.

Another use of indicator LEDs is in connection with the ATmega16U2. A resistor is connected to the 5V rail followed by a yellow LED whose cathode is attached to pin 11 (PD5) of the ATmega16U2. This is likewise done between the 5V rail and pin 10 (PD4). When the TX serial port is being used between the two microcontrollers, the yellow LED attached to pin 11 flashes. Similarly, when the RX serial port is used, the yellow LED attached to pin 10 flashes. As a result, the user can verify that USB to serial communication is occurring. These TX and RX data transmission LED circuits are displayed above in figure 5.9.

Next, is the voltage regulation which occurs within the power subsystem. Voltage regulation allows for the PCB to have the requisite voltage rails for powering each load according to its specifications. The primary location of voltage regulation occurs after the lithium-ion battery. The Li-Ion battery pack provides an input voltage of 11.1V to the input of the switching regulator (LM2576). Also connected to pin 1 (VIN) is a bypass capacitor which routes to ground. Pin 3 (GND) and pin 5 (ON/OFF) are routed to ground. Pin 2

(OUTPUT) is routed to an inductor, which in turn connects to a small network of resistors. Additionally, it is connected to the cathode of a diode whose anode is grounded. Pin 4 (FEEDBACK) connects between the resistors. Another bypass capacitor is connected in parallel with the resistors and the final 6V rail.

Since the Li-Ion rechargeable battery pack will require removal from the circuit for recharging, it will be ideal to have a header for it to connect to for easy installation and removal. Likewise, on the load end, the servos will connect via a three-pin connector. The positive pin should connect with the 6V rail, the negative pin connected to ground, and the control pin connected to an open header pin. This open header pin can be plugged into with an external jumper wire and ran directly to one of the PWM output pin headers of the ATmega328P. Below in figure 5.10 is a schematic of the components as discussed, of the power subsystem.

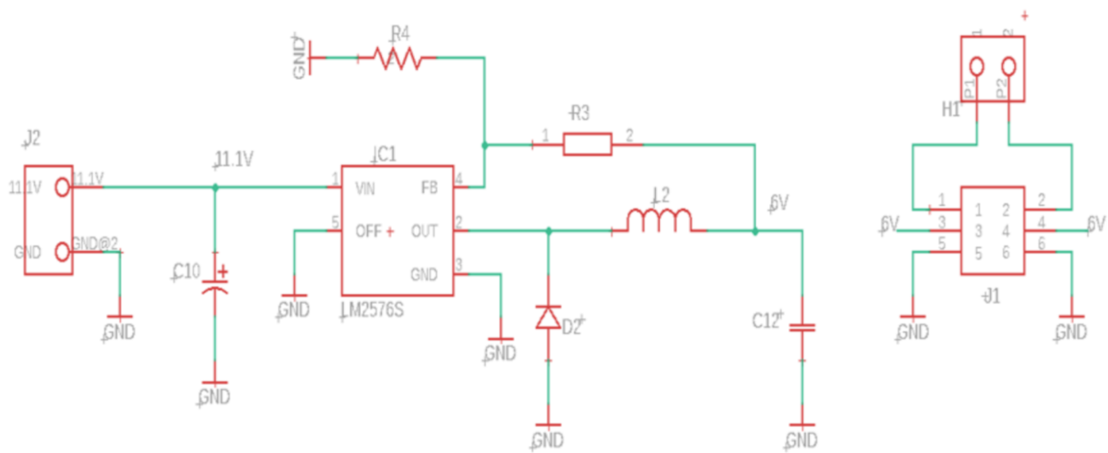

Figure 5.10. Power Subsystem Schematic Part 2.

The power subsystem, while much smaller than the other hardware subsystems, still proved to be challenging to design. This was mainly due to the number of voltage rails to consider. Utilizing the USB 2.0 Type B connection port to set up a common 5V rail for the PCB, will reduce the overall load encountered by the Li-Ion battery pack. With respect to the 6V rail for the servos, the switching voltage regulator proved instrumental in overcoming a large step-down voltage (11.1V to 6V). It will also allow up to 3A of current to be drawn on the load side, which will provide the required current for the servos during higher demand. A key aspect of implementing the discussed connections will be the utilization of headers and common connectors for ease of use. Below in figure 5.11 is a complete schematic of the power subsystem as discussed.

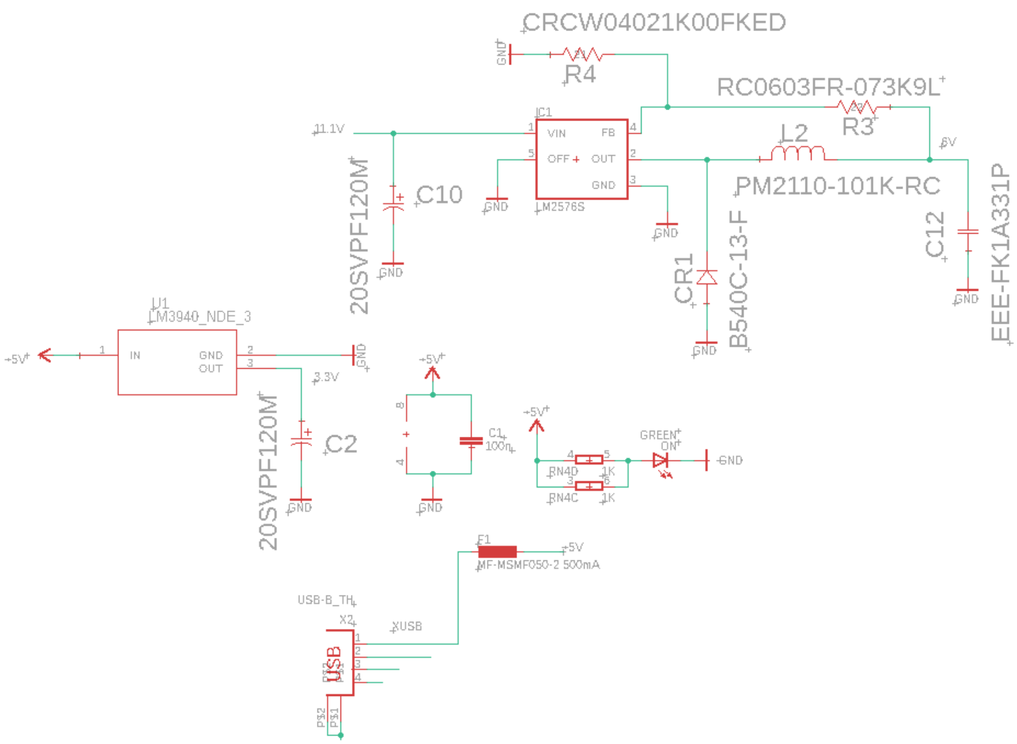

Figure 5.11. Power Subsystem Complete Schematic.

5.1.7 Overall Hardware System Schematic

Each subsystem, namely the USB 2.0 Type B, the ATmega328P, and the power subsystems were combined to create the complete circuit schematic for the ANT-FR. Regarding the next steps of design, it should be considered that to create a more modular design, and to keep the primary power sources separate, it may be advantageous to place part 2, figure 5.10, the power subsystem schematic on its own PCB. However, this will be explored more in the PCB design section. While certain optimizations of this schematic may occur in the coming weeks, it will still serve as the basis of design for the project. With the full schematic complete, the process of creating a PCB layout can begin. Below in figure 5.x is the full schematic for the ANT-FR.

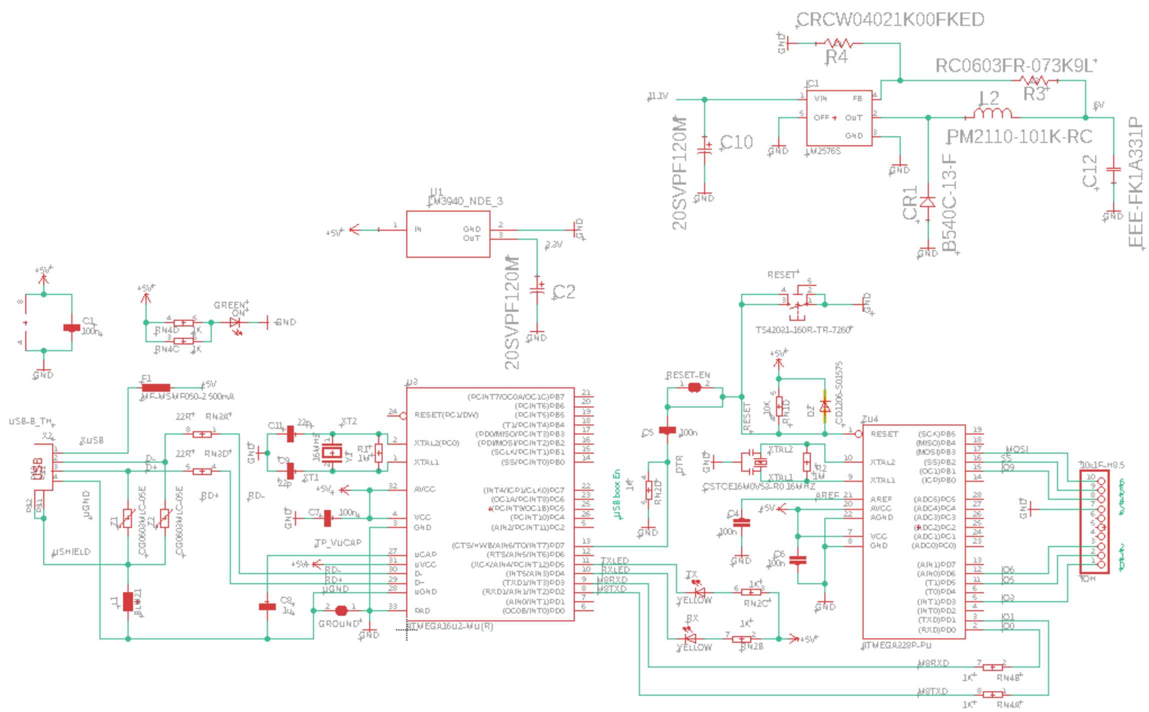

Figure 5.12. ANT-FR Full Circuit Schematic.

5.2 Software Design

The software design is a key component to this project as ANT-FR consists of mostly software because of the facial recognition and user interface. This section dives into detail on the methods and techniques used for facial recognition such as hyperplanes and support vector machines, and to the user interface components such as the database and mobile application. The explicit design for these components are crucial to this project and this section provides the general guideline on how to complete the facial recognition and user interface.

5.2.1 Facial Recognition

The facial recognition software is one of the main components for this project, which will be used to identify the targets in the field of vision of the turret. By connecting the facial recognition software to a database of images, the user can use an application to select targets and the facial recognition software will be able to determine who those targets are when they walk in front of the turret.

OpenFace, which is a free and open source face recognition with deep neural networks, will be used for implementation of the facial recognition portion of this project. OpenFace is mainly coded in Python and uses the program Torch which is a scientific computing framework. Below in figure 5.13 shows the workflow for a single input image and how OpenFace operates on a general level.

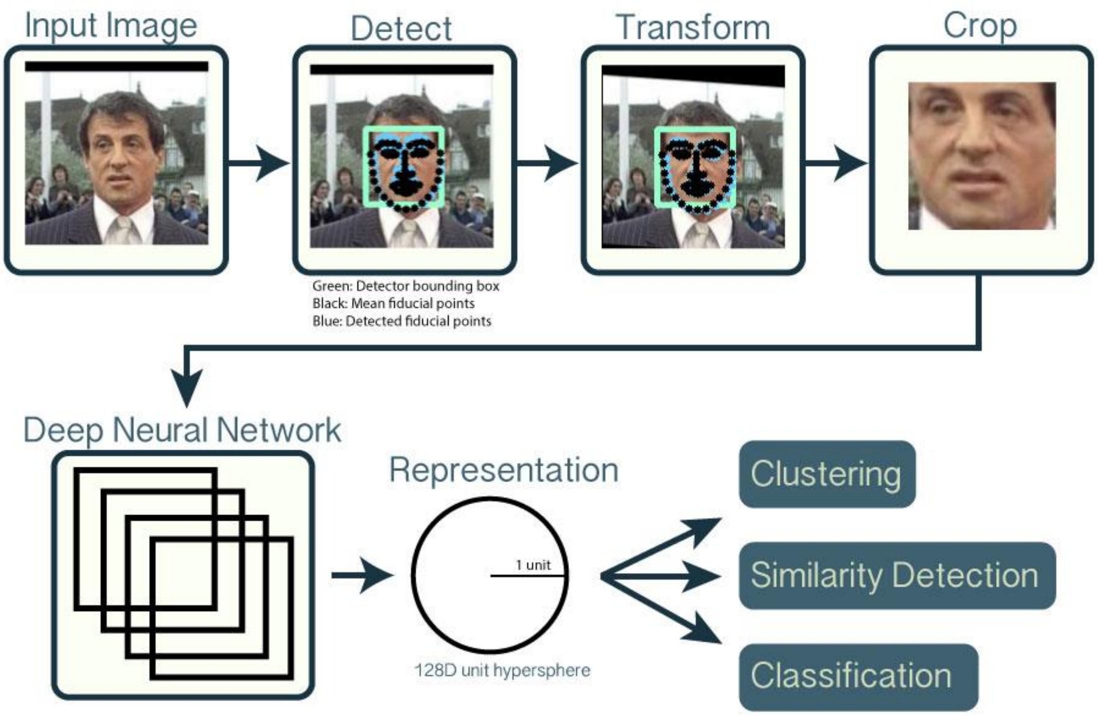

Figure 5.13. OpenFace Workflow.
(Reprinted with permission from OpenFace 2015).

As mentioned in section 3.2.1, there are four main components to facial recognition, which applies to OpenFace as well.

5.2.1.1 Face Detection

The software needs to be able to detect faces with a pre-trained model. Using OpenCV or Dlib, this can be accomplished as there are many functions available for facial detection. Some methods available would be the Histogram of Oriented Gradients or Haar Cascade Classifier. This project will be using the single adaptive boosting technique which is a team of classifiers that can be used, which is compiled by complementing each other's weaknesses. Each team size varies on the need of the user, but generally 15-30 classifiers is acceptable. Each classifier is put into a table with their correct "yes" and incorrect "no" votes for a face in an image. The first classifier is selected based on the amount of correct "yes" answers. Each classifier starts with an input image that is convolved with a pattern image as seen in figure 5.14 below.

