Autonomous NERF Turret with Facial Recognition (ANT-FR)

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***Abstract* — Sentry guns have been primarily used for military and security purposes since the early 2000's but have not been implemented for civilian use. This paper presents the design methodology for an autonomous turret that analyzes a 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. This system will be primarily utilized by consumers and businesses for leisure activities.**

***Index Terms* — DC-DC Power Converter, Digital Integrated Circuits, Face Recognition, Neural Network, Pulse Width Modulation**

I. Introduction

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. 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. One of our intended outcomes for this project is 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, we can scale the project to be easily purchased and utilized in businesses or even households

The expectations for this senior design are to build a functioning alpha prototype of an autonomous NERF turret that utilizes facial recognition software to lock onto targets. By connecting to a database of images, the autonomous turret will have the ability to access that database, 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. The turret will 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 for users to operate the turret. 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.

II. Hardware design

Figure 1 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 USB serial interface, which has the laptop and camera connected, and the servo motor outputs. The Wi-Fi connection serves 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

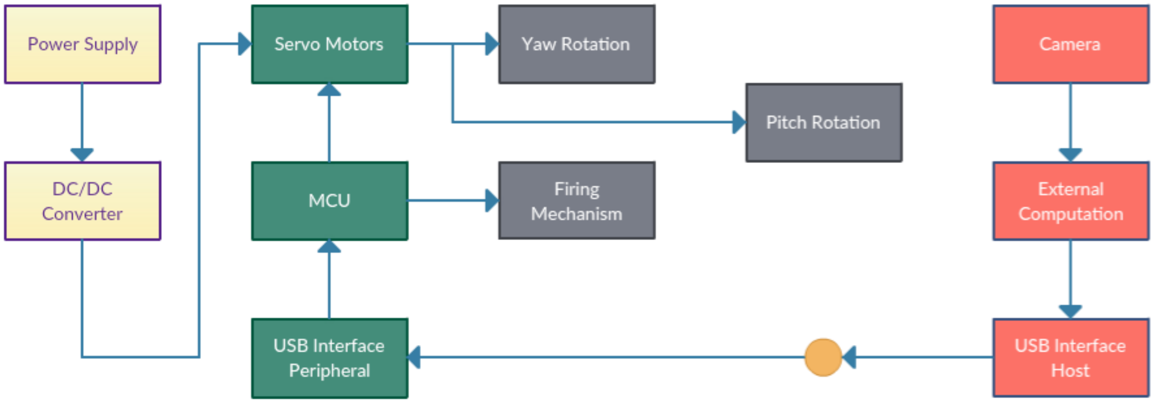

Fig. 1. Hardware block diagram for the overall embedded systems and printed circuit board.

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.

A. 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 frame for the turret and the placement of the printed circuit board. This will be the main component of the framing as most of the hardware and materials will be used here. 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 base 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. 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 2.

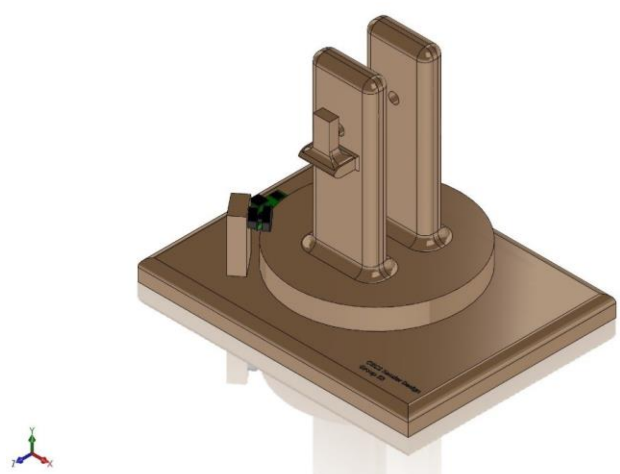

Fig. 2. ANT-FR Second Component Framing.

The third component will be the NERF gun which will be installed in-between the two pillars of the second component. The NERF gun’s trigger assembly will be dismantled and repurposed by connecting the trigger assembly directly to a relay which is attached to the printed circuit board. This will allow the software to send a signal to fire the gun. 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 desire.

B. Universal Serial Bus 2.0 Type B

The hardware of ANT-FR consists of several subsystems that make up the system, one of which being the Universal Serial Bus 2.0 Type B (USB) which is one of the more complex subsystems. This is due to 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.