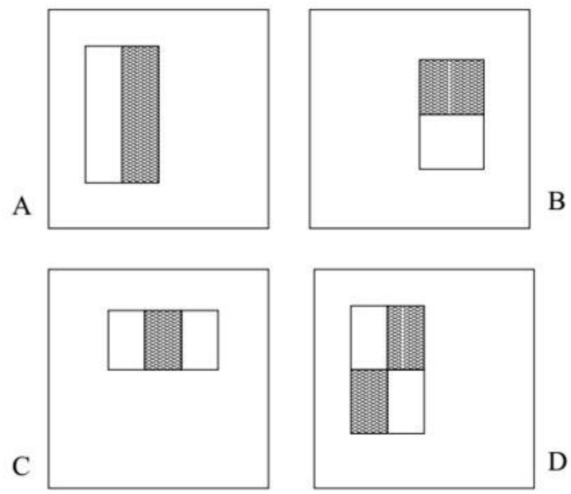

Figure 5.14. Template Patterns for Face Detection.
(Reprinted with permission from Robot Vision 2018).

The white bars are represented as +1, the black bars are -1, and the background is 0. The size of each pattern is the same size as the training image. By convolving the pattern with the training image, each classifier can determine if a face is there or not. By plotting all the correct and incorrect selections for a face and performing the same method for non-faces, a number line plot can be used to determine the threshold needed for a classifier, which can be seen in figure 5.15 below.

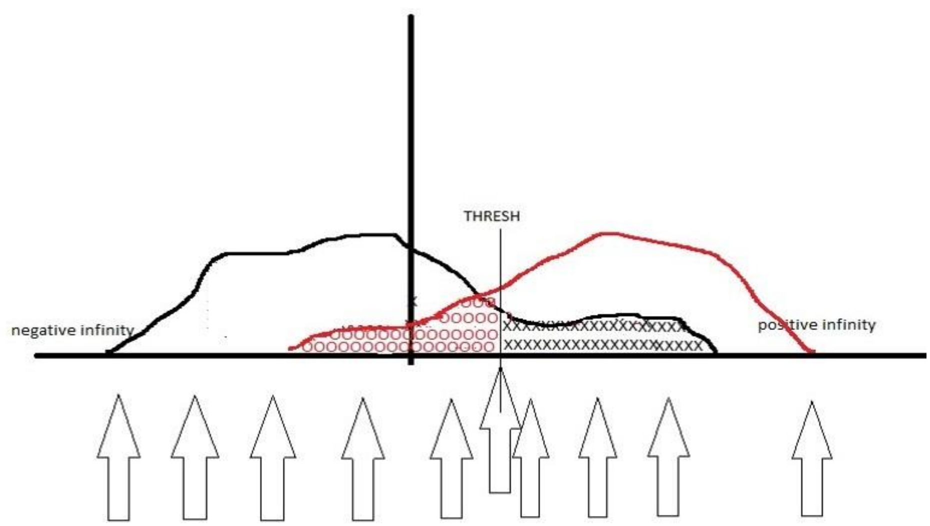

Figure 5.15. Number Line Plot of Faces and Non-Faces.
(Reprinted with permission from Robot Vision 2018).

The y-axis is irrelevant and just denotes the transition from the negative to positive side. An arbitrary threshold is selected based off the user's needs, and a classifier is now the original pattern plus the threshold. Parity is included for this classifier, but not discussed in this section. Finally, a table of weights is assigned to each classifier and the next classifier is selected that complements the team of classifiers. Essentially, a team is built off the assumption that the team can correctly say "yes" to a face and "no" to a non-face. The idea here is that we don't want to keep track of which classifier complements who but to produce a numerical method for achieving the same goal.

With adaptive boosting, we can exploit the fact that faces are rare. The Viola-Jones method can be used, which uses a cascade system to speed up the process greatly. Viola-Jones algorithm is designed to say "no" most of the time because faces are rare. The way this method works is there are a series of stages of small teams of classifiers as seen in figure 5.16 below.

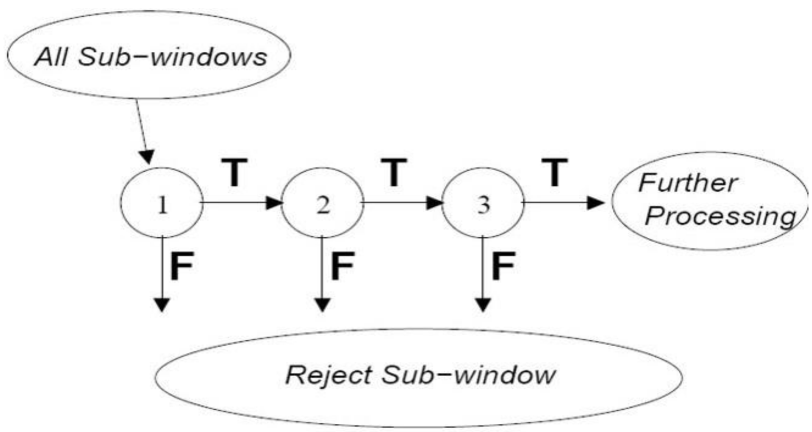

Figure 5.16. Viola-Jones Cascade Method.
(Reprinted with permission from Robot Vision 2018).

With adaptive boosting, the correctness is determined by the team size as the error decreases monotonically with each new classifier added to the team. By reducing the team size in Viola-Jones, the error for each team will be much higher, but distributed evenly across all teams. By allowing the Viola-Jones algorithm to have a higher threshold of saying "yes", the error can be shifted for fewer missed detections, but a higher false positive rate. More classifiers are added to a team until a desired missed detection and false positive rate, approximately 30%, is achieved, which is generally 15-30 classifiers. With this design, each team will pass 99.9% faces and 30% non-faces. This means that approximately 91% of "failure" are rejected with only 50 experts used, while single adaptive boosting would require all classifiers to analyze each image. This drastically speeds up the process for facial detection.

5.2.1.2 Face Landmark Estimation

The second process is the face landmark estimation which will be useful because faces can be warped and turned in different angles. When viewing an image of a person, the general face poses are roll, pitch, and yaw. These are the different angles from which a face will be detected, and using estimation, these angles can be oriented to fit a specific orientation so that the landmarks of the face will always be in the same areas. OpenCV's affine transformation library allows for a representation of a relation between two images. Using affine transformations, we can rotate, translate, and scale images which will create that relation with respect to the image center. Using homogenous coordinates will allow any number of affine transformations into one image. Combining this with Dlib's real-time face pose estimation, which allows a program to perform face pose estimation quickly, can add an annotation around the key features of a face with 68 points of reference. This can be seen in figure 5.17 below. Higher points of reference can be used if needed. Performing these techniques will make the eyes and bottom lip appear in the same location for each image.

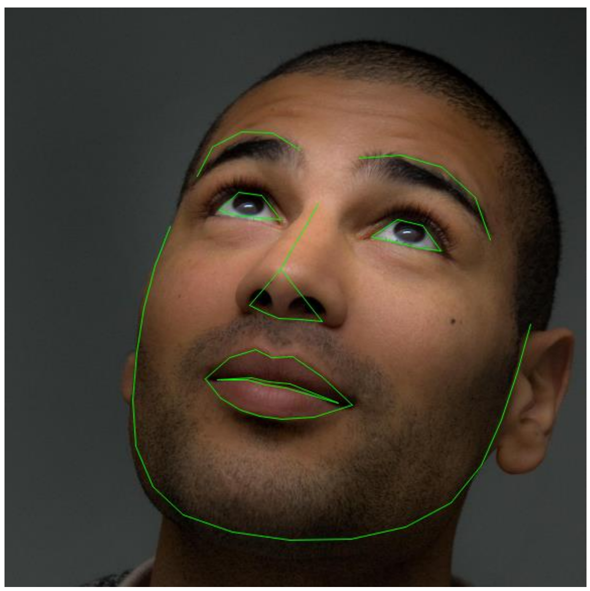

Figure 5.17. Landmarked Face.
(Reprinted with permission from Dlib C++ Library 2014).

5.2.1.3 Embedded 128-D Unit Hypersphere

The third process is to embed the face on a 128-dimensional unit hypersphere. This process has greatly increased the success of OpenFace by improving the accuracy from 76.1% to 92.9%. The hypersphere is optimized with a triple loss function that "minimizes the distance between the anchor and positive and penalizes small distances between the anchor and negative" [14]. Figure 5.18 below shows a visual representation of the hypersphere.

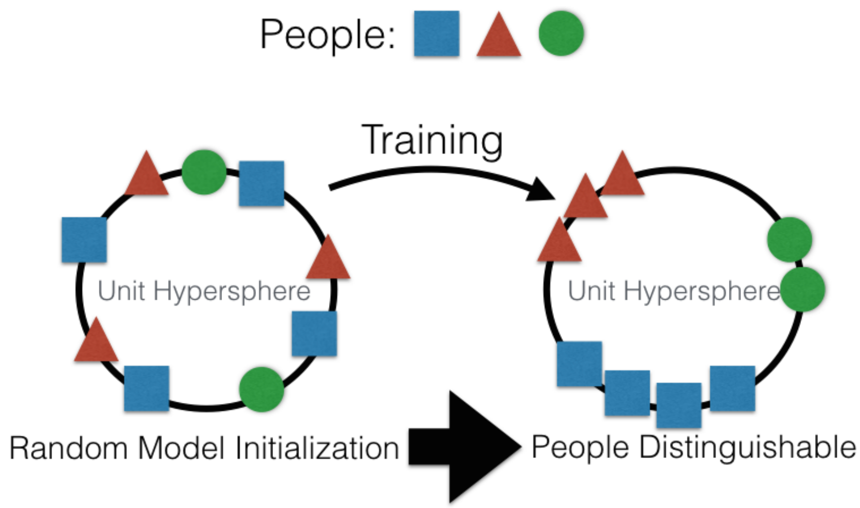

Figure 5.18. Optimization Sphere.
(Reprinted with permission from OpenFace 2016).

The points are randomly distributed because the initialization of the system is completely random for the neural networks. Through iterations of the network, the images are grouped together and will be fully optimized. First, an image is sent through as an input to the neural network which has been randomly initialized. Using the benchmark for Labeled Faces in the Wild for a training set, the image is sent through and an output is reached of a correct or incorrect response. If the answer is correct, the network is left untouched, but if the answer is incorrect, a backpropagation is performed to adjust the weights and bias of the vectors and edges within the network which can be seen in figure 5.19 below.

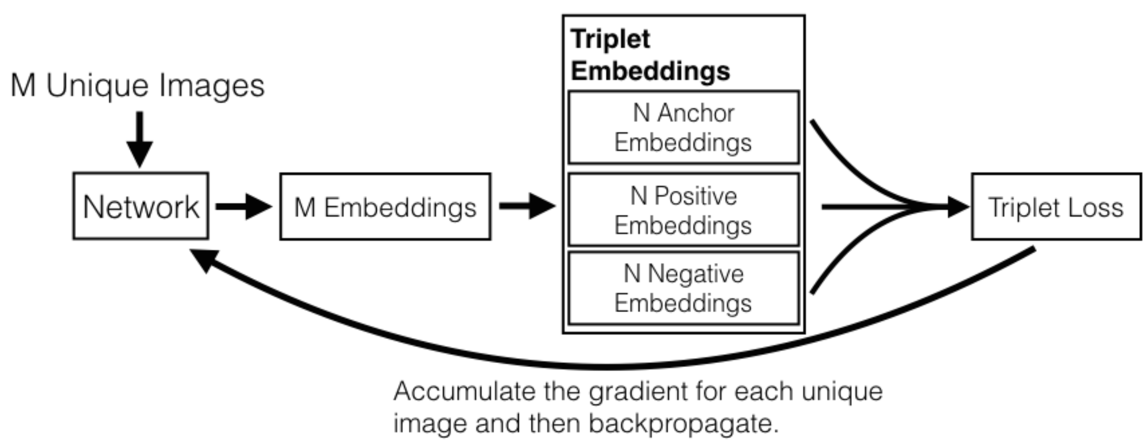

Figure 5.19. Optimization of a Single Network.
(Reprinted with permission from OpenFace 2016).

By using a single network, unique images can be mapped to the embedded triplets where previously three separate networks with shared parameters were used. By using a single network, this greatly enhances the speed of the system and assists in reducing the training time of the deep neural network from one week to only one day.

5.2.1.4 Similarity Detection

The last step is to apply a similarity technique to match the image with another image. Using scikit-learn library, which is a free software machine learning library, many classifiers are available such as support vector machines (SVM), random forests, gradient boosting, and DBSCAN. Our focus will be on SVMs which "is a supervised machine learning algorithm which can be used for both classification or regression challenges" [15]. A support vector is simply finding the correct hyperplane that encompasses all the coordinates of a given system and separates the two classes via that hyperplane, which can be seen in figure 5.20 below.

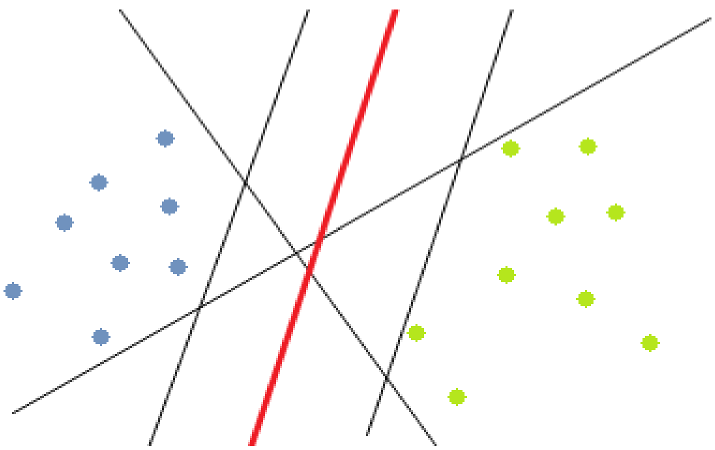

Figure 5.20. SVM Example of a Hyperplane.
(Reprinted with permission from Wikimedia Commons 2010).

The goal is to find the best hyperplane that will separate the two classes, which in figure 5.10 is the red hyperplane that is selected. A linear support vector machine is used by OpenFace which is used to match image features. Using a "kernel trick" as a technique can handle non-linear separation problems if the space is not able to become a linear hyperplane. Using SVMs as a classifier should take only a few milliseconds to classify an image and output the correct matching images. Once a match has been found and confirmed, a signal will be sent to the PCB that will initiate and activate the motion controls and trigger mechanism to fire at the target.

5.2.2 Database

There are many forms of databases available for use, but a LAMP (Linux, Apache HTTP Server, MySQL, Python) stack will be used to develop the database. The database must accept new target information which must be categorized with unique identifiers so that it may be discriminated against preexisting data. Figure 5.21 below shows the Entity-Relationship diagram which states various entities that exist within the database, which in this case is the target profile, the operator identity, a registration for a new operator, and the polling or selection of the target.