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.

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.

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.

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 are a common issue encountered in micro-electronics, thus this method of handling it is imperative.

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.

C. Microcontrollers

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. This will provide an easy and effective method for accessing the PWM, digital, and VCC pins. The subsystem consists of a bypass section, frequency oscillation, reset function, TX/RX data reception, and output to shield headers.

The main printed circuit board will contain the ATmega328P-PU as seen in figure 3. As the primary single-board microcontroller, this board will contain the sketch which provides the necessary embedded systems instructions for the operation of the autonomous turret.

As the on-board 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 ATmega16U2 is a powerful microcontroller and is pre-programmed from the factory to serve as a USB-to-serial converter. Using the ATmega16U2 rather than comparable dedicated chips may prove beneficial as its supply voltage is within that granted by the USB voltage-in terminal, removing the need to implement yet another voltage regulator.

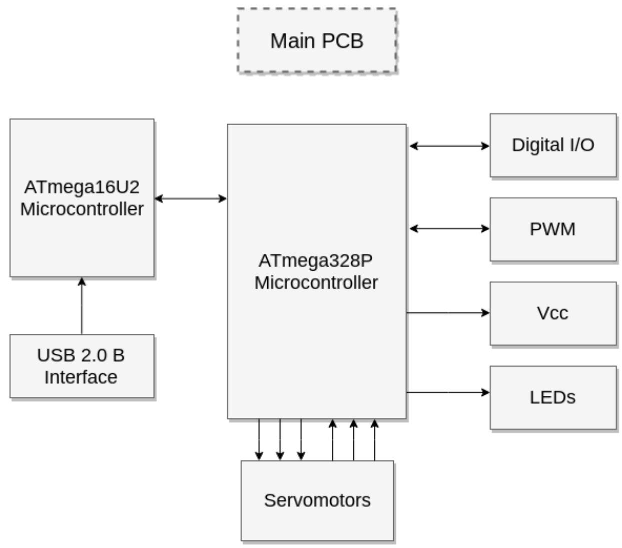

Fig. 3. Overview of the main printed circuit board.

D. Voltage Regulation

Next is the voltage regulation which occurs within the power subsystem in figure 4. 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.

As mentioned, 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. A 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 6.0V. 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.

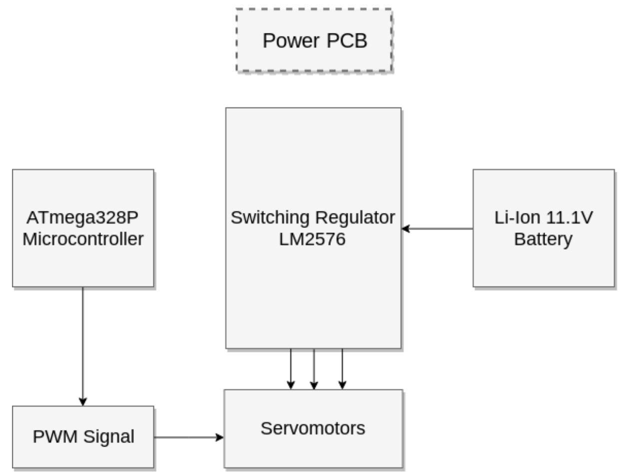

Fig. 4. Overview of the power printed circuit board.

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. The system will be responsible for tracking the position of the target in a three-dimensional space. Two servomotors are required to rotate the turret's frame, which will draw power from an external power source, regulated by the Power PCB. The servos operating on the horizontal rotation and the vertical tilt are not required to be identical as they serve different needs.

A continuously rotating servo is needed to achieve full degree of horizontal rotation for the turret. The servo will be attached to a wheel with a high degree of traction. This will be located on the end of the disc-shaped base of the sentry turret. An encoded rotating servo will be required to maintain the position of vertical tilt against the weight of gravity. This servo will be placed on one side of the frame, parallel to the large pillars sustaining the NERF gun and a metal rod will be affixed to the servo which runs through the gun.

E. Firing Mechanism

To fire the NERF gun, an electrical connection was 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 were disconnected from the onboard safety switches and spliced together as one wire. Additionally, the positive lead wire for the NiMH rechargeable battery contact was 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 was implemented. The relay utilized, has common, normally open, and normally closed terminals. The positive lead of the battery was connected to the common terminal, while the motor wire was 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 are 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.

III. SOFTWARE DESIGN

Figure 6 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, handling interrupts, and variables and conditions that supersede any currently running subroutine needs to be established in the core system. The embedded programming monitors all peripheral equipment such as the camera and the servos motors. The core system is also in charge of relative position of the turret and the processing output information for firing on the system's target. External components involve all calculations and algorithms that the onboard CPU cannot undertake, such as 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.

A. 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 shows the workflow for a single input image and how OpenFace operates on a general level.

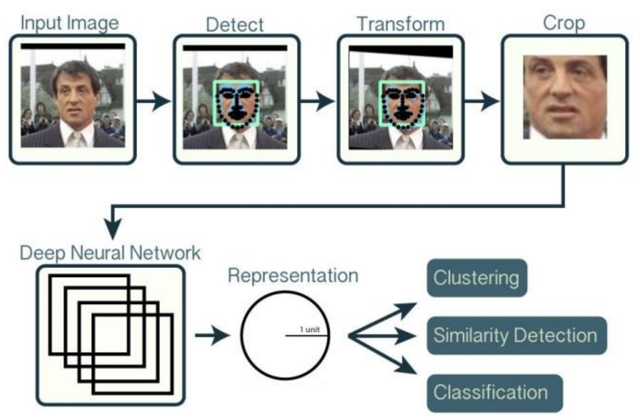

Fig. 5. OpenFace Workflow. (Reprinted with permission from OpenFace 2015).

The deep neural network is optimized using a technique called triplet embeddings in figure 7. 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

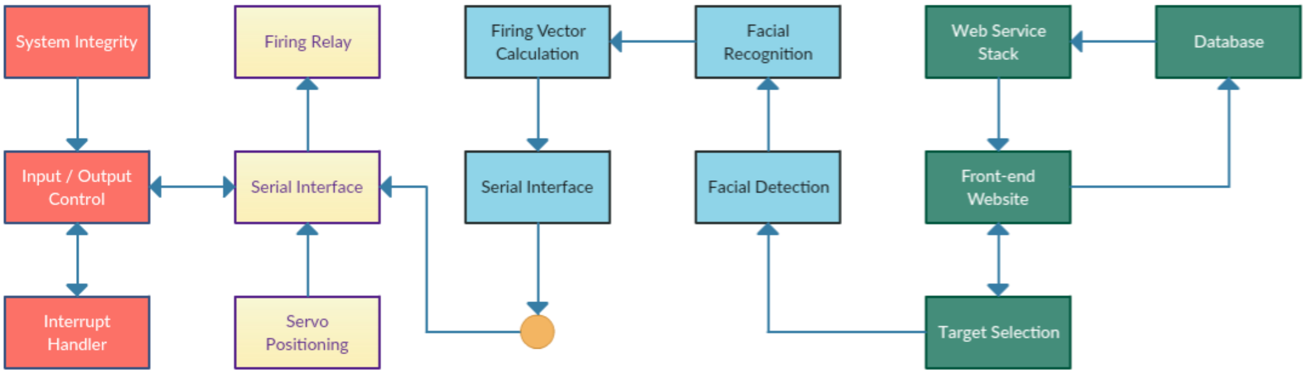

Fig. 6. Software block diagram for the overall embedded systems and facial recognition.

negative [3]. 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.

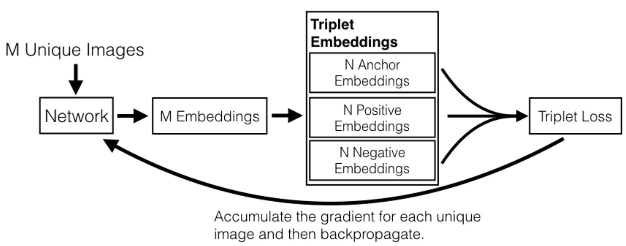

Fig. 7. Optimization of a Single Network. (Reprinted with permission from OpenFace 2016).

Once a cropped image has been passed through the deep neural network, a 128-D unit hypersphere is then optimized to cluster people together who are distinguishable, which is represented in figure 8.