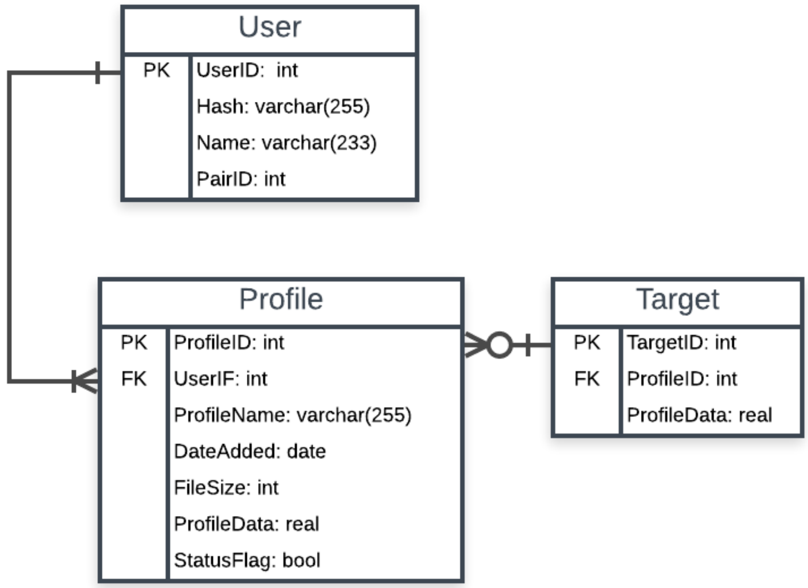

Figure 5.21. Entity Relationship Diagram.

The lines within the graph that connect the entities express cardinality and ordinality, the maximum number of times and the minimum number of times an instance of an entity can relate to the instances of another respectively. The user ID will be the primary key which will be used as the identifier for the user database. The operator profile database will use the profile ID as the primary key for identification. The selected target database uses the target ID as an identifier. The databases can communicate with each other and allows for synchronization because the keys are unique to each database. Another useful feature of the database, as described in the diagram, is the manipulation of quantifier data as to create flags that can be enabled or disabled with ease, which is taken advantage of to identify the selected target profile within the database.

5.2.3 Mobile and Web Application

The class diagram takes the entities that exist within the database as described in figure 5.22 below and appends attributes, generalizations, associations, and aggregations between the entities and objects. The resulting diagram is the visualization of the API used for the web application with the individual attributes, with the "+" qualifier being a function or method that are executed to retrieve, create, or remove information from the database using a CGI capable scripting language.

Development on the frontend will take form as a web application with an emphasis for mobile devices. The web app will allow a registered operator to explore the list of profiles within the database and then select the target for the next execution of the sentry turret operation.

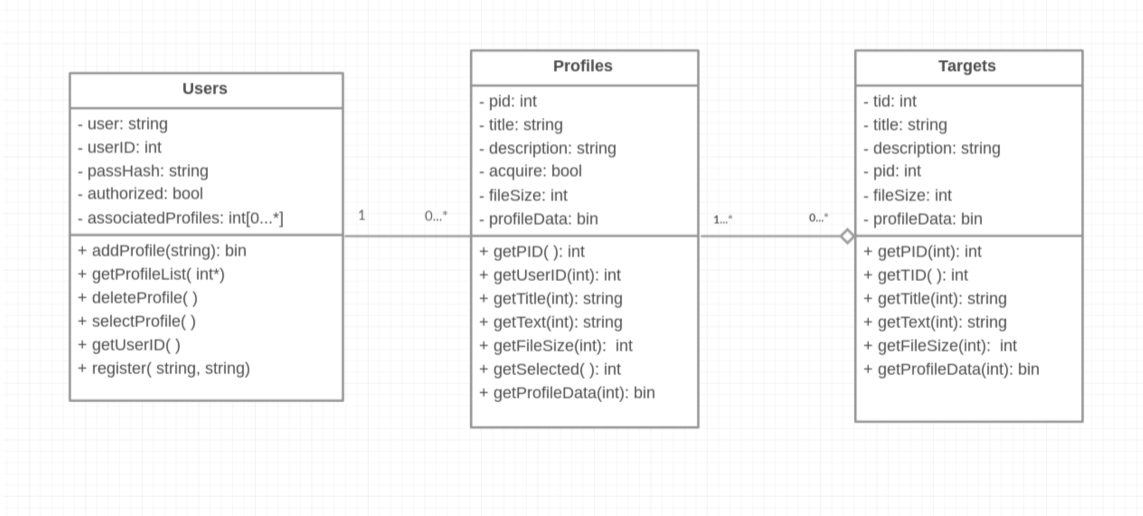

Figure 5.22. UML Class Diagram.

The web app will also allow the user upload valid new potential targets. The facial recognition software will make use of the web application to download the currently selected target profile through a secure shell connection. The front end for the app will consider the nature of modern smartphones, such as the limited screen resolution and touchscreen input. The final design for webpage that displays a profile and the options to select or deselect the target on a mobile phone can be seen in figure 5.23 below.

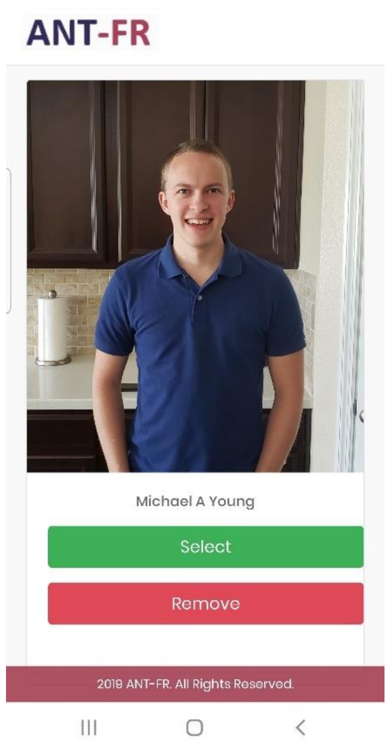

Figure 5.23. Mobile Application Design.

The selection of the target and the list of all valid targets in the database should not be publicly known and should be compartmentalized to correspond to a single paired turret, while the valid target should be freely accessible to the computer running the facial recognition software. The web application will take advantage of the larger resolution and keyboard input device, while accommodating a flexible user interface for when the webpage is resized.

6 Project Prototype Construction and Coding

As the project design matures, it will be necessary to assemble the various hardware and software subsystems in the form of prototypes. Prototyping will allow for a greater understanding and visualization of how each subsystem will function in relation to the rest of the ANT-FR. In addition to the specific subsystems that will need to be prototyped, it is important to understand what materials, subcontractors, and suppliers will be utilized throughout the project life cycle. This section discusses these various topics in greater detail.

6.1 Bill of Materials

ANT-FR requires a variety of materials, parts, and components for proper operation. Throughout the project life-cycle, these various materials will be acquired through several vendors. To stay within the outlined project budget and sponsorship, it will be important to keep track of the items ordered, acquired, and pending, as well as their total cost. By the end of senior design 1, the major components such as: the NERF gun, battery packs, turn table, microcontrollers, and voltage regulators, will be ordered and received. Many components within the total system schematic are common parts such as resistors, capacitors, diodes, inductors, fuse(s), wiring, connectors, and headers. Some of these common components can be found in the laboratories in which we have access to. As such, the remaining parts will be ordered and acquired during the early stages of senior design 2 after the PCB layout has been finalized. Below in table 6.1 is a list of expected parts with their most recent status.

Below in figure 6.1 is a picture of the materials that have been received and tested to verify that they are functioning according to their intended use.

Figure 6.1. Materials Received.

Bill of Materials

Item	Quantity	Status
NERF Gun	1	Received
NERF Rounds	200	Received
NiMH Rechargeable Battery Pack	1	Received
Li-Ion Rechargeable Battery Pack	1	Received
Continuous Servo	1	Received
Encoded Servo	1	Received
ATmega328P-PU	2	Received
AtMega16U2	2	Received
Switching Voltage Regulator	2	Received
Linear Voltage Regulator	2	Received
Turn-Table	1	Received
Camera	1	Received
USB 2.0 Type B Male-Male Cable	1	Received
Single Board Microcontroller	1	Received

Table 6.1. Bill of Materials.

6.1.1 Suppliers

Inherent with any complex project such as the ANT-FR, is a lengthy list of components, parts, and other equipment as shown in the bill of materials. To create a system that is reproducible, parts were sourced from well-established vendors, such as Digikey, Texas Instruments, and Amazon. While selecting suppliers for the materials, it was important to consider not only competitive pricing, but consumer ratings, product quality, shipping times, and return policies. Larger vendors offer low price, if not free shipping on certain items, and make returning faulty merchandise easy. More particular parts, such as the Li-Ion rechargeable battery pack and the servos were sourced from reputable websites like ServoCity and All-Battery since their specifications could only be found at specialized vendors. Care was taken to ensure that these specialized vendors sold quality parts that would meet the needs of this project. Below in table 6.2 are the suppliers utilized thus far.

Vendors Utilized

Name	Type of Merchandise
Amazon	Misc.
Texas Instruments	Circuit Components
Digikey	Circuit Components
ServoCity	Servos
Logitech	Camera
All-Battery	Rechargeable Battery

Table 6.2. Suppliers List.

6.2 Subcontractors

Throughout the construction phase of the project life cycle, it will be necessary to utilize the services of third-party companies to secure various parts and labor. The most common services utilized for a project such as the ANT-FR are PCB manufacturing, as well as component assembly. Due to the complex nature of producing an accurate and functional PCB, third party companies will be used. These types of subcontractors will speed up the production of the ANT-FR and allow the team to focus on other important aspects of design and assembly. Relevant subcontractors and their expected contribution to the ANT-FR will be discussed in this section.

6.2.1 PCB Manufacturing

After finalizing a PCB layout design in senior design 2, it will be imperative to the project schedule to get it built as soon as possible. This will allow for testing and troubleshooting, since mistakes are likely to occur within the PCB layout. PCB's can be fabricated in a variety of ways, however due to the complexity and small size of traces, they are typically manufactured by a specialized vendor. These manufacturers use state-of-the-art machinery, materials, and highly precise methods for constructing any ordered PCB. A requirement for utilizing said third party services for PCB manufacturing is having the Gerber files on hand for the design. Gerber files contain all the information about the PCB such as trace widths, component mounting locations, text, ground locations, vias, and a bill of materials to name a few. It is imperative that a software be used that can produce this type of file. Eagle CAD, the group's chosen modeling software will be able to accomplish this purpose.

PCB's can come in all shapes and sizes, with a host of customizable features. Such features include, but are not limited to, number of layers, number of printed sides, material flexibility, and so on. Intuitively speaking, the more unique features a PCB contains, the higher the cost. As a result, the layout should be kept to less than two layers, be fabricated of rigid material, utilize only one side if possible, and minimize the number of through-hole connections. Placing all the components on one PCB would aid in simplicity, however, would require more surface area, which is a direct correlator of higher cost. On the other hand, using a separate small PCB for the switching voltage regulator and 6V rail would reduce the complexity of laying out the traces. The decision whether to use one or two PCB's will be finalized with the layouts in senior design 2.

Several third-party companies provide PCB manufacturing and are popular choices among micro-electronics developers. The first is Advanced Circuits | 4PCB which specializes in PCB manufacturing and component assembly. They specifically offer discounts on PCB manufacturing for university students, albeit for senior design projects like ours. Additionally, Advanced Circuits | 4PCB is based out of and manufactures their PCBs in the United States. This is particularly compelling for the ability to order and have the PCB shipped to us quickly, and not have to worry about international shipping procedures/pricing. Another selling point of this manufacturer is a $33 cost for a 2-layer, 60 square-inch PCB. This pricing fits within the constraints and budget of our project. The final selling point to be mentioned is the availability of a free PCB layout file check, which essentially screens the Gerber files for manufacturability.

Another PCB manufacturer considered is OSHPARK, which also manufacturers here in the United States. This company operates by fabricating PCB's in bulk. For $5.00 a square inch, you receive three two-layer PCBs with the option of having them shipped in under twelve days. OSHPARK also ships all PCBs for free regardless of location. Having three PCBs included in the cost gives our team the ability to perform testing while having the peace of mind that there is a back-up board, should one of them become inoperable. One disadvantage of OSHPARK is that they do not offer component mounting services which would require us to complete the soldering of components on the PCB.

Express PCB is another manufacturer which provides PCB fabrication geared towards a wide variety of circuit developers. This fabricator does not have clear-cut pricing. The minimum price found for (3) two-layer PCB's is $51. However, this is for a standard mini board which does not include solder mask or silkscreen. Express PCB also makes it difficult to have the PCB manufactured without using their design software. After finding these drawbacks, and the difficulty with finding more information about this manufacturer, it is unlikely we will utilize their services.

6.2.2 PCB Component Assembly

In addition to PCB manufacturing, component assembly on the PCB by a third party will be considered, especially due to the complexity involved. While basic soldering skills can be learned from a host of online tutorials, the extremely small size of the components requires a higher level of skill. If there is a budget surplus, the use of a third-party service will become more viable, especially as the project life cycle comes to an end.

Advanced Circuits | 4PCB also offers component assembly. This would make them an ideal choice since the PCB could also be manufactured there. Specific pricing is dependent on the size of the PCB, number of components, required mounting technique, etc. As a result, an exact assembly price can only be obtained after a complete layout is finished. 4PCB also offers three different assembly options such as: turnkey assembly, in which they supply all the components, kitted assembly, in which we supply all the components, or combo assembly, in which we supply some of the components. This would give us flexibility to decide which option is more viable for the project budget and timeline.

PCBCART is a company based in China which performs PCB component assembly. Like the previous vendor, they offer turnkey, kitted, and combo assembly options. PCBCART offers a 15% discount to new customers, which would be beneficial considering 4PCB does not offer any discounts on component assembly. A drawback of this manufacturer, however, would be the required international shipping and its associated longer lead time. Domestic manufacturers like 4PCB have an advantage when it comes to shipping times.

6.3 Consultants

While the work was completed by the group team members for this project, every resource that was available was utilized. Past and current professors, professionals in industry, and colleagues in similar degree fields of choice were spoken to. Below is a list of consultants who assisted in finding resources, understanding conceptual information, and were highly responsive to answering questions about complex topics for this project.

Dr. Gita Reese Sukthankar is an associate professor at the University of Central Florida and conducts research in activity and plan recognition. She also directs the Intelligent Agents Lab at UCF. Dr. Sukthankar contributed greatly by connecting our team with the OpenFace project and discussing common issues that we were facing with facial recognition and video streaming. She discussed techniques for handling video streaming and cutting the stream into multiple frames per second for facial detection.

Dr. Niels Da Vitoria Lobo is an associate professor at the University of Central Florida whose research interests are in computational vision, robotics, modeling for graphics, and computer science education. He provided resources for facial detection and assisted in the understanding of concepts behind triplet loss and facial verification, recognition, and clustering. Dr. Lobo was highly influential in the topic of deep convolutional neural networks (CNN) and was able to efficiently explain the concepts of CNN and algorithms that utilized them.