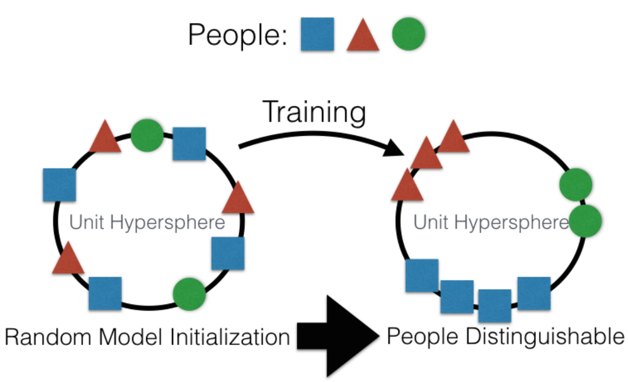

Fig. 8. Optimization Sphere. (Reprinted with permission from OpenFace 2016).

The last step is to apply a similarity technique to match the image with another image. Our focus will be on support vector machines (SVMs), which is a supervised machine learning algorithm which can be used for both classification or regression challenges [2]. 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 as in figure 9.

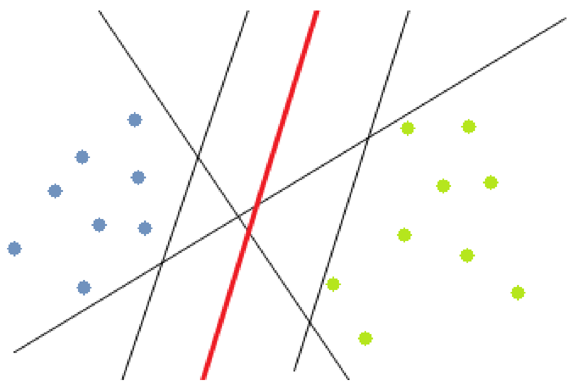

Fig. 9. SVM Example of a Hyperplane. (Reprinted with permission from Wikimedia Commons 2010).

B. Output Control

The system implements a USB to serial USART interface with a configurable baud rate. The system will receive a single packet from the host computer. The data received will be transmitted through the 5V, GND, Rx and Tx lines to the USB 2.0 header. The ATmega16U2-MU microcontroller will convert the information into USART format, which is then sent to the ATmega328P-PU to be processed.

While there is no serial input information or if the information is set in an invalid format, the system will remain in an idling subroutine that monitors the turret's surroundings and maintains its current position. After a set of values is received and is confirmed to be in the proper format, the system will interrupt the idling subroutine.

After interrupting the system, the serial information will be stored to the internal memory of the ATmega328P-PU using a single array of bits taken as integers. This array is updated by the system to maintain a concise block of data to prevent memory leaks.

One servomotor will implement yaw rotation. This rotation is controlled with pulse width modulation, stalled at 1500 microseconds and rotating clockwise with increments, and is deferred by time. Another servomotor will implement pitch rotation, controlled using absolute units in terms of degrees centered at 90 and allowing for a maximum deviation of 60 degrees. A power relay is used to control both the hopper intake and the barrel fly-wheel motors of the NERF gun using Boolean values to shoot 'true' or to stall 'false'.

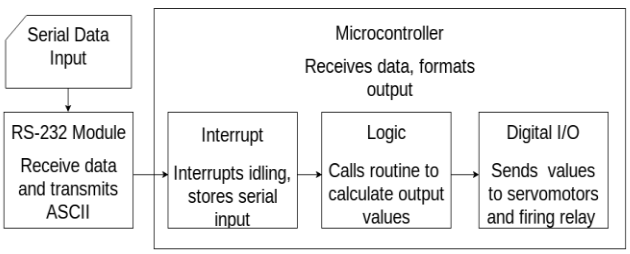

Fig. 10. Microcontroller software flow diagram overview.

After the turret performs its output operations sequentially, the initial interrupt will terminate, and the system will resume its idling subroutine. The idling-interrupt-return runtime will continue while there is still external power and data input to draw from.

IV. CONCLUSION

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 and 2 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.

Overall, 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 a face when a face enters its field of vision, and the camera will be able to continuously track the face while it is within its field of vision. Once a face has been detected, the facial detection will begin tracking the face if they stay within view. 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 wanted to gain valuable knowledge in the systems engineering field and how to go from researching and design to building a functioning prototype.

V. TEAM BIOGRAPHY

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. 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.

Nicolas Jaramillo is a senior computer engineering student, minoring in intelligent robotic systems. 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 is responsible for the development of the frontend and backend applications, as well as the embedded systems operation on the PCB.

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. 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.

ACKNOWLEDGEMENT

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