Mr. Brando Amos is a Ph.D. student in Computer Science at the University of Carnegie Mellon and has conducted research in the fields of Machine learning, scientific computing, and heterogeneous compilers. He is a major contributor to the OpenFace project and has been highly responsive to answering questions about the project and techniques for conducting classifications on a 128-D embedded hypersphere, such as using support vector machines.

6.4 Hardware Prototyping

As parts, equipment, and components become available, it will be important to begin testing each of them for proper functionality. This will allow us to identify any faulty parts that may need to be replaced or reselected. Additionally, each subsystem such as the USB 2.0 type B system, ATmega328P-PU system, and voltage regulation system will need to be assembled separately on a breadboard and tested for proper input/output. The total hardware system can be connected as a prototype after each subsystem is verified. By prototyping each subsystem on its own, it will be easier to test individual components, and troubleshoot problem areas. Prototyping will also ensure that the hardware schematic for the ANT-FR is fully functional and capable of achieving the desired results. Initial software programming and prototyping can accelerate once a functional hardware prototype is built.

6.4.1 USB 2.0 Type B Subsystem

The USB 2.0 Type B subsystem is one part of the total hardware system which will benefit from prototyping. At the core of this subsystem is the ATmega16U2 microcontroller. Connected to the ATmega16U2 are overcurrent protection, electrostatic discharge protection, and electromagnetic interference protection components. Establishing these connections with the microcontroller, along with the 5V power rail, will be crucial to ensuring that the total hardware system will be protected from these circuit hazards. Once this 5V rail is safely established within the USB subsystem, integration with the ATmega328P will be possible.

6.4.2 ATmega328P-PU Subsystem

Prototyping the ATmega328P subsystem is another important step to realizing the full hardware system of the ANT-FR. While there are less components to be connected directly to the ATmega328P microcontroller, it will be crucial to ensure that this subsystem correctly operates. Because of the ATmega328P VCC pin sharing a common node with the power LED on the 5V rail, it will be possible to tell if the microcontroller is receiving power if the LED is on. After utilizing the appropriate pins for the secondary components such as resistors, capacitors, and an oscillator, the data transmission pins should connect with the USB 2.0 type B subsystem to ensure communication between the two microcontrollers. This will be accomplished on a breadboard with the proper testing equipment such as a multi-meter, power supply, and oscilloscope. Communication between the two microcontrollers will be evident as the corresponding LEDs light up during successful data transmission between the TX/RX pins. Ensuring this communication is vital since the ATmega328P must be able to communicate via USB to the external computer for image processing.

6.4.3 Voltage Regulator Subsystem

The voltage regulation and power supply subsystem are the final subsystems that will need to be prototyped. While the USB subsystem provides the 5V rail for the PCB to operate on, the 6V rail is created using an external Li-Ion rechargeable battery pack and a switching voltage regulator. The switching regulator requires several secondary components such as resistors, capacitors, an inductor, and a diode to function. This relatively simple circuit should be built on a breadboard. Input/output voltages should be measured with a multi-meter to verify circuit integrity and validity. Additionally, the servos can be connected across this 6V rail and ground to ensure they will power on.

6.4.4 Subsystem Summary

With each subsystem prototyped, it will be important to connect each of them to ensure they interact well together. The USB 2.0 Type B subsystem connects with the ATmega328P subsystem through the TX/RX pins, as well as the reset line. Additionally, the voltage regulation subsystem connects to the above by connecting the data lines of the servos to the PWM pins of the ATmega328P-PU.

While prototyping the full schematic will be crucial for developing the ANT-FR, it will be beneficial to connect the voltage regulation subsystem and servos to a single board microcontroller. This will give greater clarity to how the 6V rail and servos will integrate with the PCB. The single-board microcontroller is a tested and fully functional system, therefore it can be relied on while performing additional prototyping of the servos, as well as software prototyping. Functionality of the prototype PCB system can be compared to the single-board microcontroller. While the single-board microcontroller will not be utilized in the ANT-FR, it will serve as a valuable prototyping and testing tool for getting the embedded systems operational.

7. Project Prototype Testing Plan

In this chapter, the specifics behind prototyping hardware and software subsystems will be detailed. Expected testing plans and procedures for each subsystem prototype will be explored. As the project life cycle matures in senior design 2, having specific testing plans and procedures will give greater structure and clarity. Additionally, any problematic areas within the hardware and software design will be exposed and can then be rectified. The following plans will be subject to expansion as new testing parameters come to light.

7.1 Hardware Testing Environment

Testing the hardware system of the ANT-FR will require a safe and robust environment. This will be accomplished primarily at the electronics laboratories of the Valencia West campus. Adequate testing equipment will be necessary for investigating each subsystem, these include power supplies, digital multi-meters, oscilloscopes, function generators, and breadboards. In addition, a variety of common circuit components such as resistors, capacitors, inductors, diodes, spare wires, and LEDs should be available. Utilizing these facilities will provide a level of convenience and validity that testing outside of a formal laboratory cannot guarantee.

7.2 Hardware Specific Testing

Upon completion of any hardware subsystem prototype, it will be important to run through a series of tests to ensure proper input/output. The main subsystems to be prototyped and tested includes: the USB 2.0 Type B system, the ATmega328P-PU system, the switching voltage regulator circuit, and the linear voltage regulator circuit. The following sub-sections describe the testing parameters for prototyping that has been conducted.

7.2.1 ATmega328P-PU Testing

Purpose:

The purpose of this test is to ensure the functionality of the microcontroller and that it is properly loaded with the correct bootloader.

Test Materials:

- Full Computer System
- Atmel IDE
- Arduino Uno Rev3 Single-board Microcontroller
- ATmega328P-PU boot-loaded

Prerequisites:

Ensure that the full computer system is powered on, the Arduino UnoRev3 single-board microcontroller is connected to the computer and has power, and the Atmel IDE is loaded with test code to show the LED statuses of the single-board microcontroller.

Procedure:

1. Install the ATmega328P-PU microcontroller onto the Arduino Uno Rev3 single-board microcontroller by removing the existing microcontroller.
2. Connect the Arduino Uno Rev3 to the full system computer and verify that it is receiving power.
3. Run the test code to show the system is powered on and the microcontroller is operational.

Expected Results:

The Arduino Uno Rev3 single-board microcontroller should show the LED statuses of being powered on which would verify that the microcontroller has the correct bootloader and is functional. Figure 7.2 below shows the output expected for this test plan.

Figure 7.2. ATmega328P-PU Output of Testing Plan.

7.2.2 Camera Testing

Purpose:

The purpose of this test is to ensure the functionality of the camera and that it properly turns on and can record in real time.

Test Materials:

- Full Computer System
- Camera
- Camera Software

Prerequisites:

Ensure that the full computer system is powered on and that the camera is plugged into the computer.

Procedure:

1. Install or open the manufacturer camera software.
2. Run the camera software and adjust necessary settings if needed.

Expected Results:

A video output should be showing on the full computer system which shows a video streaming in real time of the field of vision of the camera.

7.2.3 Switching Voltage Regulator

Purpose:

The purpose of this test is to successfully regulate 11.1V down to 6V for use as a power rail for the servos.

Test Materials:

- Breadboard
- Power supply
- Digital multimeter
- LM2576 Switching regulator and corresponding passive components

Prerequisites:

Obtain the necessary supporting passive components required for operating the switching voltage regulator.

Procedure:

1. Assemble the circuit associated with the LM2576 on the voltage regulation subsystem.
2. Connect the power supply at the input of the circuit and adjust the input to 11.1V.
3. Using the digital multimeter, probe across the output capacitor and observe the voltage.

Expected Results:

With an input of 11.1V from the power supply, the output voltage of the circuit should read 6V on the digital multimeter. Below in figure 7.2 is the result of the above procedures.

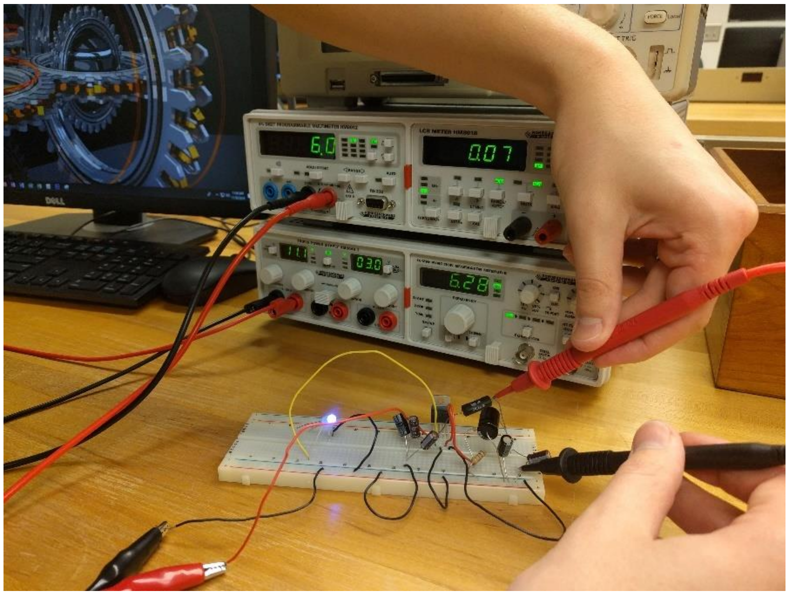

Figure 7.2. LM2576 Output of Testing Plan.

7.2.4 Linear Voltage Regulator

Purpose:

The purpose of this test is to successfully regulate 5V down to 3.3V.

Test Materials:

- Breadboard
- Power supply
- Digital multimeter
- LM3940 linear regulator and corresponding passive components

Prerequisites:

Obtain the necessary supporting passive components required for operating the linear voltage regulator.

Procedure:

1. Assemble the circuit associated with the LM3940 on the voltage regulation subsystem.
2. Connect the power supply at the input of the circuit and adjust the input to 5V.
3. Using the digital multimeter, probe across the output capacitor, and observe the voltage.

Expected Results:

With an input of 5V from the power supply, the output voltage of the circuit should read 3.3V on the digital multimeter. Below in figure 7.3 is the result of the above procedures.

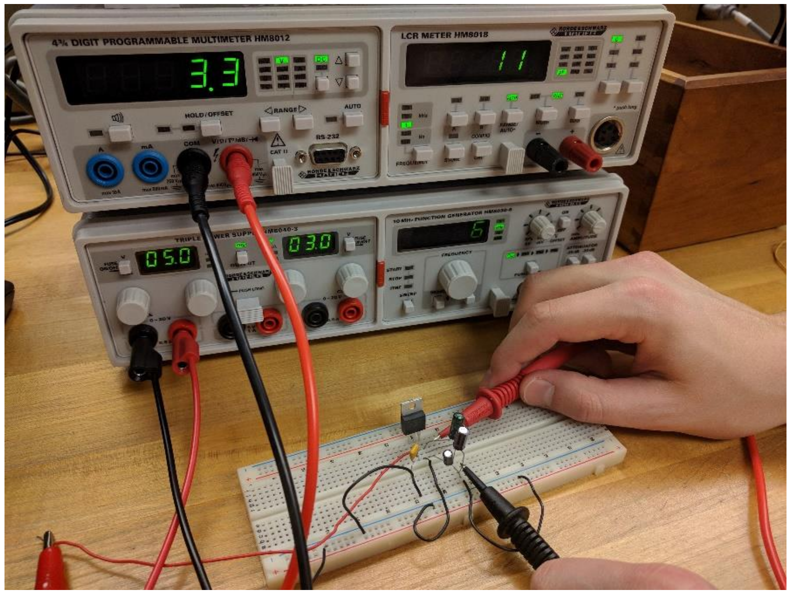

Figure 7.3. LM3940 Output of Testing Plan.

7.3 Software Testing Environment

The software test environment will vary depending on which section of the testing is being conducted. Since most of this project is software focused, the testing needs to be done well in advanced compared to the testing of the hardware. The application for the user interface and the facial recognition software can be tested without the PCB being completed. A full computer system with a camera will be used as the test environment for the facial recognition software. A smart phone or full computer system will be used for the test environment of the user interface application. Both components can be done in parallel but will require testing between them at the end to ensure that user interface can interact with the facial recognition.

The embedded system coding will be done using the Atmel IDE and testing on a single-board microcontroller. The final test plan will be to use this code and implement it on the PCB and tested to ensure accuracy. The embedded systems will be the middle man that communicates with the PCB and the facial recognition software. The final test plan will be to implement the user interface, facial recognition, and embedded systems to communicate in real time.

7.4 Software Specific Testing

This subsection will provide the layout to conduct the software specific testing to this project. Each major component is broken down such as embedding systems, user interface, and facial recognition. These sections are further broken down to explain the steps to produce the results needed. Many of these components can be conducted in parallel of one another as they are independent systems until they need to communicate their results to the next system.

7.4.1 Facial Recognition Testing

This subsection will discuss the testing plan to ensure the facial recognition software is implemented correctly and that each component is in sync with one another. Each sequence is in order and should be conducted in this order to ensure the next components have the efficient prerequisites needed to work.

7.4.1.1 Face Detection Test

Purpose:

The purpose of this test is to determine if a person's face is present in the field of view of the camera, and to draw a box around a person's face that is detected.

Test Materials:

- Full Computer System
- Camera Module
- Python IDE

Prerequisites:

Python code that has been written to read in and analyze a video stream to detect a face present in that video stream using OpenCV. Then parsing that information and sending that video stream through the face detection algorithm.

Procedure:

1. Power on the full computer system and plug in the camera.
2. Run the python program and obtain the video stream by creating a VideoCapture object using object = cv2.VideoCapture().
3. Parse the information being received and perform the face detection algorithm.
4. Output the video stream in a new window after running the face detection algorithm.

Expected Results:

The program should output a video stream of a detected face with a bounding box, if a face has been detected. This bounding box will appear around the face that has been detected and continue to follow the face while the person moves in the field of view of the camera. If no person is detected, nothing happens.

7.4.1.2 Face Landmark Estimation Test

Purpose:

The purpose of this test is to determine the landmark features of a detected face by parsing the image of a detected face and manipulating that image to align key features in similar orientations.

Test Materials:

- Full Computer System
- Camera Module
- Python IDE

Prerequisites:

A powered on full system computer with a camera. Python code that has been written to read in and analyze a detected face and produces an output of that detected face using OpenCV.

Procedure:

1. Load an image using src = cv2.imread().
2. Apply an affine transformation from the relations between three points using cv2.warpAffine( );
3. Apply a rotation to the image being transformed with respect to the image center.
4. Use Dlib's Real-Time Face Pose Estimation to add an annotation around the face.
5. Output the video stream in a new window after running the face landmark estimation algorithm.

Expected Results:

The program should output a video stream of a detected face with the landmark annotations. These annotations will continue to show as the face is moving within the field of vision of the camera.

7.4.1.3 Similarity Detection Testing

Purpose:

The purpose of this test is to determine the similarity between two faces and to send a signal if a target matches one of the faces that has been detected.

Test Materials:

- Full Computer System
- Camera Module
- Python IDE

Prerequisites:

A powered on full system computer with a camera. Python code that has been written to read in and analyze 128-D embedded hypersphere in OpenCV which shows the key features of a detected face.

Procedure:

1. Read in the data from the hypersphere to determine key features.
2. Train the support vector machine algorithm by using cv2.SVM.train().
3. Detect the regions classified by the SVM by using cv2.SVM.predict().
4. Obtain the information about the support vectors by using cv2.SVM.get_var_count() and cv2.SVM.get_support_vector_count().
5. Compare results with cv2.createEigenFaceRecognizer() and verify if a detected face matches.
6. Send signal to confirm matching detected face.

Expected Results:

The program should send a signal to the PCB if a selected target's face has been detected. This signal will initiate a sequence to move the NERF turret and fire at the target. To verify the recognition is being done, an output of matching images can be done to check if the algorithm works.

7.4.2 Back-End Testing

The database and server testing are essential to making sure that the database does not overload, and that the facial recognition software has a valid communication to the database. This section covers the topics of uploading, selecting, deleting, and the retrieval of information within the database.

7.4.2.1 Data Upload, Selection, and Deletion Test

Purpose:

To test whether the CGI scripts will upload input files onto the database and if the JavaScript creates HTML objects to display all uploaded files to both the website and mobile app. Verify that the database can remove files completely and move files throughout database.

Test Materials:

- Two valid profiles
- Server Database

Prerequisites:

The testing must be performed on a computer or laptop with an internet browser and running an instance of Microsoft Windows. The tester must also use a mobile smartphone or tablet whose operating system is Android OS 7.0 or higher. A stable internet connection is needed in the form of an ethernet, Wi-Fi, or cellular data connection.

Procedure:

1. Upload a single data packet to the database using the GUI provided by either the web application or the mobile application, with a known name, file size, and description.

2. Reload the page so that the JavaScript files update and create new HTML objects to display the profile.
3. Upload a second packet whose contents and descriptive information are dissimilar from the first packet.
4. Reload the page again to update the webpage.
5. On both the web and mobile application, the user must be able to select a target profile to highlight from the available list and confirm their selection. For testing purposes, there must be at least two distinguished packets or target profiles, within the database.
6. For deletion, the user must select the profile to delete it from the list and then confirm the selection.

Expected Results:

After updating the database and returning to the list of profiles, the information of both packets must be encapsulated separately and displayed without conflict or overlap. The user must confirm that the files were submitted without error and it must fit within the screen while accounting for screen resolution. After a selection is made, the target's profile must be linked to a separate section that can easily be viewed and accessed from both the web page and the mobile app. For deletion, once confirmed, all instances of the file must be disassociated from other objects in the database and then it will be removed with its data and description purged. The list of target profiles will be updated as to not include the deleted profile and to indicate if a target is selected.

7.4.2.2 Database Retrieval and Connectivity Test

Purpose:

To verify that the external devices can connect to the server and send an HTTP or FTP request to download the selected target profile. Test that all TCP/IP or named pipes protocols are open and available to connection and that the account of the primary user is enabled.

Test Materials:

- Server database.
- Ping application for Windows Command Line.
- SQL Database managing software.

Prerequisites:

GNU Wget is installed and at least one profile is uploaded onto the server and is selected as a target. Testing computer with Windows OS, Windows 7 or later preferred.

Procedures:

1. View a profile in the mobile app or the web page, from either the list of profile targets or from the selected profile, then download the file.

2. Download the profile from the server using the GNU wget command.
3. Now, to test the connectivity, ping the server by running the command "ping" followed by either the name or the IP address of the server.
4. Create a Universal Data Link file (.udl) by creating a black text file and changing the extension from ".txt." to ".udl".
5. Configure the UDL file to test the connection to the SQL server enabling either Microsoft OLE DB Provider for SQL Server or the SQL Server Native Client 11.0 in the option.
6. Select "Start Test".

Expected Results:

All three methods to download a file should be able to send a request to download the selected file from the database, accessible from a separate section, as a single profile file. The files downloaded must be identical to the originals that had been uploaded beforehand. For connectivity section, if the execution of the UDL file has been properly configured, a single message box will appear stating that the connection test was successful.

7.4.3 Front-End Testing

The front-end system is more based on aesthetics instead of functionality because a consumer prefers convenience over efficiency. However, while the design portion is essential to please a consumer, the functionality needs to be heavily tested to verify that the user will be happy. This section covers the web application and mobile application testing to select targets and add new ones to the database.

7.4.3.1 Mobile and Web Application Test

Purpose:

Verify that the web page's contents and functions are all accessible on a variety of internet browsers.

Test Materials:

- Website
- Smartphone

Prerequisites:

A minimum of two web browsers installed on the computer used for testing and at least one profile uploaded onto the database. One smartphone with the application installed.

Procedures:

1. Login to the website using multiple web browsers.
2. View all available sections and attempt to enter them.

3. Resize the page in both height and width.
4. View sections again using new settings.
5. Repeat steps 1 through 4 but using a smartphone application.

Expected Results:

Contents of the webpage should remain intact, allowing for resizing until a quarter of the maximum width. All sections should be accessible from all browser pages at all tested resolutions and widths. The same should apply to the mobile application which would be fluent in design and transition from horizontal to vertical display.

8 Project Operation

This section covers the operation of all functions within the ANT-FR system. This includes the operations of the embedded systems, user interface, facial recognition and the setup of the printed circuit boards.

8.1 Hardware Operation

The hardware of ANT-FR consists of the NERF gun (mounted to the frame), camera, servos (mounted to the frame), 5V relay, power printed circuit board, primary printed circuit board, Li-Ion rechargeable battery pack, Ni-MH rechargeable battery pack, NERF gun hopper, various cables, and a laptop. For the system to function accurately, these components must be assembled and connected properly. When handling either of the PCB's, batteries, servos, and cables, care should be taken to avoid electrical shock. Mishandling can cause electrical shock to the user, or damage to the components.

ANT-FR's NERF gun and servos are permanently mounted to the frame, thus requiring no assembly. For the NERF gun to be powered, the long blue plastic cover should be removed from the top of the stock of the gun, and the NERF Rival 7.2V 1.5Ah Ni-MH rechargeable battery pack should be inserted. This battery will only fit in the NERF gun one way. Once inserted, replace the blue plastic cover to secure the battery. Next, the two wires (red and blue) exiting the side of the NERF gun, need to be connected to the small blue relay. The red wire should be inserted into the center contact, while the blue wire should be inserted into the "NO" contact. A small flat-head screwdriver is used to tighten the connection. The servo with the wheel attached (in contact with the turn table) should be plugged into the power PCB. This servo has a 3-pin female connector which should be inserted to the 6-pin male connector (J1) on the power PCB. Insert the servo connector into the 3 male pins closest to the center of the board, with the yellow side of the connector closest to H1. Next, the vertical servo attached on the side of the turret needs to be connected to J1 on the remaining set of 3 male pins, making sure the yellow side of the servo connector is closest to H1.

ANT-FR requires the use of an external web-camera with a USB connection. The camera used has a hook-and-loop style material attached on the bottom making for easy assembly onto the frame which has the matching material attached. Firmly place the camera onto the mounting bar on the top of the frame, making sure to align the hook-and-loop pads. Finally, plug the USB cable into the laptop.

The blue 5V relay mentioned earlier, needs to be connected to the primary PCB. Three female to male jumper wires should be used. Utilizing the female side of a single jumper wire, plug into the center male pin labeled "+" on the relay. The male end of this jumper wire should be plugged into "5V" on H2 of the primary PCB. Next, the female side of a single jumper wire is plugged into the male pin labeled "-" on the relay. Its male end is plugged into one of the "GND" ports of H2 on the primary PCB. Finally, the female side of a single jumper wire is plugged into the male pin labeled "S" on the relay. Its male end is plugged into "D1" on H2 of the primary PCB.

In order to power the servos and power PCB, the Tenergy 11.1V Li-Ion rechargeable battery pack should be plugged into the red J2 dean’s connector. Two male to male jumper wires should be used to connect the power and primary PCB’s. Plug a male end of a jumper wire into H1 of the power PCB on the side closest to “H1”. The other end of the jumper wire should be plugged into “PWM1” on H2 of the primary PCB. Again, a male end of a jumper wire is plugged into H1 of the power PCB in the remaining opening. The other end of the jumper wire should be plugged into “PWM2” on H2 of the primary PCB.

Finally, the primary PCB needs to be connected to the laptop. A USB 2.0 to USB 2.0 Type B cable must be used. Connect the USB 2.0 Type B end of the cable to J1 on the primary PCB. The standard USB 2.0 end of the cable should be plugged into the laptop.

For the two PCB’s to share a common ground connection, the lone jumper wire attached to J2 on the power PCB needs to be connected to the remaining “GND” port on H2 of the primary PCB. Additional high impact rounds can be loaded into the hopper of the NERF gun by sliding open the clear hatch on the top of the hopper and placing them inside. DO NOT force high impact rounds into the hopper, otherwise jamming may occur.

8.2 Software Operation

The software operation covers the user application and facial recognition. The embedded systems coding is not covered as the only required process is to verify the source code from Appendix E.1 is loaded onto the ATmega328P-PU.

8.2.1 User Web Application

Before the user can start, they must ensure that they have a stable internet connection. If the website does not load or if elements are missing from the page, please enable JavaScript.

The user must login to their account by inputting their email and password into the indicated fields. If the user does not have an account, they must register by following the link beneath the login fields. The user will be prompted to input their full name, email, password, and then confirm their password. Once the user submits their information, they will return to the login page and then login to their account.

New users will be greeted to a screen with two options, “Clear” and “New Profile”. The user may create new profiles to display under the same page by pressing or clicking “New Profile”. This action will prompt a modal with fields so that the user may input the desired profile’s information. Please note that while the system allows for repeated or null entries for the profile name, the “tag” identifier must be unique and not null. The user will then confirm their submission and will redirected to confirm this, they must then return to the previous page and the new target profile will be displayed.

To select or deselect targets, the user must create at least one profile. For each card containing the image and name of the profile, there will be two buttons, “Submit” and “Remove”. Pressing or clicking the “Submit” button will add the identifier tag to list of targets, while pressing “Remove” will remove the same target from the list. Additionally, pressing or clicking “Clear” will remove all targets from the list of targets.

To logout of the web application, the user must select the “Logout” option from the navigation bar. In wide view screens, this option will be visible on the top-right corner of the screen. For tall screens or mobile devices, the user must press or click right corner of navigation bar and then press or click “Logout” to exit.

8.2.2 Facial Recognition

The facial recognition requires many dependencies to be in place before operation of the code. The first dependency is to install OpenFace using conda. Install miniconda with the following commands in your linux terminal:

wget https://repo.continuum.io/miniconda/Miniconda3-latest-Linux-x86_64.sh

bash Miniconda3-latest-Linux-x86_64.sh

and follow instructions. Add a Python 2.7 environment with:

conda create --name openface python=2.7

Activate the new env with:

source activate openface

Now that miniconda has been installed and an environment has been created, the opencv and related libraries are required. Install dependencies Add the conda-forge channel with:

conda config --add channels conda-forge

conda install opencv numpy pandas scipy scikit-learn scikit-image dlib txaio twisted autobahn OpenSSL pyopenssl imagehash service_identity

The next step is to install Torch and dependencies. First deactivate the openface environment. Next, open a new terminal and run:

git clone https://github.com/torch/distro.git ~/torch --recursive
cd ~/torch; bash install-deps; ./install.sh

Execute the following to install the Torch deps

for NAME in dpnn nn optim optnet csvigo cutorch cunn fblualib torchx tds; do luarocks install $NAME; done

Finally, install open face in the "openface" environment using:

source activate openface git clone https://github.com/cmusatyalab/openface.git ~/openface
cd openface python setup.py install

Download dlibs models with:

./models/get-models.sh

Now that OpenFace, OpenCV and Torch have been installed, a few extra python libraries and programs need to be installed. The first one is to manually install the pyserial library using the pip with the following command:

pip install pyserial

Next, the installation of the openssh client is needed to communicate with the database of targets using the commands:

sudo apt-get openssh-client -y
sudo apt-get sshpass -y

The next step is to create a database of images and the associated classifiers to classify each image for recognition. A database of images can be obtained in many ways and a collection of camera pictures and webcam pictures were utilized to create the ANT-FR target database for demonstration. Using the pyimagesearch OpenCV Face recognition by Adrian Rosebrock, the source code can be used to create the classifications needed by running the terminal commands:

python extract_embeddings.py --dataset dataset \--embeddings output/embeddings.pkl \--detector face_detection_model \--embedding-model openface_nn4.small2.v1.t7

python train_model.py --embeddings output/embeddings.pickle \--recognizer output/recognizer.pkl \--le output/le.pkl

Once the classifiers have been created, the main source code for the system can executed with the following terminal command:

python ANTFR_Facial_Recog.py --detector face_detection_model \--embedding-model openface_nn4.small2.v1.t7 \--recognizer output/recognizer.pkl \--le output/le.pkl

A video screen should now open on the monitor and display a live feed while outlining targets who are in the database of images. The source code can be since in Appendix E.2.

9 Administrative Content

This section covers various housekeeping topics such as the timing of the project life cycle, overall budget, team member biography's and responsibilities, and relevant conclusions. While often over looked in a large design project, these topics are crucial to the overall success of the ANT-FR.

9.1 Milestone Discussion

Milestones are a great accomplishment for any project, but they also give a strict timeline to team members and help to drive the team to complete tasks on time and hopefully within budget constraints. The purpose of our milestones is to give a flexible enough mark that the team can work to accomplish but have the room to modify the milestone as new issues or design constraints arise. We started this project in an agile development environment where we held weekly Scrum meetings. This allowed each team member enough flexibility to work on their tasks to the best of their ability while providing a bit of structure for them to start with.

9.1.1 Gantt Chart

Below in figure 8.1 is our project's timeline for tasks and deadlines for those tasks in Senior Design 1. Figure 8.2 shows our timeline and milestones for Senior Design 2. Using an application for project management called Asana, our team was able to effectively delegate tasks to each team member and stay up to date on each member's task and the progress they were making.

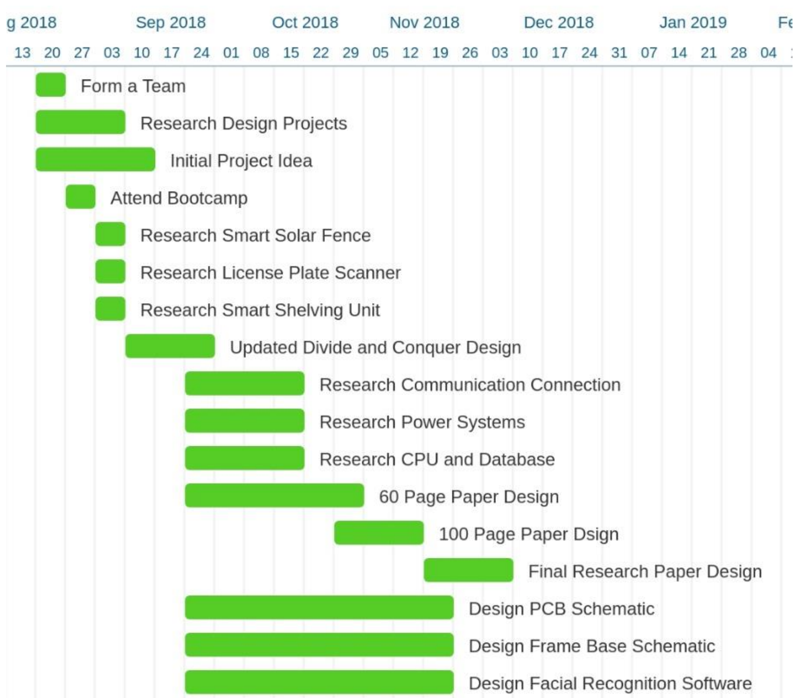

Figure 9.1. Gantt Chart Senior Design 1 Progression.

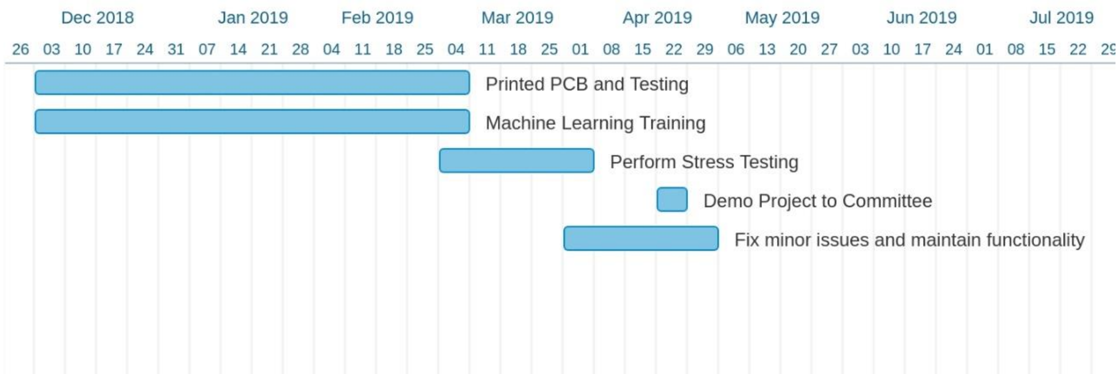

Figure 9.2. Gantt Chart Senior Design 2 Progression.

9.2 Budget and Finance Discussion

The estimated cost analysis for parts and equipment are listed below in table 8.1 and represents a conservative averaged estimation for the cost of each item from several vendors. Additional product details are being selected as the design process advances. Further quantity and price adjustments will be made as the project development life cycle advances. With respect to project financing and equipment, our team has sponsorships through the companies Soar Technology Inc. and Valencia College Division of Engineering and Built Environments. Soar Technology Inc. has graciously provided $1500 for the development of the ANT-FR project. Additionally, Valencia College’s Division of Engineering and Built Environments has offered our team the use of its 3D printing laboratory for the construction/testing of the turret. Both sponsorships will provide the necessary funding and environment to plan, design, build, and test the ANT-FR.

The project finance goal will be to stay within budget constraints while minimizing total costs and staying within the design parameters and desired outcomes. Even though this will be an alpha prototype design, materials and production costs should be minimized. This is critical for future development and scalability. Additionally, the primary hardware components such as: servos, battery packs, printed circuit board design, and foam dart gun are expected to be the highest cost items. There will be several miscellaneous parts needed for the project such as resistors, capacitors, wiring, soldering materials, LEDs, and so on. A more comprehensive list of these miscellaneous parts will be more apparent as the project design comes to fruition.

Company	Part	Cost
Digikey	PCB Components	$109.50
All-Battery	Servo Power Supply	$89.98
ServoCity	Servos	$283.73
Jameco	Relay	$15.40
Logitech	Camera	$159.74
Amazon	NERF Gun	$133.87
JLCPCB	PCB Manufacturing	$53.09
Hardware Store	Robot Frame	$98.45
Miscellaneous	Miscellaneous	$126.94
	Estimated Total	**$1070.70**

Table 9.1. Proposed Project Budget.

9.3 Decision Matrix

Table 8.2 below details the primary factors considered when selecting this project. The project is weighted against two additional ideas that were proposed by other team members. While only three projects are used for this design matrix, approximately 30 various designs were evaluated before the final decision was made. Cost, scalability, and familiarity with technology carries the heaviest weights among the seven factors. This engineering design received the highest score at 66. Additionally, this project received extra consideration when one of our sponsors indicated they were interested in supporting a project of this type. The structure of the team, namely having two computer engineers and one electrical engineer, made for an excellent fit for this project considering the complexity of the facial recognition design. Table 8.3 below shows the legend for the design matrix.

Projects Considered							
	Weight	**Automated Turret**		**License Plate Scan**		**Smart Fence**	
Criterion	**1-5**	**Rating**	**Score**	**Rating**	**Score**	**Rating**	**Score**
Ease of Implementation	3	2	6	1	3	1	3
Maintainability	2	3	6	2	4	2	4
Scalability	4	4	16	4	16	1	4
Low Cost	5	2	10	3	15	0	0
Sponsorship	3	4	12	4	12	1	3
Familiarity of Technology	4	3	12	2	8	1	4
Educational Goals	1	4	4	4	4	3	3
Total	**22**	**22**	**66**	**20**	**62**	**9**	**21**

Table 9.2. Decision Matrix.

Rating Description	Weight Description
0 - No Fit	1 - Low
1 - Low Fit	5 - High
2 - Fit	Score = Rating * Weight
3 - Good Fit	
4 - Excellent Fit	

Table 9.3. Decision Matrix Legend.

9.4 Personnel

ANT-FR consists of two computer engineering students and one electrical engineering student each of which brings in unique traits and skillsets to the project. Below is a brief bibliography of each team member who worked on ANT-FR and their core responsibilities for this project. While we divided up responsibilities, each team member had a direct impact on all areas involved with this project at every design conception, but assigning key tasks increased the project efficiency. Each member was responsible for the following: assuring their component was working according to the design, the timeline is followed so that their sections are completed in a timely manner, and that they are performing the necessary research for the project, which includes the research paper content for their designated responsibilities.

9.4.1 Steffen J. Camarato

Steffen J. Camarato is a senior computer engineering student who is also minoring in intelligent robotic systems. He served in the United States Marine Corps where he learned valuable skills in leadership and project management, as such, he takes on the role as the project manager for ANT-FR. Steffen currently works in a 3D Printing Laboratory and provides great insight for 3D printing and various drafting and design technologies. He has taken courses in Introduction to Robotics, Robotics Systems, and Robot Vision which provides an educational background for the facial recognition component of this project. Steffen's background supports key components for this project, such as the machine learning, facial recognition, and the robotic design, which he is responsible for.

9.4.2 Nicolas Jaramillo

Nicolas Jaramillo is a senior computer engineering student, minoring in intelligent robotic systems. He has taken courses in Robotic Systems, Robot Vision, Embedded Systems, and Principles of Software Development. He is a founding member of his high school's F.I.R.S.T. Robotics team, taking part in competitions throughout Florida and heading the team's treasury and electrical systems departments. Nicolas has experience in formal presentations, cooperation between different subsystems, and tracking costs and materials of projects. He has a great understanding in various programming languages, ranging from assembly to general purpose and to object-oriented. Nicolas has a solid foundation to develop the software components of this project. These software components include processing digital signals, controlling system peripherals, and connectivity between the database of targets and the facial recognition runtime. Nicolas is responsible for the development of the applications frontend and backend, as well as the embedded systems operation on the PCB.

9.4.3 Michael A. Young

Michael A. Young is a senior electrical engineering student. He has over two and a half years of experience working with an electrical engineering team designing low/medium voltage power systems for industrial applications. Michael also has extensive experience working with AutoCAD and modeling 2D/3D projects. Additionally, he has further focused his technical skills by taking courses in Fundamentals of Electric Power, Electric Machinery, and Introduction to Smart Grid. Altogether, Michael's experience in power systems design makes him the perfect fit for leading the team in designing the printed circuit board (PCB), power components, and assisting in modeling key framing components, which will be his responsibilities for this project.

9.5 Project Summary and Conclusions

Our team chose ANT-FR for our project because we wanted to work on a project that we would be passionate about. Dr. Lei Wei, who teaches Senior Design I at the University of Central Florida, made a comment during class about what a good senior design project typically is, he said:

> *"There are generally two ways to have a great senior design project. The first is to have an interdisciplinary project which always produces a good project because many disciplines come together to work on one goal. The other way is to find a project your team would be passionate about working on because if you're passionate about it, you will work hard to get the project done and it will be great."*

This quote resonated with our team, and once we heard about this project and a company looking to sponsor ANT-FR, we knew we had a solid idea. Each member was ecstatic to be playing with NERF guns and designing a project that would be fun and exciting to test, but also take us out of our comfort zones to work on areas that we only learned about from coursework. We were slightly overzealous because our passion was much greater than our experience, as we were unaware of the major difference between facial detection and facial recognition. Once the research phase began, our team saw the real challenges in facial recognition and why the University of Central Florida has an entire research department dedicated to Computer Vision.

A user will be able to use an application to view images, add images, delete images, and select/deselect an image as a target. ANT-FR will be able to detect objects when an object enters its field of vision and the camera will be able to continuously track the object while it is within its field of vision. Once an object has been detected, the facial detection will begin checking if the object is a human. Once ANT-FR has confirmed a human is within its field of vision, the facial recognition software will start to check if that person is within our database of images and if that person is selected as a target. The NERF turret will utilize a gun from the NERF Rival series because the balls can be easily loaded via hopper which improves the efficiency of the turret compared to using darts. Once the facial recognition verifies a target, a signal is sent to the gun to start firing at the target until that target is no longer recognizable or leaves the field of vision.

In conclusion, we want to stimulate the minds of future engineering students to take a step out of their comfort zones and incorporate facial recognition on a bigger scale than what has been done in the past. We also hope to gain valuable knowledge in the systems engineering field and how to go from researching and design to building a functioning prototype.

9.6 Acknowledgements

This project was funded and supported by Soar Technology, Inc. (SoarTech) and Valencia College Division of Engineering and Built Environments. Without their generosity for funding and facility resources, we may have never completed this project and we are grateful for this. We would like to thank Dr. Gita Reese Sukthankar and Dr. Niels Da Vitoria Lobo for comments that narrowed our research scope and for their time spent speaking with us about our project.

We would also like to show our gratitude to our family and friends who supported us throughout our education and continued to push us further as we worked on this project. Their commitment and dedication were a key factor in motivating us to strive for excellence.

Appendices

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Appendix B – Copyright Permissions

Below are the correspondence emails and other forms of written verification for approval to use content of images and information from for this research paper.

11/15/2018 Mail - sjcamarato@Knights.ucf.edu

To: Steffen Camarato
Subject: Re: Request permission to use your materials

Hi Steffen, of course that's fine! Please just add an appropriate citation wherever you use the material.

-Brandon.

On Sun, Oct 28, 2018, 7:02 PM Steffen Camarato <sjcamarato@knights.ucf.edu> wrote:

> Good Evening Mr. Amos,
>
> I'm a Senior Computer Engineering Student at the University of Central Florida. My team and I are currently working on our Senior Design Project and we were interested in using OpenFace located here:
>
> http://cmusatyalab.github.io/openface/
>
> We were like to cite your work and use some of the images in the documentation for our technical report and would like to request authorization to do so.
>
> Please let me know if you have any questions.
>
> Respectfully,
>
> **Steffen J. Camarato**
> Computer Engineering Laboratory Assistant at Valencia College
>
> **Education.** B.S. Computer Engineering Student at University of Central Florida
> A.A. Articulated Engineering from Valencia College
> **Organizations.** Institute of Electrical and Electronics Engineers
> **Mobile.** (760) 529-6471 **Email.** sjcamarato@gmail.com
> **LinkedIn.** https://www.linkedin.com/in/sjcamarato

https://outlook.office.com/owa/?path=/mail/AQMkADhiN2U5OGI2LWM1MTYtNDJkMy05ZjEwLTFhNzAxMGFjYjQ4NwAuAAADLzcBDbV8R0233tZwp… 3/3

Figure B.1. OpenFace Copyright Permission.

11/15/2018 Mail - sjcamarato@Knights.ucf.edu

Re: Request for Permission to use images

Davis King <davis@dlib.net>

Tue 11/13/2018 11:29 PM

To: Steffen Camarato <sjcamarato@Knights.ucf.edu>;

Yes, of course you can!

On Tue, Nov 13, 2018 at 3:56 PM Steffen Camarato <sjcamarato@knights.ucf.edu> wrote:

Good Afternoon Mr. King,

I am currently working on my senior design research paper and I am interested in using Dlib Real-Time Face Pose Estimation located here:

http://blog.dlib.net/2014/08/real-time-face-pose-estimation.html

I wanted to request permission to use some of the information and images in my paper, with proper citations. Would that be okay?

Respectfully,

Steffen J. Camarato
Computer Engineering Laboratory Assistant at Valencia College

Education. B.S. Computer Engineering Student at University of Central Florida
A.A. Articulated Engineering from Valencia College
Organizations. Institute of Electrical and Electronics Engineers
Mobile. (760) 529-6471 **Email.** sjcamarato@gmail.com
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Figure B.2. Dlib Copyright Permission.

11/15/2018 Mail - sjcamarato@Knights.ucf.edu

Re: OnLine 4453: Steffen Camarato

Niels da Vitoria Lobo <niels@cs.ucf.edu>

Mon 11/12/2018 6:35 PM

To:Steffen Camarato <sjcamarato@Knights.ucf.edu>;

Cc:niels@cs.ucf.edu <niels@cs.ucf.edu>;

>
> Good Evening Professor,
>
>
> I'm currently working on my senior design research paper and I would like t=
> o add some images and content from your class lectures. Would you mind if I=
> used some of your information, citing appropriately?

yes, please cite, if you use. But I am not sure if you
need to get permission from UCF or not.

Best.
--NL

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Figure B.3. Professor Niels Lobo Copyright Permission.

Appendix C – Datasheets

This section contains all relevant datasheets that were used for referencing the research conducted and the design of this project. Only the first page or two of the datasheet is provided in this report, however, the datasheets extends to multiple pages.

Features

- High Performance, Low Power AVR® 8-Bit Microcontroller
- Advanced RISC Architecture
  - 125 Powerful Instructions – Most Single Clock Cycle Execution
  - 32 x 8 General Purpose Working Registers
  - Fully Static Operation
  - Up to 16 MIPS Throughput at 16 MHz
- Non-volatile Program and Data Memories
  - 8K/16K/32K Bytes of In-System Self-Programmable Flash
  - 512/512/1024 EEPROM
  - 512/512/1024 Internal SRAM
  - Write/Erase Cycles: 10,000 Flash/ 100,000 EEPROM
  - Data retention: 20 years at 85°C/ 100 years at 25°C[1]
  - Optional Boot Code Section with Independent Lock Bits
    In-System Programming by on-chip Boot Program hardware-activated after reset
    True Read-While-Write Operation
  - Programming Lock for Software Security
- USB 2.0 Full-speed Device Module with Interrupt on Transfer Completion
  - Complies fully with Universal Serial Bus Specification REV 2.0
  - 48 MHz PLL for Full-speed Bus Operation : data transfer rates at 12 Mbit/s
  - Fully independant 176 bytes USB DPRAM for endpoint memory allocation
  - Endpoint 0 for Control Transfers: from 8 up to 64-bytes
  - 4 Programmable Endpoints:
    IN or Out Directions
    Bulk, Interrupt and IsochronousTransfers
    Programmable maximum packet size from 8 to 64 bytes
    Programmable single or double buffer
  - Suspend/Resume Interrupts
  - Microcontroller reset on USB Bus Reset without detach
  - USB Bus Disconnection on Microcontroller Request
- Peripheral Features
  - One 8-bit Timer/Counters with Separate Prescaler and Compare Mode (two 8-bit PWM channels)
  - One 16-bit Timer/Counter with Separate Prescaler, Compare and Capture Mode (three 8-bit PWM channels)
  - USART with SPI master only mode and hardware flow control (RTS/CTS)
  - Master/Slave SPI Serial Interface
  - Programmable Watchdog Timer with Separate On-chip Oscillator
  - On-chip Analog Comparator
  - Interrupt and Wake-up on Pin Change
- On Chip Debug Interface (debugWIRE)
- Special Microcontroller Features
  - Power-On Reset and Programmable Brown-out Detection
  - Internal Calibrated Oscillator
  - External and Internal Interrupt Sources
  - Five Sleep Modes: Idle, Power-save, Power-down, Standby, and Extended Standby
- I/O and Packages
  - 22 Programmable I/O Lines
  - QFN32 (5x5mm) / TQFP32 packages
- Operating Voltages
  - 2.7 - 5.5V
- Operating temperature
  - Industrial (-40°C to +85°C)
- Maximum Frequency
  - 8 MHz at 2.7V - Industrial range
  - 16 MHz at 4.5V - Industrial range

Note: 1. See "Data Retention" on page 6 for details.

ATMEL®

8-bit AVR® Microcontroller with 8/16/32K Bytes of ISP Flash and USB Controller

ATmega8U2

ATmega16U2

ATmega32U2

7799E–AVR–09/2012

Figure C.1. ATmega16U2 Datasheet.

Features

- High Performance, Low Power AVR® 8-Bit Microcontroller
- Advanced RISC Architecture
  - 131 Powerful Instructions – Most Single Clock Cycle Execution
  - 32 x 8 General Purpose Working Registers
  - Fully Static Operation
  - Up to 20 MIPS Throughput at 20 MHz
  - On-chip 2-cycle Multiplier
- High Endurance Non-volatile Memory Segments
  - 4/8/16/32K Bytes of In-System Self-Programmable Flash progam memory (ATmega48P/88P/168P/328P)
  - 256/512/512/1K Bytes EEPROM (ATmega48P/88P/168P/328P)
  - 512/1K/1K/2K Bytes Internal SRAM (ATmega48P/88P/168P/328P)
  - Write/Erase Cycles: 10,000 Flash/100,000 EEPROM
  - Data retention: 20 years at 85°C/100 years at 25°C[1]
  - Optional Boot Code Section with Independent Lock Bits
    In-System Programming by On-chip Boot Program
    True Read-While-Write Operation
  - Programming Lock for Software Security
- Peripheral Features
  - Two 8-bit Timer/Counters with Separate Prescaler and Compare Mode
  - One 16-bit Timer/Counter with Separate Prescaler, Compare Mode, and Capture Mode
  - Real Time Counter with Separate Oscillator
  - Six PWM Channels
  - 8-channel 10-bit ADC in TQFP and QFN/MLF package
    Temperature Measurement
  - 6-channel 10-bit ADC in PDIP Package
    Temperature Measurement
  - Programmable Serial USART
  - Master/Slave SPI Serial Interface
  - Byte-oriented 2-wire Serial Interface (Philips I^2C compatible)
  - Programmable Watchdog Timer with Separate On-chip Oscillator
  - On-chip Analog Comparator
  - Interrupt and Wake-up on Pin Change
- Special Microcontroller Features
  - Power-on Reset and Programmable Brown-out Detection
  - Internal Calibrated Oscillator
  - External and Internal Interrupt Sources
  - Six Sleep Modes: Idle, ADC Noise Reduction, Power-save, Power-down, Standby, and Extended Standby
- I/O and Packages
  - 23 Programmable I/O Lines
  - 28-pin PDIP, 32-lead TQFP, 28-pad QFN/MLF and 32-pad QFN/MLF
- Operating Voltage:
  - 1.8 - 5.5V for ATmega48P/88P/168PV
  - 2.7 - 5.5V for ATmega48P/88P/168P
  - 1.8 - 5.5V for ATmega328P
- Temperature Range:
  - -40°C to 85°C
- Speed Grade:
  - ATmega48P/88P/168PV: 0 - 4 MHz @ 1.8 - 5.5V, 0 - 10 MHz @ 2.7 - 5.5V
  - ATmega48P/88P/168P: 0 - 10 MHz @ 2.7 - 5.5V, 0 - 20 MHz @ 4.5 - 5.5V
  - ATmega328P: 0 - 4 MHz @ 1.8 - 5.5V, 0 - 10 MHz @ 2.7 - 5.5V, 0 - 20 MHz @ 4.5 - 5.5V
- Low Power Consumption at 1 MHz, 1.8V, 25°C for ATmega48P/88P/168P:
  - Active Mode: 0.3 mA
  - Power-down Mode: 0.1 µA
  - Power-save Mode: 0.8 µA (Including 32 kHz RTC)

Note: 1. See "Data Retention" on page 7 for details.

8-bit AVR® Microcontroller with 4/8/16/32K Bytes In-System Programmable Flash

ATmega48P/V*
ATmega88P/V*
ATmega168P/V
ATmega328P**

****Preliminary**

* Not recommended for new designs.

Rev. 8025I–AVR–02/09

Figure C.2. ATmega328P-PU Datasheet.

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TEXAS INSTRUMENTS

LM2576xx Series SIMPLE SWITCHER® 3-A Step-Down Voltage Regulator

1 Features

- 3.3-V, 5-V, 12-V, 15-V, and Adjustable Output Versions
- Adjustable Version Output Voltage Range,1.23 V to 37 V (57 V for HV Version) ±4% Maximum Over Line and Load Conditions
- Specified 3-A Output Current
- Wide Input Voltage Range: 40 V Up to 60 V for HV Version
- Requires Only 4 External Components
- 52-kHz Fixed-Frequency Internal Oscillator
- TTL-Shutdown Capability, Low-Power Standby Mode
- High Efficiency
- Uses Readily Available Standard Inductors
- Create a Custom Design with WEBENCH Tools
- Thermal Shutdown and Current Limit Protection

2 Applications

- Simple High-Efficiency Step-Down (Buck) Regulator
- Efficient Preregulator for Linear Regulators
- On-Card Switching Regulators
- Positive-to-Negative Converter (Buck-Boost)

3 Description

The LM2576 series of regulators are monolithic integrated circuits that provide all the active functions for a step-down (buck) switching regulator, capable of driving 3-A load with excellent line and load regulation. These devices are available in fixed output voltages of 3.3 V, 5 V, 12 V, 15 V, and an adjustable output version.

Requiring a minimum number of external components, these regulators are simple to use and include fault protection and a fixed-frequency oscillator.

The LM2576 series offers a high-efficiency replacement for popular three-terminal linear regulators. It substantially reduces the size of the heat sink, and in some cases no heat sink is required.

A standard series of inductors optimized for use with the LM2576 are available from several different manufacturers. This feature greatly simplifies the design of switch-mode power supplies.

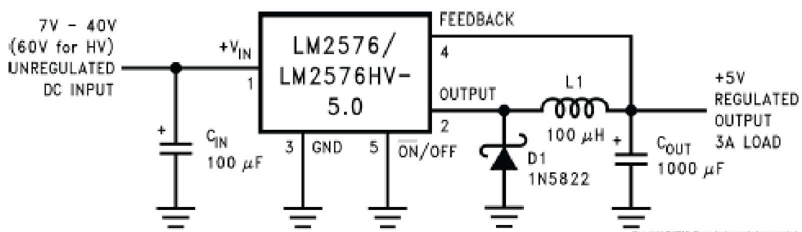
Other features include a ±4% tolerance on output voltage within specified input voltages and output load conditions, and ±10% on the oscillator frequency. External shutdown is included, featuring 50-μA (typical) standby current. The output switch includes cycle-by-cycle current limiting, as well as thermal shutdown for full protection under fault conditions.

Device Information(1)

PART NUMBER	PACKAGE	BODY SIZE (NOM)
LM2576 LM2576HV	TO-220 (5)	10.16 mm × 8.51 mm
	DDPAK/TO-263 (5)	10.16 mm × 8.42 mm

(1) For all available packages, see the orderable addendum at the end of the data sheet.

Fixed Output Voltage Version Typical Application Diagram



An IMPORTANT NOTICE at the end of this data sheet addresses availability, warranty, changes, use in safety-critical applications, intellectual property matters and other important disclaimers. PRODUCTION DATA.

Figure C.3. LM2576 Voltage Regulator Datasheet.

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TEXAS INSTRUMENTS

LM3940

SNVS114G – MAY 1999 – REVISED FEBRUARY 2015

LM3940 1-A Low-Dropout Regulator for 5-V to 3.3-V Conversion

1 Features

- Input Voltage Range: 4.5 V to 5.5 V
- Output Voltage Specified over Temperature
- Excellent Load Regulation
- Specified 1-A Output Current
- Requires only One External Component
- Built-in Protection against Excess Temperature
- Short-Circuit Protected

2 Applications

- Laptop and Desktop Computers
- Logic Systems

3 Description

The LM3940 is a 1-A low-dropout regulator designed to provide 3.3 V from a 5-V supply.

The LM3940 is ideally suited for systems which contain both 5-V and 3.3-V logic, with prime power provided from a 5-V bus.

Because the LM3940 is a true low dropout regulator, it can hold its 3.3-V output in regulation with input voltages as low as 4.5 V.

The TO-220 package of the LM3940 means that in most applications the full 1 A of load current can be delivered without using an additional heatsink.

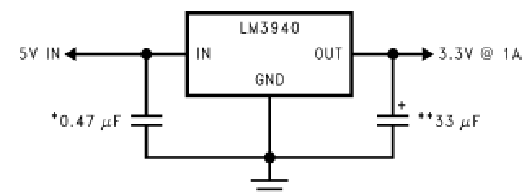
The surface mount DDPAK/TO-263 package uses minimum board space, and gives excellent power dissipation capability when soldered to a copper plane on the PC board.

Device Information(1)

PART NUMBER	PACKAGE	BODY SIZE (NOM)
LM3940	SOT-223 (4)	6.50 mm x 3.50 mm
	DDPAK/TO-263 (3)	10.18 mm x 8.41 mm
	TO-220 (3)	14.986 mm x 10.16 mm

(1) For all available packages, see the orderable addendum at the end of the datasheet.

Simplified Schematic



*Required if regulator is located more than 1 inch from the power supply filter capacitor or if battery power is used.
**See *Application and Implementation*.

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Figure C.3. LM3940 Voltage Regulator Datasheet.

Appendix D – Reference Designs

Below is a list of reference design schematics that were utilized in designing key components and testing for this project.

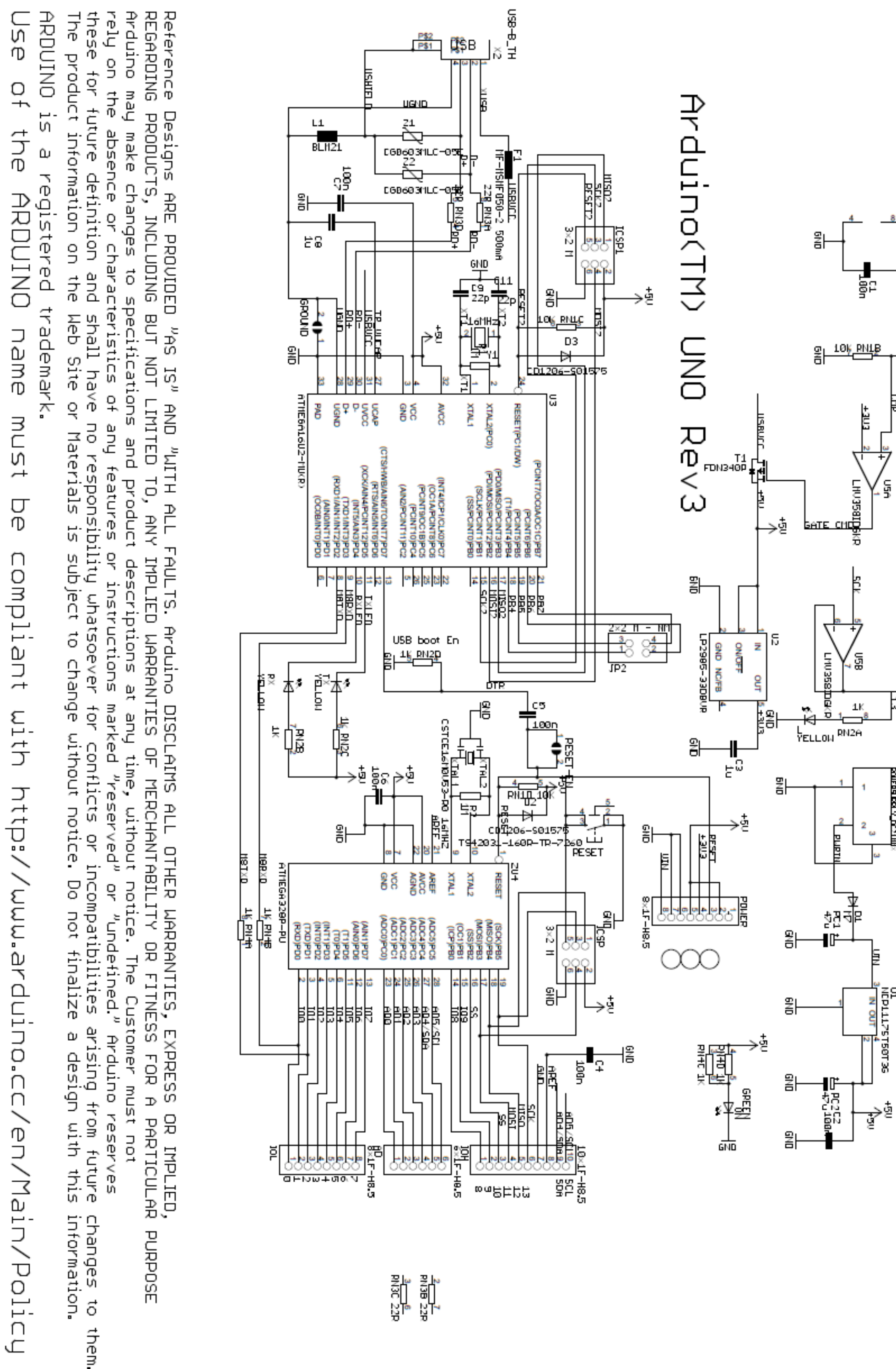

Figure D.1. Arduino Uno Rev3 Reference Schematic.

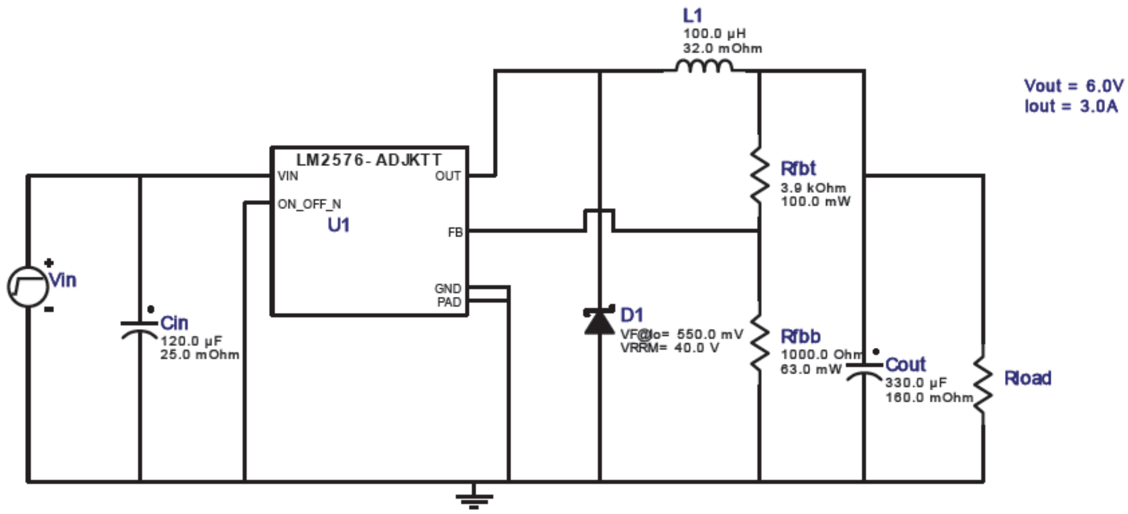

Figure D.2. LM2576 Reference Schematic.

Appendix E – Software

Appendix E contains the main source code files that were being used for the ANT-FR system.

E.1 Embedded Systems

```
/* Libraries */

#include <Servo.h>

/* Initialize Global Variables */

// Servo
Servo servoYaw;
Servo servoPitch;

// Serial input
int incoming[3];

// Constants
int previousPitch = 90;
int MAX_ANGLE = 99;
int MIN_ANGLE = 81;
int relay = 7;
int counter = 0;

/* Initialization method */

void setup()
{

  servoYaw.attach(3);
  servoPitch.attach(5);
  pinMode(relay, OUTPUT);
  Serial.begin(9600);
  servoPitch.write(90);

} // END void setup()

/* Main method */

void loop()
{

  /*    Parse Input:
            Taken input from serial connection
            Store input to int array incoming[3]
  */

  if (Serial.available() >= 3){
    for (int i = 0; i < 3; i++){
      incoming[i] = Serial.read();
    }
```

```
    /*  Yaw Rotation: incoming[0]
            Control PWM to enable yaw rotation for a period of 60ms
            Key:
                0 - CCW     1200
                1 - None    1500
                2 - CW      1800
    */

    if(incoming[0] <= 2 && incoming[0] >= 0){

      if(incoming[0] == 1){
        //Serial.println("Yaw rotation: None"); // Remove when not
debugging
        servoYaw.writeMicroseconds(1500);
      }
      if(incoming[0] == 0){
        //Serial.println("Yaw Rotation: Left"); // Remove when not
debugging
        servoYaw.writeMicroseconds(1200);
        delay(60);
        servoYaw.writeMicroseconds(1500);
      }
      if(incoming[0] == 2){
        //Serial.println("Yaw Rotation: Right"); // Remove when not
debugging
        servoYaw.writeMicroseconds(1800);
        delay(60);
        servoYaw.writeMicroseconds(1500);
      }

    } // END Yaw Rotation

    /*  Pitch Rotation: incoming[1]
            Control PWM to enable pitch rotation in degrees
            Key:
                0 - Current = Previous - 1
                1 - Current = Previous
                2 - Current = Previous + 1
            'Previous' initiates at 90 degrees
            'Current' does not fall below MIN_ANGEL or above MAX_ANGLE
    */

    if(incoming[1] <= 2 && incoming[1] >= 0){
      if(incoming[1] == 1){
        //Serial.println("Pitch Rotation: None"); // Remove when not
debugging
        previousPitch = previousPitch;
      }

      if(incoming[1] == 0){
        if(previousPitch == MIN_ANGLE)
            previousPitch = previousPitch;
        else
            previousPitch = previousPitch - 20;

        //Serial.println("Pitch Rotation: Down"); // Remove when not
debugging
```

```
        servoPitch.write(previousPitch);
      }

      if(incoming[1] == 2){
        if(previousPitch == MAX_ANGLE)
            previousPitch = previousPitch;
        else
            previousPitch = previousPitch + 20;

        //Serial.println("Pitch Rotation: Up"); // Remove when not
debugging
        servoPitch.write(previousPitch);
      }

    } // END Pitch Rotation

    /*  Relay Firing: incoming[2]
            Control digital output to enable gun flywheel motors
            Key:
                0 - Stop
                1 - Fire
    */

    if(incoming[2] <= 1 && incoming[2] >= 0){
        if(incoming[2] == 1 && counter == 0){
            //Serial.println("NERF: FIRE");
            digitalWrite(relay, HIGH);
            delay(500);
            digitalWrite(relay, LOW);
            delay(50);
            counter = 9;
        }
        else if(incoming[2] == 1 && counter != 0){
            digitalWrite(relay, LOW);
            counter--;
        }
        else{
            digitalWrite(relay, LOW);
        }
        //Serial.println("NERF: STOP"); // Remove when not debugging

    } // END Relay Firing

  } // END Parse Input

} // END void loop()
```

E.2 Facial Recognition

```
#
# Disclaimer: Thanks to Adrian Rosebrock at pyimagesearch.com for their
tutorials in
```

```
# deep learning and face, which provided a foundation for this project.
Also to OpenCV
# libraries and forums and OpenFace for their pretrained deep neural
network.
#

# import the necessary packages
from imutils.video import VideoStream
from imutils.video import FPS
import numpy as np
import argparse
import imutils
import pickle
import time
import cv2
import os
import sys
import serial
import struct
import json

# construct the argument parser and parse the arguments
ap = argparse.ArgumentParser()
ap.add_argument("-d", "--detector", required=True,
                help="path to OpenCV's deep learning face detector")
ap.add_argument("-m", "--embedding-model", required=True,
                help="path to OpenCV's deep learning face embedding
model")
ap.add_argument("-r", "--recognizer", required=True,
                help="path to model trained to recognize faces")
ap.add_argument("-l", "--le", required=True,
                help="path to label encoder")
ap.add_argument("-c", "--confidence", type=float, default=0.5,
                help="minimum probability to filter weak detections")
args = vars(ap.parse_args())

# Connect to data server and update target list
print("[Updating Target Database...]")
os.system('./connect.sh')
textFile = open("targetList.txt")

# Pull updated target information and add it to the target database
target = json.load(textFile)

# Open stderror file for debugging and testing
f = open("errorFile.txt", "w")
original_stderr = sys.stderr
sys.stderr = f

# load our serialized face detector from disk
print("[Initializing Face Detector...]")
protoPath = os.path.sep.join([args["detector"], "deploy.prototxt"])
modelPath = os.path.sep.join([args["detector"],

"res10_300x300_ssd_iter_140000.caffemodel"])
detector = cv2.dnn.readNetFromCaffe(protoPath, modelPath)
```

```
# load our serialized face embedding model from disk
print("[Initializing Face Recognizer...]")
embedder = cv2.dnn.readNetFromTorch(args["embedding_model"])

# load the actual face recognition model along with the label encoder
recognizer = pickle.loads(open(args["recognizer"], "rb").read())
le = pickle.loads(open(args["le"], "rb").read())

# initialize the video stream, then allow the camera sensor to warm up
print("[Warming Up Camera...]")
vs = VideoStream(src=0).start()
time.sleep(2.0)

# initialize serial communication
print("[Establishing Serial Connection to PCB...]")
serial1 = serial.Serial('/dev/ttyACM0', 9600)

# Output STDOUT to txt file because of error:
# QObject::moveToThread: Current thread (0x5c72b00) is not the object's
thread (0x483c900).
# Cannot move to target thread (0x5c72b00)
# Issue with openCV wait.key(0) function and version control. Can't fix
without uninstall
stdF = open("stdoutput.txt", "w")
sys.stdout = stdF

# Initialize the name variable, incase no detections are in field of
view
name = ''

# loop over frames from the video file stream
while True:
    # grab the frame from the threaded video stream
    frame = vs.read()

    # resize the frame to have a width of 600 pixels (while
    # maintaining the aspect ratio), and then grab the image
    # dimensions
    frame = imutils.resize(frame, width=600)
    (h, w) = frame.shape[:2]

    # construct a blob from the image
    imageBlob = cv2.dnn.blobFromImage(
        cv2.resize(frame, (300, 300)), 1.0, (300, 300),
        (104.0, 177.0, 123.0), swapRB=False, crop=False)

    # apply OpenCV's deep learning-based face detector to localize
    # faces in the input image
    detector.setInput(imageBlob)
    detections = detector.forward()

    # loop over the detections
    for i in range(0, detections.shape[2]):
        # extract the confidence (i.e., probability) associated with
        # the prediction
        confidence = detections[0, 0, i, 2]
```

```
        # filter out weak detections
        if confidence > args["confidence"]:
            # compute the (x, y)-coordinates of the bounding box for
            # the face
            box = detections[0, 0, i, 3:7] * np.array([w, h, w, h])
            (startX, startY, endX, endY) = box.astype("int")

            # extract the face ROI
            face = frame[startY:endY, startX:endX]
            (fH, fW) = face.shape[:2]

            # ensure the face width and height are sufficiently large
            if fW < 20 or fH < 20:
                continue

            # construct a blob for the face ROI, then pass the blob
            # through our face embedding model to obtain the 128-d
            # quantification of the face
            faceBlob = cv2.dnn.blobFromImage(face, 1.0 / 255,
                                             (96, 96), (0, 0, 0),
swapRB=True, crop=False)
            embedder.setInput(faceBlob)
            vec = embedder.forward()

            # perform classification to recognize the face
            preds = recognizer.predict_proba(vec)[0]
            j = np.argmax(preds)
            proba = preds[j]
            name = le.classes_[j]

            # draw the bounding box of the face along with the
            # associated probability
            if proba >= 0.7:
                text = "{}: {:.2f}%".format(name, proba * 100)
                y = startY - 10 if startY - 10 > 10 else startY + 10

                if 'steffen' == name:
                    cv2.rectangle(frame, (startX, startY), (endX,
endY),
                                  (0, 255, 0), 2)
                    cv2.putText(frame, text, (startX, y),
                                cv2.FONT_HERSHEY_SIMPLEX, 0.45, (0,
255, 0), 2)
                elif 'nicolas' == name:
                    cv2.rectangle(frame, (startX, startY), (endX,
endY),
                                  (255, 0, 0), 2)
                    cv2.putText(frame, text, (startX, y),
                                cv2.FONT_HERSHEY_SIMPLEX, 0.45, (255,
0, 0), 2)
                elif 'michael' == name:
                    cv2.rectangle(frame, (startX, startY), (endX,
endY),
                                  (0, 0, 255), 2)
                    cv2.putText(frame, text, (startX, y),
                                cv2.FONT_HERSHEY_SIMPLEX, 0.45, (0, 0,
255), 2)
```

```
                else:
                    name = None
            else:
                name = None

            # calculate the centroid of the bounding box
            centroidX = (startX + endX) / 2
            centroidY = (startY + endY) / 2

    # Handle multiple targets in field of view
    if len(target) > 1 and name != None:
        if 'steffen' in name and 'steffen' in target:
            realTarget = 'steffen'
        elif 'michael' in name and 'michael' in target:
            realTarget = 'michael'
        elif 'nicolas' in name and 'nicolas' in target:
            realTarget = 'nicolas'
        else:
            realTarget = target
    else:
        realTarget = target

    # If target is in field of view, turret moves and tracks target
    if name in realTarget:
        # name is a target, if confidence level is > 70% shoot target
        if proba >= 0.7:

            # Adjust yaw rotation based on the centroid of X
            if centroidX < 250:
                tempA = 2  # Move yaw rotation to the right
                tempC = 0  # Don't fire
            elif centroidX > 350:
                tempA = 0  # Move yaw rotation to the left
                tempC = 0  # Don't fire
            else:
                tempA = 1  # Do not move
                tempC = 1  # fire at target

            # Adjust pitch rotation based on the centroid of Y
            # if centroidY < 175:
            #   tempB = 2 # Move pitch rotation up
            # elif centroidY > 425:
            #   tempB = 0 # Move pitch rotation down
            # else:
            #   tempB = 1 # Don't move

            # Write to the PCB with values needed.
            serial1.write(struct.pack('>BBB', tempA, 1, tempC))

        else:
            # Do nothing and don't move
            serial1.write(struct.pack('BBB', 1, 1, 0))

    else:
        serial1.write(struct.pack('BBB', 1, 1, 0))  # Do nothing and
don't move
```

```
    name = None  # reset name variable to stop the system from looping
infinetely

    # show the output frame
    cv2.imshow("Frame", frame)
    key = cv2.waitKey(1) & 0xFF

    # if the `q` key was pressed, break from the loop
    if key == ord("q"):
        serial1.write(struct.pack('BBB', 1, 1, 0))  # Do nothing and
don't move
        break

# Close the stderror output file
sys.stderr = original_stderr
f.close()
stdF.close()  # close stdout file

# do a bit of cleanup
cv2.destroyAllWindows()
vs.stop()
```